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Decision support for management identification of best forest treatments for life-cycle carbon offsets, fire reduction, and avoiding future costs

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Climate change concerns have raised the awareness of the significant role that forests can play in the mitigation of increasing CO_2 emissions. At the same time, climate change impacts are affecting the ability of forests to deliver on mitigation goals, primarily through changes in wildfire area burned and fire mortality impacts.

Forest managers are being asked to maximize / increase carbon sequestration and carbon offsets in forest management planning while endeavoring to control climate change impacts on specific forest types. Guidance is needed on site-specific treatments for each forest type and region that maximizes carbon while also addressing other goals in planning documents for forest lands.

To work toward seemingly contrary goals of carbon maximization and fire risk reduction demands tools that track the carbon impacts from any stand treatment, aggregate them across the landscape, integrate fire impacts, identify how products will be used, and for how long, and identify where changes in forest policy or economics might change optimal treatments.

Tool outputs include estimates of carbon storage in forests, in harvested wood products, and estimated feedstock for wood energy that offsets fossil fuels.

We use the forest vegetation simulator (FVS)[1] growth model with fire impacts simulated using the Fire and Fuels Extension (FFE)[2] of FVS.

Carbon estimates for each management regime are derived using four models:

1) the FVS default carbon model,
2) the FVS model based on Jenkins [3] algorithms for carbon allocation,
3) the Forest Carbon Assessment Tool (FCAT)[4] model using Jenkins algorithms for carbon allocation and
4) the FCAT model using volume based algorithms for determining carbon in tree components within the system.

The analysis framework is designed to be flexible enough to assess the possible impacts of climate change on growth and fires, alternate mitigation approaches (treatments and wood uses), and alternate future markets for bio-based fuels.

This modeling builds on previously developed stand and landscape modeling tools that indicate how treatments affect, over time, carbon storage in forests, altered emissions from wildfire, carbon storage in products, emission offsets from biofuels use, and emission offsets from wood product substitution.[5,6] From these studies it was clear there is substantial variation in the long-term carbon storage and offset effects of treatments across forest types, and forest conditions.

Because western forests are subject to increasing impacts from wildfire and insects and diseases, the project has focused on major forest types in 11 states - Arizona (AZ), California (CA), Colorado (CO), Idaho (ID), Montana (MT), New Mexico (NM), Nevada (NV), Oregon (OR), Utah (UT), Washington (WA), and Wyoming (WY).

Specific forest types were selected for analysis in consultation with the USFS Washington Office - ponderosa pine (PP), Douglas-fir (DF), lodgepole pine (OP), Englemann spruce/subalpine fire (S/F), California mixed conifer (MC), wet forest types grouped into a fir/spruce/mountain hemlock group (H/C), pinyon juniper (P/J), and hardwoods (HW). These forest types dominate the landscape on federal and/or non-federal ownerships, and comprise 70% of the candidate plots in the FIA database (Table 1).

Prior studies determined there is tremendous variation between plots in the same forest type across all regions, and even within the same region. For that reason we have developed a database containing outputs for a range of simulated treatments on a subset of all FIA plots in the 11 western states (Table 1). The subset that was used has been field surveyed, was sampled in the latest inventory period for each state, contains forest inventory and has forest types of interest. There were some simulation failures resulting in simulations for 18,025 plots.

Table 1: Data summary of inventory used for the landscape level analysis covering 11 western states

State	Total FIA Plots	Total Measured Plots	Total Candidate Plots	Plots in Study Forest Types	Total FIA Plots Simulated
AZ	25,581	7,383	2,284	1,645	1,626
CA	19,229	8,586	3,921	1,758	1,754
CO	13,459	3,709	2,341	1,833	1,808
ID	12,501	5,060	1,454	1,143	1,143
MT	23,059	6,070	2,236	1,735	1,735
NM	21,491	3,829	2,542	2,252	2,223
NV	16,572	2,101	407	331	331
OR	17,203	7,491	3,796	2,498	2,497
UT	16,002	5,448	2,578	1,984	1,984
WA	10,875	6,179	2,424	1,484	1,483
WY	17,834	2,494	1,981	1,455	1,441
Total	193,806	58,350	25,964	18,118	18,025

Where Total FIA Plots =Total number of FIA plots in each state database, Total Measured Plots=Plots in FIA database with measurements (PLOT, COND, TREE), Total Candidate Plots=Number of FIA plots that are candidates for simulation. Candidates were measured and are in the current panel (AZ, CA, CO, ID, MT, NV, OR, UT, WA) or are the last periodic inventory (NM, WY), Plots in Study Forest Types=Number of plots that match the desired forest types for the analysis including, Douglas-fir (DF), Hemlock/cedar (H/C), hardwood (HW), ponderosa pine (PP), other pines (OP), pinyon-juniper (P/J) and spruce/fir (S/F), Total FIA Plots Simulated=Final number of plots after dropping any plots that produced simulation errors in FVS.

Simulations for any treatment scenario can be run on all selected FIA plots with summarization possible by a range of stand characteristics and aggregation levels.

As an example, Table 2 shows various average stand output measures after 30 years of forest growth simulation for no treatment and three fire treatment alternatives for Idaho National Forests by forest type.

Treatments were done on stands with high or moderate fire risk. High risk stands were identified as those where the crowning index (CI) is <25 (i.e. crowning fire behavior is possible with wind speeds below 25 mph), and moderate risk stands are those with a CI of 25-50.

The modeled fire risk reduction treatments assume a thin from below to a basal area of 45 ft^2/ac if the stand is high risk and to ½ the current basal area if the stand is at moderate fire risk. Merchantable wood is removed from the site and non-merchantable residuals are treated to reduce fire risk, usually through burning.

- Fire1 is a single fire risk reduction treatment that is simulated when/if stand reaches a high or moderate risk state.
- Fire2 is similar to Fire1 except that treatments will occur more than once as long as the fire risk hits the threshold for moderate risk, until only 50 trees/acre remain.
- Fire3 also uses the threshold risk indices to initiate treatment, but continues to treat them every 20 years thereafter to maintain low fire risk conditions.

Table 2: Average outputs for Idaho National Forests FIA plots simulated for three decades under four treatment scenarios.

		Forest Type							
Output Measure	Scenario	DF	H/C	HW	OP	P/J	PP	S/F	All_NF
Average of Total Stand Carbon after 3 decades (t/acre)	Base	52	85	27	46	25	40	60	52
	Fire1	31	57	23	30	20	26	42	35
	Fire2	31	54	22	28	21	26	41	33
	Fire3	30	54	22	29	20	25	41	33
Average Basal Area Mortality/acre under severe fire weather conditions (%)	Base	68	81	73	86	84	50	75	72
	Fire1	45	33	75	69	98	45	46	50
	Fire2	44	32	76	67	98	45	45	49
	Fire3	46	33	75	69	98	46	46	51
Average Cubic Foot Mortality/acre under severe fire weather conditions (ft^3/acre)	Base	2,345	4,577	717	2,729	653	1,236	2,935	2,485
	Fire1	600	827	545	981	404	576	800	726
	Fire2	549	684	490	775	449	542	692	631
	Fire3	569	762	491	913	309	518	745	677

Simulations can also be done for specific stands and treatments to provide detailed carbon accounting of treatments over time. Figure 1 summarizes a single Douglas-fir forest type stand from Eastern Washington simulated forward 110 years with a fire risk reduction treatment applied every 30 years. The treatment reduces basal area to 60 ft^2/acre (BA60) using a thin from below prescription rather than the 45 ft^2/acre (BA45) used in the landscape summaries above.

The analysis includes a summary of the carbon consequences of removing this volume from the forest and using it to manufacture wood products with consequent downstream impacts on carbon offsets, including the forest products carbon, displacement offsets from using biomass in place of fossil fuels, and substitution impacts of using wood products in place of fossil intensive building products like steel and concrete based on CORRIM life cycle analysis[7].

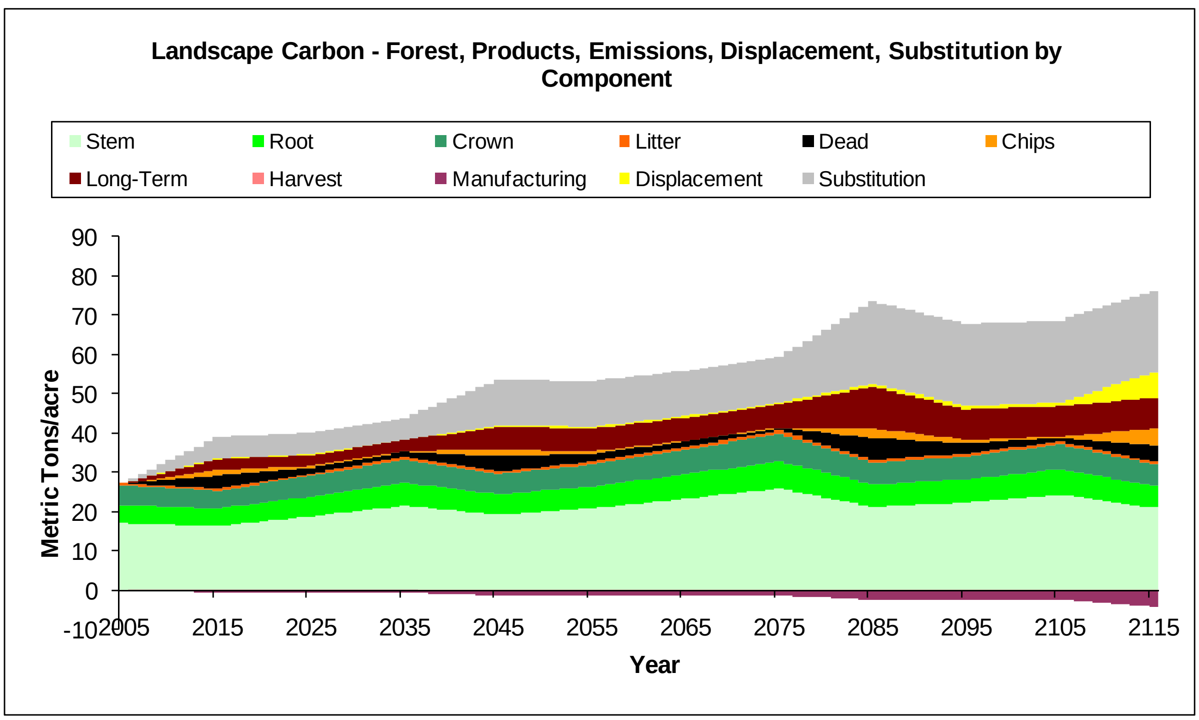

Figure 1: Carbon consequences of fire risk reduction treatments applied every 30 years to a Douglas-fir forest type

The carbon emissions from fossil fuel use in reforestation, harvesting and manufacturing processes are shown below the x-axis in Figure 1. The net stored and offset carbon benefit including all carbon pools after 100 years is 66 metric tons/acre. If we had treated this same stand by reducing basal area to 45 ft^2/acre (BA45) in each of the 3 entries, the net carbon benefit would have been 62 metric tons/acre of stored carbon or 4 metric tons/acre less than the BA60 treatment.

In both cases these carbon outcomes assume no fires had occurred on this particular stand. Adding fire risk into the equation alters the outcomes somewhat.

Were a fire to occur in the first 3 decades, the average basal area mortality is 16% higher under the BA60 treatment than under a BA45 treatment and the cubic foot mortality is 36% higher under a BA60 than BA45 treatment (182 ft^3/acre (1.2 t/ac) vs. 117 ft^3/ac (.7 t/acre) of mortality). Over the entire simulation period, basal area mortality is approximately equal and cubic foot mortality is 28% higher under the BA60 scenario (141 ft^3/ac (~.9 t/acre) vs. 102 ft^3/ac (~.7 t/acre)) plus smoke emissions estimated at 0.11 vs. 0.10 tons/acre. The timing of fire occurrence influences the total carbon storage potential and fire emissions. Recently treated stands would have lower emissions, lower mortality rates and more carbon stored off site in product and carbon offset pools than stands that were nearing the anniversary date for a harvest entry.

These stand and landscape level summaries demonstrate some of the capabilities of the analytic framework to estimate the carbon consequences of management actions across the west. The treatments we have chosen to simulate using FIA plots include a range of fire risk reduction treatments, carbon maximization strategies, revenue maximization strategies, maximizing forest carbon and tree size. Other regimes are possible.

The outputs of stand values can then be aggregated in many ways. Here we have shown summaries by forest type, but **we can also summarize by location, county, state, owner, National Forest, habitat type, ecoregion, forest density, fire risk, or virtually any other parameter that is in the FIA databases**.

The analytic Framework as the underpinnings of a carbon analysis toolkit

These results highlight uses for the analysis framework to evaluate forest management strategies in the western USA in their effectiveness to simultaneously reduce fire risk and increase carbon storage and carbon offsets.

Our main goal is to identify specific treatments that can help federal forest managers develop better plans and NEPA responses for the forest types they manage and to highlight the carbon consequences of the kinds of management activities they are currently undertaking.

Our second goal is to identify how improved fire risk classification, changes in fire rates from climate change, and changes in the value and use of carbon and biofuel products will alter the viability of various management options for forest types across the west. That aspect of the study is still ongoing. We envision many potential downstream uses of the framework to address an array of planning needs on public and private lands.

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