DEVELOPMENT OF CARBON RESPONSE TRAJECTORIES USING FIA PLOT DATA AND FVS GROWTH SIMULATOR: CHALLENGES OF A LARGE SCALE SIMULATION PROJECT

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Abstract— The Forest Carbon Management Framework (ForCaMF) integrates Forest Inventory and Analysis (FIA) plot inventory data, disturbance histories, and carbon response trajectories to develop estimates of disturbance and management effects on carbon pools for the National Forest System. All appropriate FIA inventory plots are simulated using the Forest Vegetation Simulator (FVS) growth model to develop the carbon response trajectories for undisturbed, managed, and disturbance from fire, pests, and in some regions wind. The challenges presented by the number of plots, number of FVS variants, selection of localization variables, growth calibration, regeneration, and disturbance magnitude calibration will be presented. The carbon response curve fitting process will also be presented. These response curves developed by forest type, disturbance type, initial carbon bin, and disturbance magnitude are then used in a stochastic simulation process that combines the annual disturbance maps over a 20 year period to determine a forest by forest realization of carbon changes at the forest level in response to observed disturbance patterns. The resulting response curves can also be used to develop estimates of potential carbon response under alternative management or disturbance scenarios.

INTRODUCTION

The National Forest System (NFS) plays a critical role in mitigating greenhouse gas emissions in the U.S. Various efforts are underway to access current conditions and potential trends of C on the forest of the NFS. One of these efforts, looking at the effects of disturbance on C accumulation is the Forest Carbon Management Framework (ForCaMF). ForCaMF combines Forest Inventory and Analysis plot information, Forest Vegetation Simulator (FVS) growth and carbon estimates, and Landsat-derived disturbance histories to provide forest level C stocks over a 20 year time frame.

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STUDY AREA/DATA SOURCES

The U.S. Forest Inventory and Analysis (FIA) program provides a national-consistent and statistically-valid sample documenting trends in forest extent, status, condition, and resources (Bechtold and Patterson 2005). For each FIA plot on NFS lands, variables useful for C estimation are collected on the ground such as forest type, tree species, tree size, stand age, and recent disturbance. The FIA database (O'Connell et al 2014) is queried for appropriate plots for each state to calculate tree volume, biomass, and C stocks via allometric equations based on the inventory information for each plot. Over 71,000 plots are being assessed and simulated for this and subsequent analyses. Table 1 shows the breakdown of plots by region and state.

Table 1—Number of FIA inventory plots by region and state. Note: WY is listed for both R2 and R3 but only counted once in the total.

Region	State	FS Plots	Region	State	FS Plots	Region	State	FS Plots
R1	ID	5285	R5	CA	4639	R9	CT	0
	MT	4949					DE	0
	SD	591	R6	OR	4945		IA	0
	WA	3940		WA	2362		MA	0
							MD	0
R2	CO	2017	R8	AL	772		NL	0
	KS	0		AR	2046		RI	0
	NE	40		FL	1786		IL	415
	SD	480		GA	886		IN	303
	WY	832		KY	409		ME	32
				LA	548		MI	3845
R3	AZ	2667		MS	1159		MN	3293
	NM	2290		NC	1331		MO	1358
				OK	210		HM	437
R4	ID	4512		SC	916		NY	7
	NV	1001		TN	600		OH	128
	UT	2586		TX	661		PA	423
	WY	832		VA	1795		VT	332
							WI	1848
							WV	697
						R10	AK	1716
							Total	71089

MODELING FRAMEWORK

The Forest Carbon Management Framework (ForCaMF, Healey et al 2014, Raymond et al. 2015) was developed to leverage Landsat imagery, FIA plot data, and forest growth models in combination. Each FIA plots is simulated using the appropriate FVS (Crookston and Dixon 2005, Dixon 2002, Stage 1973) variant under a range of disturbances (undisturbed, management, fire, insect, and wind) customized for each region. The resulting C numbers are provided by the Fire and Fuels Extension (FFE) to FVS (Rebain 2010). For each region the FIA plots are grouped by forest type (Table 2), initial carbon bin (defined by 25, 50, 75, and 100% quartiles of initial C by region), disturbance type, and disturbance magnitude ((25, 50, 75, and 100% canopy disturbance). Each of these bins has a mean trend line fit to all FIA plot trajectories using generalized estimation equations (GEE, Hardin and Hilbe 2003) using the geeglm() function in the R statistical software package (R Core Team 2015). See Raymond et. al. (2015) for additional details on the fit process. These resulting trajectories for each combination of forest type, initial carbon, disturbance type, and disturbance magnitude are then combined with disturbance maps in a stochastic simulation framework (Healey et al. 2014) to arrive at estimates for each national forest.

Table 2—Forest types by region. R1 used defined dominance types. R2-10 use FIA forest types groups.

R1
ABLA
HMIX
IMIX
PICO
PIPO
PSME
TMIX

R2
spruce/fir
other softwoods
pinyon/juniper
douglas-fir
ponderosa pine
fir/spruce/mountain hemlock
lodgepole pine
other western softwoods
oak/hickory
elm/ash/cottonwood
aspen/birch
other hardoods
woodland hardwoods

R3
pinyon/juniper
douglas- fir
ponderosa pine
fir/spruce/mountain hemlock
other western softwoods
elm/ash/cottonwood
aspen/birch
woodland hardwoods

R4
pinyon/juniper
douglas-fir
ponderosa pine
western white pine
fir/spruce/mountain hemlock
lodgepole pine
hemlock/sitka spruce
western larch
other western softwoods
oak/hickory
elm/ash/cottonwood
aspen/birch
woodland hardwoods

R5
pinyon/juniper
douglas-fir
ponderosa pine
western white pine
fir/spruce/mountain hemlock
lodgepole pine
redwood
other western softwoods
california mixed conifer
aspen/birch
alder/maple
western oaks
tanoak/laurel
other hardoods
woodland hardwoods

R6
pinyon/juniper
douglas-fir
ponderosa pine
western white pine
fir/spruce/mountain
lodgepole pine
hemlock/sitka spruce
western larch
other western softwoods
elm/ash/cottonwood
aspen/birch
alder/maple
western oaks
tanoak/laurel
other hardoods
woodland hardwoods

R8
white/red/jack pine
spruce/fir
longleaf/slash pine
loblolly/shortleaf pine
other eastern softwoods
oak/pine
oak/hickory
oak/gum/cypress
elm/ash/cottonwood
maple/beech/birch
aspen/birch
other hardwoods
tropical hardwoods

R9
white/red/jack pine
spruce/fir
loblolly/shortleaf pine
other eastern softwoods
hemlock exotic softwoods
oak/pine
oak/hickory
oak/gum/cypress
elm/ash/cottonwood
maple/beech/birch
aspen/birch
other hardoods

R10
spruce/fir
fir/spruce hemlock
lodgepole pine
hemlock/sitka spruce
elm/ash/cottonwood
aspen/birch
alder/maple

RESULTS AND DISCUSSION

R8 Case Study

The FVS growth results are grouped by forest type, initial carbon, disturbance type, and disturbance magnitude. Individual plot trajectories are shown for loblolly/shortleaf plots for undisturbed (Figure 1a), management (1b), and fire (1c) for carbon bin 2, disturbance magnitude 1 (number of plots that ended up grouped in each respective bin). The resulting fit trajectories for loblolly/shortleaf pine plots are shown for undisturbed (Figure1d) across the 4 initial carbon bins and management, carbon bin 2, and 4 disturbance magnitudes (Figure 1e). The 4 trajectories in 1e start at the same initial C level as the red line in 1d, but because the management simulation are targeted to remove 25, 50, 75, and 100% of the cover each management scenario starts below the initial starting point for cb=2 in 1d. The results show that for this forest type/disturbance type/initial carbon bin

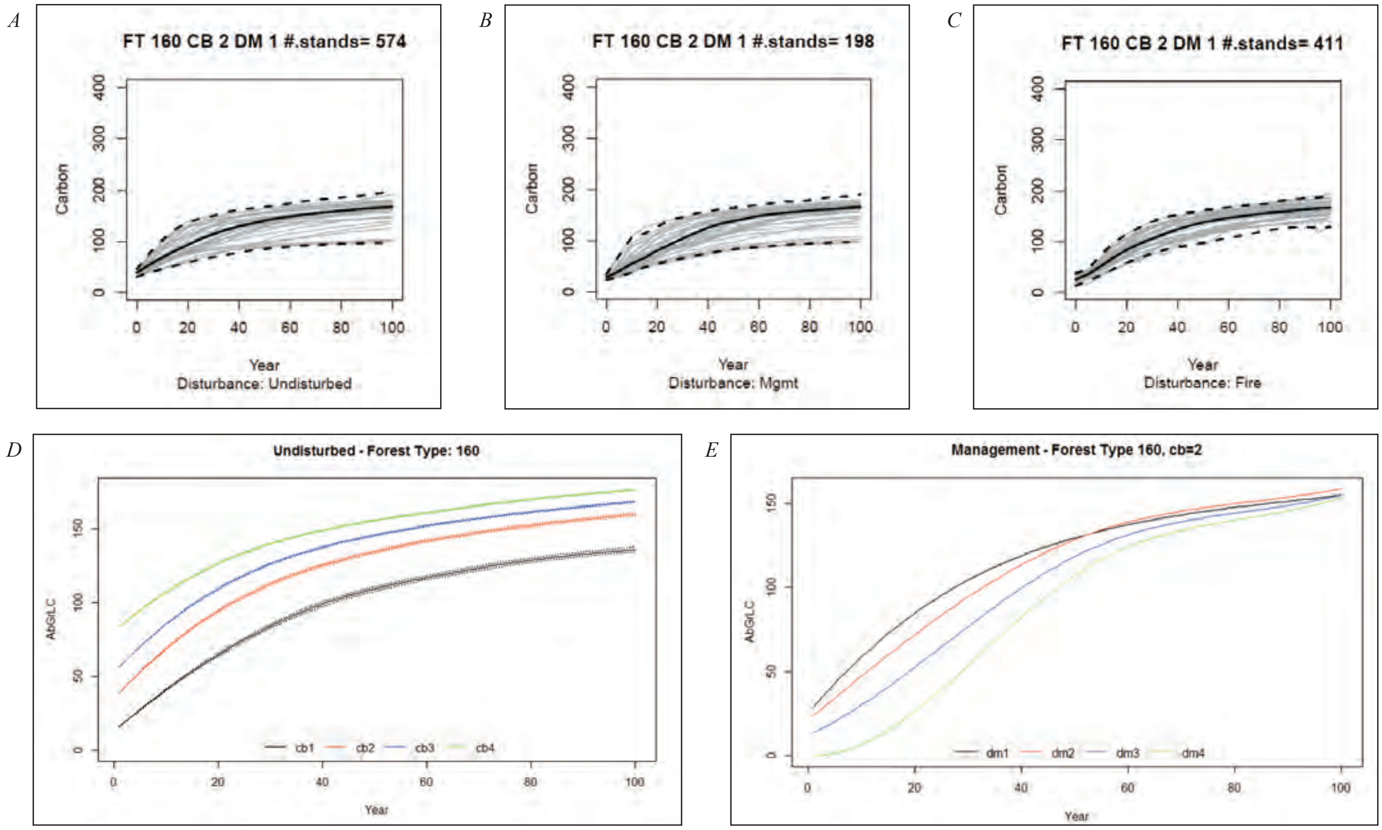

Figure 1—Individual growth trajectories for R8, forest type 160 (loblolly/shortleaf pine), carbon bin 2, disturbance magnitude 1 for undisturbed (a), management (b), and fire (c). The fit results for all 4 carbon bins are show for undisturbed (d) and for a single initial carbon bin (2) and the 4 disturbance magnitudes for the management (e) scenarios.

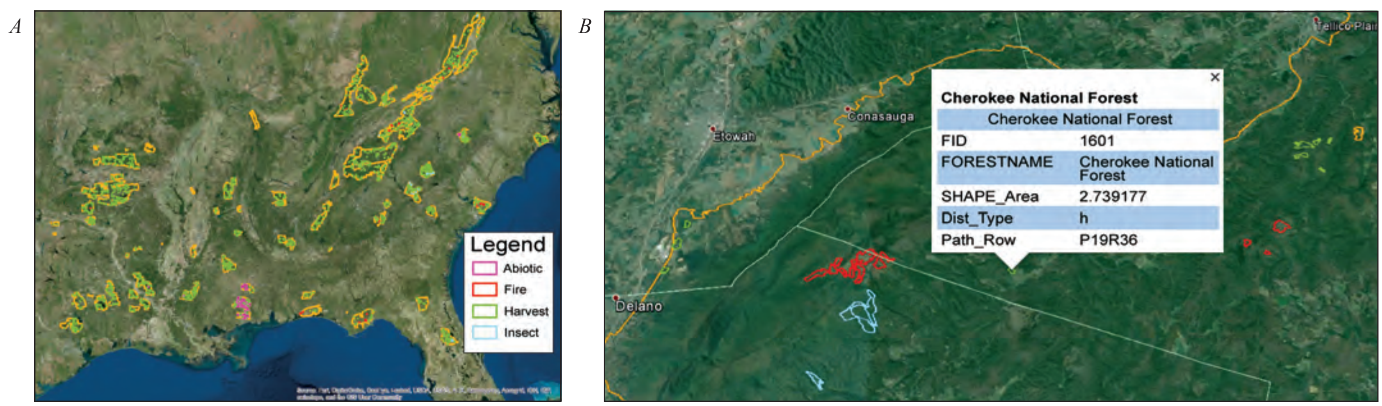

Figure 2—Composite disturbance map for R8 (a.), all years combined to show scope of impacts of disturbance across area. Orange outline are NFS lands, disturbances are as indicated in legend. Disturbance map zoomed in (b.) to show specific detail on an individual disturbance on the Cherokee NF.

combination each disturbance magnitude recovers, although at different rates over the 100-year simulation and achieve about the same level of C as the undisturbed plot. These fit trajectories are developed for all forest type, initial carbon bin, disturbance type, and disturbance magnitude combinations.

Landsat derived disturbance maps are developed for the 1999-2001 time frame (Figure 2) for each region. The disturbance maps are then combined with the individual trajectories in a stochastic simulation framework (Healey et al. 2014) for estimates of C for individual national forests. The simulations for R8 are currently running at the time of writing of this abstract.

Modeling Other Regions

R8, while having a large number of states, only uses a single FVS variant. For most western regions multiple FVS variants are required for each state (e.g. CA – 5 variants, OR – 7 variants, WA – 5 variants). This complicates the process of running the simulations because each variant has minor differences that need to be dealt with. The simulation and analysis framework has been taught to automatically separate FIA plots by variant to run the simulations and then to combine the results back together for the next steps in the analysis process.

In addition each region has preliminary simulations run so that existing calibration data in the FIA databases can be used to develop regional calibration statistics. These preliminary simulations are also used to establish initial carbon and cover values for the plots that are used as part of the disturbance map creation. The regional calibration statistics are developed to adjust FVS growth rates based on growth data from the databases. All plots have regional calibration adjustments applied. This has the effect of increasing growth for some species but may decrease growth for others. In addition to the regional calibration adjustments, plots that have sufficient increment data for that individual plots also are further adjusted using the plot specific increment information. This approach ensures that plots that contribute to the regional calibration statistics use their own plot specific information, but plots that do not include increment information are calibrated using the regional average information.

Challenges

R1 simulations had the advantage of a complete establishment model in the Inland Empire variant used for the region. Other regions, R8 for example, do not have the full establishment model and therefore regeneration assumptions have be developed separately from the FVS growth model. For all other regions a regeneration model was developed using the SEEDING table and management history information contained in the FIA database. For each state all plots that contain seedling records are classified by forest type, overstory condition, and time since observed management to create a population of potential inventory records for any plots that need regeneration. When a regeneration event occurs in a simulation (management or disturbance activity) the pool of candidate stands for the matching forest type and management type is used to randomly select a plot. If the existing plot has seedling records its own seedling records are used for regeneration. If the current plot does not have seedling records a sample population from the seedling database is created, expanding age as needed to have a sufficient sample pool (>30) and a plot is selected to provide species composition and number of individuals by species for the regeneration event. The size of individual seedling records introduced into the simulation is scaled by type and intensity of the disturbance.

Running multiple simulations for 70,000+ plots results in the use of considerable disk space so all results are stored in ZIP files to reduce storage use. The simulation results for all simulations run so far (800,000 and counting) now takes over 106 GB of disk space.

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LITERATURE CITED

Bechtold, William A. and Paul L. Patterson (editors). 2005. The Enhanced Forest Inventory and Analysis Program – National Sampling Design and Estimation Procedures. SRS-80. U.S. Department of Agriculture, Forest Service, Southern Research Station. 85 p.

Crookston, Nicholas L.; Dixon, Gary E. 2005. The forest vegetation simulator: a review of its structure, content, and applications. Computers and Electronics in Agriculture. 49: 60-80.

Dixon, Gary E. (comp.). 2002 (Revised: February 25, 2015). Essential FVS: A user's guide to the Forest Vegetation Simulator. Internal Report. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Forest Management Service Center. 226 p.

Hardin, J.W.; Hilbe, J.M. 2003. Generalized Estimation Equations. Chapman and Hall. New York. 222 p.

Healey, S. P.; Urbanski, S. P.; Patterson, P. L.; Garrard, C. 2014. A framework for simulating map error in ecosystem models. Remote Sensing of Environment. 150: 207-217.

O'Connell, Barbara M.; LaPoint, Elizabeth B.; Turner, Jeffery A.; Ridley, Ted; Pugh, Scott A.; Wilson, Andrea M.; Waddell, Karen L; Conkling, Barbara L. 2014. The Forest Inventory and Analysis Database: Database description and user guide version 6.0.1 for Phase 2. U.S. Department of Agriculture, Forest Service. 748 p. [Online]. Available: http://www.fia.fs.fed.us/library/database-documentation/.

R Core Team. 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: http://www.R-project.org/.

Raymond, C. L.; Healey, S.; Peuzzi, A.; Patterson, P. 2015. Representative regional models of post-disturbance forest carbon accumulation: Integrating inventory data and a growth and yield model. Forest Ecology and Management. 336: 21-34.

Rebain, Stephanie A (comp.). 2010 (revised March 23, 2015). The Fire and Fuels Extension to the Forest Vegetation Simulator: Updated Model Documentation. Internal Rep. U.S. Department of Agriculture, Forest Service, Forest Management Service Center. Fort Collins, CO. 403 p.

Stage, A. R. 1973. Prognosis model for stand development. Res. Paper INT-137. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT. 32 p.