Simulating Silvicultural Treatments Using FIA Data

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Abstract.—Potential uses of the Forest Inventory and Analysis Database (FIADB) extend far beyond descriptions and summaries of current forest resources. Silvicultural treatments, although typically conducted at the stand level, may be simulated using the FIADB for predicting future forest conditions and resources at broader scales. In this study, silvicultural prescription methodologies were simulated using FIA inventory plots from Montana that rated high for fire hazard. Database operations were used to couple the FIADB with the silvicultural prescriptions process, allowing successful simulation of silvicultural treatments. Cut- and leave-tree tables were created for each FIA sample plot using computer "marking" algorithms, allowing estimation of current and future forest attributes (volume, growth, wildfire hazard, and treatment costs). Simple database operations can be used to mimic complex silvicultural prescriptions using FIA inventory data from major ownerships, States, or regions, allowing evaluation of treatment effects and future forest conditions.

Forest Inventory and Analysis (FIA) data have traditionally been used to summarize current forest conditions. Forest resource assessments for States and regions, for example, have been invaluable sources of information for forest managers and decisionmakers alike. However, there is a growing need not only for current forest assessments, but also for evaluation of various management alternatives. In other words, given the current status of forests as inventoried by FIA, what would be the effect of a specific management action applied to said forest acreage?

Given the technological advances in database management and forest ecosystem modeling, a large portion of FIA analysis and reporting in the future may involve simulating management actions on current forest conditions. Just as FIA was founded over 75 years ago to answer the question, "how much forest," more timely and complex questions now arise, such as "given current forest conditions, what might be the effect of specific management treatments?"

One of the most immediate and controversial forest management issues nationally involves the fire hazard problem in the West, and the kinds and costs of treatments being proposed to address it. For example, what forest types are most vulnerable to crown fires? What silvicultural treatments are most effective for reducing stand-level fire hazard, and how much do they cost? At a statewide or regional level, what is the potential contribution of a strategic hazard reduction program to the Nation's wood supply, and how much might it cost? The consistent and comprehensive data collected by the FIA inventory provide a uniform and objective basis for addressing these questions. Toward this end, we developed a methodology for simulating silvicultural treatments in the FIADB environment and evaluating their effectiveness for reducing hazard in the dry, low elevation forests of Montana.

Silvicultural Prescription Process

To mimic hazard reduction treatments using the FIADB, the silvicultural treatment process needs to be reduced to its elemental steps and incorporated into database logic. The silvicultural prescription process involves five distinct steps: inventory assessment, diagnosis, prescription development, prescription implementation, and evaluation/monitoring.

Inventory Assessment.—Inventory is quantified or translated in terms of stand density, structure, and species composition for use in the silvicultural prescription process. Density is expressed in terms of trees per acre, basal area per acre, or

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Stand Density Index (SDI) (Reineke 1933), with location, site, and species used to determine break points between high-, medium-, and low-density classes. Structure is described in terms of trees, basal area, or SDI per acre by diameter class, with species and site criteria used to classify conditions into one-, two-, or multi-storied structures. Species composition is typically expressed in terms of percent basal area representation by species, which is used in conjunction with habitat type criteria (Pfister *et al.* 1977) to classify forest types. The FIADB is a robust source for all of these data, providing the necessary inputs for the silvicultural prescription process.

Diagnosis.—The diagnosis of individual forest stands is based on the inventory. Inventory data are interpreted in terms of location and ecological context to assess current conditions versus those desired to achieve the management objective. For the Montana FIA inventory, each plot may be treated as an individual stand, where its current stand density, structure, and species composition can be used to diagnose fire hazard and priority for fuel-reduction treatment.

Prescription Development.—For every stand evaluated in the prescription process, a target future stand condition is developed. A "target" stand specifies the density, structure, and species composition that best contribute to meeting the management objectives. In this study, for example, target conditions to achieve low fire hazard would include low to moderate stand density, one-, two-, or multi-storied structures dominated by large trees, predominantly ponderosa pine. Current conditions are diagnosed from the inventory, and compared to the target conditions. To the extent that existing conditions differ from and are not trending toward the target conditions over time, some form of management intervention is indicated. This leads to the third step in the process – prescription development. In this step, one or more treatments are designed or selected for manipulating existing forest conditions to create the desired conditions, either immediately or over time.

Implementation.—The fourth step of the prescription process is implementation, which involves on-the-ground management activities ranging from silvicultural cutting to treatment or removal of activity fuels. If silvicultural treatments are simulated for FIA inventoried forest acreage, then implementation involves database manipulation of tree records in accordance with prescription guidelines.

Evaluation/Monitoring.—The final stage of the prescription process involves evaluation and monitoring of stand conditions following prescription implementation. Post-treatment stand conditions are typically assessed to determine if the prescribed treatments had the desired effects. In an FIA inventory context, this step in the prescription process involves modeling and estimating stand attributes such as fire hazard, treatment costs/revenues, and future growth responses.

Simulating the Prescription Process

The 1999–2000 periodic FIA inventory for Montana (USDA INT 1999a, 1999b) was used in this simulation of silvicultural treatments to reduce crown fire hazard. Only dry, low- to mid-elevation forests were included because these forests show the greatest departure from historically sustainable conditions (Fiedler *et al.* 2003). All silvicultural prescription process steps were followed to simulate treatments within the FIADB:

1. Inventory.—All FIADB inventory plots were screened to select those that qualified as ponderosa pine, Douglas-fir, or dry lower mixed conifer forest types, based on species composition and habitat type.
2. Diagnosis.—Conditions that contribute to high fire hazard (high stand density, complex structure, composition of late-seral species) were identified.
3. Prescription development.—Characteristics of a target stand with low fire hazard (i.e., low to moderate density, structure predominated by large ponderosa pine) were incorporated into the comprehensive prescription.
4. Prescription implementation.—Two prescriptions (thin-from-below and comprehensive) were proposed to reduce fire hazard in subject FIA plots (stands).
5. Evaluation and monitoring.—Stands (pre- and post-treatment) were evaluated for crown fire hazard using the Fuel and Fire Extension (Scott and Reinhardt 2001) of the Forest Vegetation Simulator (Beukema *et al.* 2000, Crookston and Havis 2002, Wykoff *et al.* 1982). Harvest

costs, product values, and slash treatment costs were estimated using harvest cost models (Keegan *et al.* 2001), databases (Bureau of Business and Economic Research 2001), and data collected from land management agencies and the private sector, respectively.

The thin-from-below prescription (TB) removes all trees up to 9 inches diameter, followed by treatment of activity fuels. The comprehensive prescription (COMP) marks 40-50 square feet per acre of mostly large serals to leave. Then it uses low thinning to greatly reduce ladder fuels, and improvement/selection cutting to reduce density and remove undesirable trees in the mid/upper canopy, followed by treatment of activity fuels (Fiedler 2000; Fiedler *et al.* 1999, 2001).

The two treatment prescriptions were applied to selected FIA plots through development of a "marking" algorithm. The algorithm feeds the inventory database table through a decision matrix (silvicultural prescription logic) where each individual tree record is sent either to a leave table or cut table, depending on the tree's size and species and on characteristics of other trees in the stand. Leave tables are used to summarize post-treatment stand conditions and model fire hazard. Cut tables are used to determine the cost/revenue of implementing the silvicultural cuttings and treating the slash.

The marking algorithm decision matrix varies by prescription. For the TB prescription, trees sorted to the leave table were greater than or equal to 9 inches in d.b.h. without considering residual stand density, structure, or species composition. For the COMP prescription, trees sorted to the leave table were based on an iterative process of selection preferences based on density, structure, and species composition. Density of the reserve stand was set at 45 square feet per acre for this simulation. Species preference was set in order of ponderosa pine, western larch, lodgepole pine, and Douglas-fir. Desired stand structure was set on the basis of a target basal area per acre by 4-inch diameter classes: >20" (20 ft^2/ac); 16-20" (10 ft^2/ac); 12-16" (7 ft^2/ac); 8-12" (5 ft^2/ac); 4-8" (2.5 ft^2/ac); and <4.0" (0.5 ft^2/ac). If insufficient basal area density was present in any given diameter class, a second set of logic rules was used to "borrow" basal area from other d.b.h. classes as needed to reach the density target of 45 square feet per acre, while still approximating the desired structure.

Simulation Output

The methods used in this study successfully simulated the silvicultural prescription process, even the complex comprehensive prescription that integrated several silvicultural cutting treatments. Using each FIADB plot as an individual stand unit and corresponding tree records as constituents of a hypothetical "stand table," allowed simulation of forest management activities at a statewide scale. Sorting the FIADB tree records through a "marking" algorithm into cut and leave tables enabled modeling post-treatment stand conditions and crown fire hazard (fig. 1), as well as net revenues/costs associated with alternative hazard reduction prescriptions (figs. 2 and 3).

Output of the treatment simulations showed that the COMP treatment reduced fire hazard for most treated stands. Crowning index, which is the windspeed necessary to maintain

Figure 1.—*Distribution of acres by crowning index for existing high-hazard forest conditions, and after thin-from-below and comprehensive restoration treatments (adapted from Fiedler* et al. *2004).*

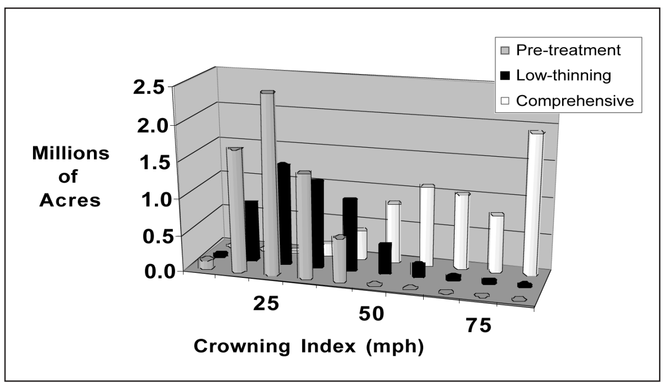


Figure 2.—*Distribution of acres by net revenue for the comprehensive restoration treatment (adapted from Fiedler* et al. *2004).*

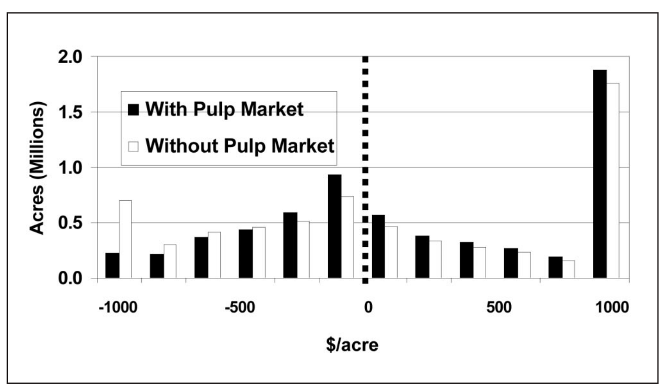
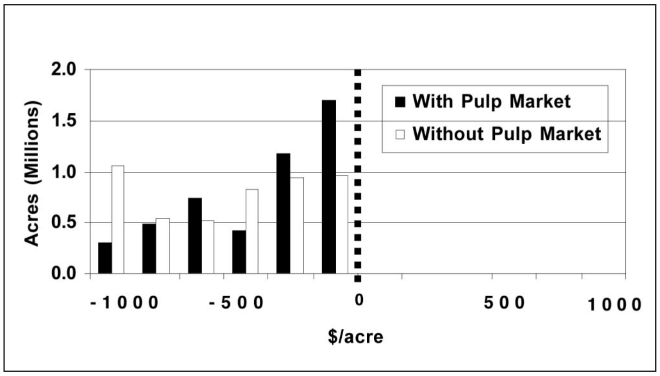


Figure 3.—*Distribution of acres by net revenue for the thin-from-below treatment (adapted from Fiedler* et al. *2004).*



a crown fire once it has reached the main canopy, increased dramatically following application of this treatment (fig. 1). In contrast, TB treatment had only a slight effect on crown fire hazard, with little change in crowning index from pre-treatment levels (fig. 1). By using the cut-tree stand table to determine treatment costs/revenues, it was evident that a large portion (approximately half) of the stands receiving the COMP treatment produced net revenues (fig. 2), while all stands receiving the TB treatment required out-of-pocket expenditures (fig. 3). A complete account of simulation results is presented in Fiedler *et al.* (2004).

Conclusions

Silvicultural prescriptions can be simulated for large areas (e.g., major ownerships, States) by using basic database management procedures to manipulate tree records in the FIADB. The database procedures involve use of a marking algorithm to sort individual tree records into separate leave and cut database tables. These leave- and cut-tree tables allow modeling of post-treatment fire hazard and the revenues/costs associated with treatment activities. This approach also allows managers to design hazard reduction treatments that are both effective and cost-efficient. In addition, it can help policymakers evaluate hazard reduction treatments for our Nation's forests before they are ever implemented on the ground.

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Literature Cited

Beukema, S.J.; Reinhardt, E.; Greenough, J.A.; *et al.* 2000. Fire and fuels extension: model description. Working draft prepared by ESSA Technologies Ltd., Vancouver, B.C. for U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Moscow, ID. 58 p.

Bureau of Business and Economic Research. 2001. The log price reporting system. Missoula, MT: The University of Montana.

Crookston, N.L.; Havis, R.N., eds. 2002. In: Proceedings, 2nd forest vegetation simulator conference; 2002 February 12–14; Fort Collins, CO. Proc. RMRS-P-25. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Fiedler, C.E.; Keegan, C.E.; Arno, S.F.; Wichman, D.P. 1999. Product and economic implications of ecosystem restoration. Forest Products Journal. 49: 19–23.

Fiedler, C.E. 2000. Understanding the ecosystem: its parts and processes - silvicultural treatments. In: Proceedings, the Bitterroot ecosystem management research project: what we have learned. RMRS-P-17. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 19–20.

Fiedler, C.E.; Arno, S.F.; Keegan. C.E.; Blatner, K.A. 2001. Overcoming America's wood deficit: an overlooked option. BioScience. 51: 53–58.

Fiedler, C.E.; Keegan, C.E., III; Woodall, C.W.; Morgan, T.A. 2004. A strategic assessment of crown fire hazard in Montana: potential effectiveness and costs of hazard reduction treatments. Gen. Tech. Rep. PNW-GTR-622. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 48 p.

Keegan, C.E.; Niccolucci, M.J.; Fiedler, C.E.; Jones, J.G.; Regel, R.W. 2001. Harvest cost collection approaches and associated equations for restoration treatments on national forests. Forest Products Journal. 52: 96–99.

Pfister, R.D.; Kovalchik, B.L.; Arno, S.F.; Presby, R.C. 1977. Forest habitat types of Montana. Gen. Tech. Rep. INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 174 p.

Reineke, L.H. 1933. Perfecting a stand-density index for even-aged stands. Journal of Agricultural Research. 46: 627–638.

Scott, J.H.; Reinhardt, E.D. 2001. Assessing crown fire potential by linking models of surface and crown fire behavior. Res. Pap. RMRS-RP-29. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 59 p.

U.S. Department of Agriculture. 1999a. Montana forest survey field procedures. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station.

U.S. Department of Agriculture. 1999b. Interior West forest resource inventory field procedures. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station.

Wykoff, W.R.; Crookston, N.L.; Stage, A.R. 1982. User’s guide to the stand prognosis model. Gen. Tech. Rep. INT-133. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 14 p.