A Framework for Evaluating Forest Restoration Alternatives and their Outcomes, Over Time, to Inform Monitoring: Bioregional Inventory Originated Simulation Under Management

Jeremy S. Fried, Theresa B. Jain, Sara Loreno, Robert F. Keefe, and Conor K. Bell[1]

Abstract—The BioSum modeling framework summarizes current and prospective future forest conditions under alternative management regimes along with their costs, revenues and product yields. BioSum translates Forest Inventory and Analysis (FIA) data for input to the Forest Vegetation Simulator (FVS), summarizes FVS outputs for input to the treatment operations cost model (OpCost) and estimates haul costs for harvested material with the Haul Time model to (1) implement silvicultural sequences; (2) generate harvested tree lists to estimate wood produced and treatment cost; and (3) calculate decadal stand descriptors that characterize management outcomes regarding stand attributes, forest resilience, and carbon dynamics. A BioSum project dataset can support monitoring at Forest and Regional scales by providing initial conditions, and a testbed for evaluating assumptions and potential prescriptions and how their impacts evolve over time. As re-measurements on FIA plots continue over time, they can play a key validation and calibration role, developing new knowledge of management's latent effects, improvements to future versions of FVS, and refinements in BioSum parameterization. BioSum is a versatile, multi-purpose tool designed to inform managers, planners and decisionmakers charged with sorting through myriad options by highlighting potentially superior choices based on user defined criteria. This paper illustrates the analytic power available via application to the real-world problem of developing fire resilience prescriptions and evaluating the modification in stand trajectories, wildlife habitat related stand attributes, fire resistance, economic trade-offs and logistical considerations that would result from their application in the Western United States.

A BRIEF HISTORY OF BIOSUM

The BioSum framework originated in 2002, when the U.S. Forest Service Pacific Northwest (PNW) Forest Inventory and Analysis (FIA) Program was tasked with estimating how much woody biomass feedstock might feasibly be produced, to supply both wood manufacturing and bioenergy facilities, assuming fuels management was applied over large forested landscapes in southwest Oregon and northern California, Arizona, and New Mexico. We developed a biomass summarization (BioSum) analysis in which we applied the Forest Vegetation Simulator (FVS) as a silvicultural treatment implementation engine to stand data from the many thousands of FIA plots that represented an entire State, or substate region. We relied on the Fire and Fuels Extension to FVS (FFE-FVS) to generate the torching index and crowning index metrics that served as a basis for evaluating and comparing fire hazard metrics pre- and post-treatment (Fried and others 2005). Treatment costs were estimated with the STHARVEST spreadsheet model (Fight and others 2003), and wood transportation costs using a raster GIS analysis workflow that linked plot locations with existing and proposed processing facilities. There was no projection of stands forward in time, and the FVS database extension did not yet exist. Consequently, FVS text file output had to be parsed with perl and awk scripts and other tools, to fetch desired outputs back to an analysis database where treatment efficacy, wood production and value, and treatment and transportation costs could be summarized and compared (Fried and others 2005). Much of this workflow seems primitive in light of FVS's current capabilities.

The PNW Research Station's Focused Science Delivery Program provided significant seed

[1]**Jeremy S. Fried**, Research Forester, U.S. Forest Service, Pacific Northwest Research Station, FIA, Portland, OR, jsfried@fs.fed.us; **Theresa B. Jain**, U.S. Forest Service, Rocky Mountain Research Station, Moscow, ID, tjain@fs.fed.us; **Sara Loreno**, Ecotrust, Portland, OR, sloreno@ecotrust.org; **Robert F. Keefe**, University of Idaho Moscow, ID, robk@uidaho.edu; and **Conor K. Bell**, University of Idaho, Moscow, ID, cbell@bellenco.com.

Citation for proceedings: Keyser, Chad E.; Keyser, Tara L., eds. 2017. Proceedings of the 2017 Forest Vegetation Simulator (FVS) e-Conference. e-Gen. Tech. Rep. SRS-224. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 200 p.

funding, generously matched with FIA Program support, to formalize what had been a manual, kludgy, error-prone and problematic hand-cranked "model." BioSum 3 became a user-friendly tool with workflow management software ready for beta-testing in 2007. The Fuel Reduction Cost Simulator (FRCS) (Fight and others 2006) treatment cost spreadsheet tool was substituted for STHARVEST and a formal spatial analysis workflow was documented to handle haul cost calculation. BioSum 3 was applied to a 25 million acre study area in western Oregon and northern California to demonstrate the proof-of-concept, to characterize the kinds of wood that could be produced by fuel treatments (Barbour and others 2008), and to extend it to include optimization of treatment selection and siting of processing facilities (Daugherty and others 2007).

Analytic capacity was extended in 2011 in BioSum 4 to allow any FIA or calculated FVS data item to participate in the determination of treatment effectiveness. These new capabilities were exercised for the dry mixed conifer fuel synthesis (Jain and others 2012) in which treatment effectiveness was informed by changes to three aspects of fire hazard: (1) fire suppression safety, (2) crown fire severity, and (3) economic impact. These aspects are tied to FFE-FVS predictions of surface flame length, torching index, torching probability, and mortality volume. For the first time, FVS projections were analyzed to understand the carbon implications of fuel treatment under different fire return intervals, considering mortality and harvested products (Fried and others 2013).

BIOSUM 5

The launch of two extramurally funded projects in 2012-2013 made it possible to account for delayed treatment, the possibility of re-treatment, and treatment longevity. BioSum was transformed into a dynamic framework under which many thousands of stands could be treated at multiple time points, and stand attributes under alternative management, including grow-only, could be tracked and compared. Version 5 also brought (1) the introduction of regeneration into BioSum simulations via the REPUTE (Vandendrieche 2010) protocol; (2) the replacement of FRCS with the OpCost model (Bell and others, 2017a), written in R, developed specifically for use with BioSum; and (3) a computationally fast, graph-theory based haul cost analysis workflow developed with R code in lieu of the previous ArcGIS workflow that was both slow and memory-limited. With these developments, it became clear that BioSum had the potential to be more widely useful, beyond just fuels treatment analyses, for any forest scenario analysis for which it is important to consider broad scale outcomes over a heterogeneous forested landscape. It could be used, for example, to analyze carbon dynamics associated with management and disturbance, considering forest objectives other than fire resilience (e.g., individual or multiple stand attributes related to wildlife habitats), and for analyzing wood supply in a spatially explicit fashion. We are completing a wood supply analysis for BioChar feedstocks as part of a study funded by Oregon State University's Institute for Working Forest Landscapes. Habitat elements that can be tracked in FVS, such as number of large live and dead trees, canopy cover and down wood, could also be a basis for evaluating the success of silvicultural treatments for achieving desired outcomes under alternative disturbance and climate scenarios.

BioSum 5, renamed "Bioregional Inventory Originated Simulation Under Management" while retaining the existing acronym, marries FIA plot data with the FVS model, and adds custom models for estimating treatment and haul costs, along with a treatment heuristic optimizer. A user can design as many treatments as desired and apply the framework to a landscape as small as a 1 million acre National Forest or as large as the entire Western United States. FIA data has the advantage of informing about both private and public lands—both are needed to truly understand wildlife habitats and other services provided in forested landscapes. Without the BioSum software, work flow management posed a nearly insurmountable challenge given the number of parameters that must be tracked and the large sample sizes that FIA data provide. It is not uncommon for a single BioSum project covering a multi-State area and dozens of management alternatives to grow to over 100GB. It can be helpful to think of BioSum as generating an enormous knowledge base, populated by FVS

output generated via simulating thousands of FIA plots, which comprise a representative sample of the entire forested landscape, using dozens, or even hundreds, of silvicultural prescriptions. In the BioSum simulation environment, FVS's role is to compute relevant stand metrics and apply multiple silvicultural sequences to generate alternative stand trajectories. BioSum is responsible for managing work and data flow, merchandising harvested wood by species and size and moving it to processing facilities. BioSum also estimates treatment cost via OpCost, and supports analysts as they seek to understand the effects and costs of alternative management strategies.

MODEL FRAMEWORK

In essence, BioSum deploys FVS to simulate management of any desired subset of a fully representative sample of all forest based on the consistent, quality controlled field measurements collected by FIA. BioSum also contains a spatial element to address the location of forests relative to road networks and wood processing facilities, including biorefineries that produce renewable energy. We see it as a potentially valuable tool for management experimentation, because it can generate information about management effects, costs and revenues under alternative objectives, constraints or policies, at much broader spatial scales and in greater levels of complexity than can be achieved using FVS alone. Such pre-implementation knowledge could be thought of as predictive or hypothetical monitoring.

This simplified schematic (fig. 1) traces the workflow beginning with FIA plot data, which BioSum translates into FVS stand files. FVS then simulates multiple, alternative, user-designed silvicultural sequences of up to 4 treatments, implemented at 10-year intervals, interleaved with stand projection between treatments. BioSum then imports FVS output, and sends it to both OpCost for simulating treatment costs for each decade for each

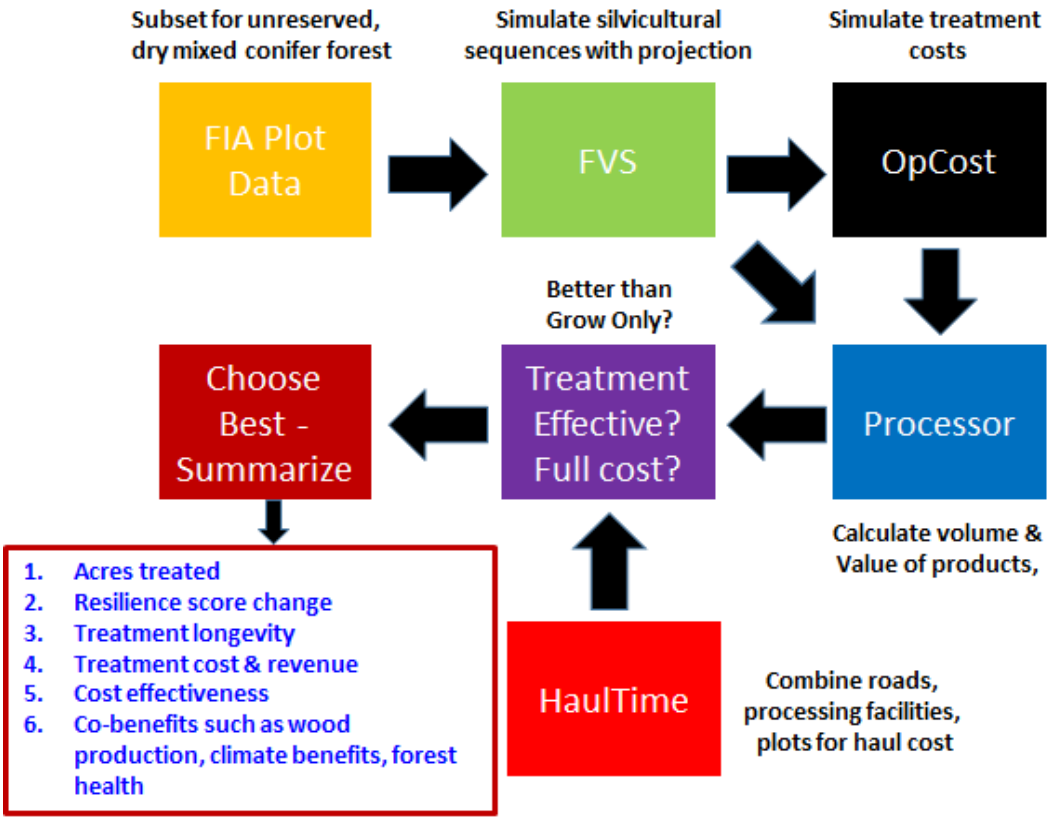

Figure 1—Data and processing workflow within the BioSum analysis framework.

stand-sequence combination and to "Processor" which accounts for wood product volumes and values.

OpCost manages over 100 equations covering 11 types of logging machinery and 11 harvest systems composed of multiple machines (Bell and others, 2017a). Predictions from all applicable equations for a stand, given the selected harvest system, are generated and averaged to obtain a treatment cost. Validation of OpCost predictions has been published (Bell and others 2017b) and work on implementing a harvest system optimization option in BioSum and OpCost is continuing.

Next to enter the workflow are travel times from every plot to every potentially relevant processing facility estimated via R (R Core Team 2017) scripts that implement a graph theory representation of the road network. Ultimately, we must define what an effective management sequence looks like, and how to choose the best one when there are several candidates. This numbered list shows a few of the kinds of summaries that can emerge from the end of the pipe. Because we project stand trajectories following treatment, we can address treatment longevity directly.

USING BIOSUM

There is no one correct way to use BioSum. We and research partners have used BioSum to, for example:

1. Assess the status of and opportunities to achieve risk reduction and other goals in current forests
2. Apply silvicultural prescriptions today, and monitor how effects play out over time
3. Simulate dynamic management over four projection cycles
4. Evaluate outcomes of silvicultural alternatives over a wide range of possible options, in order to rate or rank them by appropriate metrics
5. Predict and evaluate the product mix that forested landscapes can produce under different policies, legal and economic restrictions, or incentives
6. Convert FIA data into FVS format to assess or experiment with stand data from a representative sample of the forested landscape

The illustrative example presented here can be thought of as a blend of uses: assessment (#1), silvicultural prescription scenarios (#2) and effectiveness (#4). Through this proactive monitoring analysis, BioSum provides an initial, model-informed test of a hypothesis designed to evaluate alternative management choices. Over time, the continuous remeasurement of the FIA sample plots offers the opportunity to obtain monitoring feedback about the real world outcomes of such management, assuming that implementation actually happens at a scale sufficient for detection by the FIA plot network. This can be best seen as a supplement to stand-to-landscape effectiveness monitoring that is needed to judge outcomes of particular implementations in particular places to promote learning, inform future management decisions, and improve model accuracy.

FUEL TREATMENT EXAMPLE

To illustrate one use of the framework, we looked at the effectiveness and costs of mechanical fuel treatments designed to reduce fire hazard and enhance fire resistance, focusing on dry mixed conifer forests across the geographic range of 13 FVS variants in CA, OR, WA, ID and MT (FVS version 1778). This FIA sample represents 29 million acres with over 7,000 conditions (full or partial plots). By applying the BioSum analysis framework, these conditions become stands that get modeled in FVS. These stands cover almost every gradient imaginable, across density, volume, site quality, age, structure complexity, species fire tolerance, terrain, road access, and proximity to wood processing facilities. Where a stand sits in this hyperspace determines its inherent resistance, amenability to restoration treatment, longevity of treatment benefits, and net treatment costs or revenues.

Relying on the FVS Structural Statistics Report as a basis for characterizing forest structure and drawing on prescription examples shared during interviews with silviculturists across the region, three stand types were recognized: (1) multi-storied stands, for which we devised six versions of an "improvement cut" prescription designed to maintain multi-storied stand structure while reducing overstory canopy density and understory tree count; (2) single story stands, which we addressed with three versions of

a "commercial thin" prescription, and (3) young stands containing trees too small to be suitable for either of these kinds of prescriptions, which we did not model for this study. Table 1 shows ranges of key prescription parameters. For both multi- and single-storied stands, prescriptions were designed to first cut low vigor trees (those with live crown ratio < 40 percent or height to DBH ratios exceeding 80), then cut tree species considered not resistant to fire, such as white and grand fir, then additional trees until prescription targets were achieved, subject to specified DBH ranges. Mechanized whole-tree logging was modeled on slopes under 40 percent and cable manual whole-tree logging on steeper slopes to minimize generation of in-forest residues; such residues were piled and burned only when they resulted in surface fuels exceeding 15 tons/acre as simulated in FVS. Post-treatment regeneration was added using the REPUTE model. Grow-only simulations provide a baseline against which to compare the stand trajectories achieved via active management.

Treatment Effectiveness

BioSum analyses have long relied on metrics produced by FFE-FVS, such as torching and crowning indices, torching probability, surface flame length and derivatives of predicted fire-induced mortality volume as indicators of hazard, and on changes in such metrics as a measure of effectiveness. However, experience has demonstrated that FFE-FVS metrics are driven much more by surface fuel model choices than tree attributes, and despite years of effort to finesse FFE-FVS's fuel model selections, confidence that model outcomes are realistic has been elusive. Instead, we derive resistance metrics from tree information—the kind of information that FIA plots most reliably provide.

We used four management approaches to increasing stand resistance to fire: (1) elevating canopy base height, (2) reducing canopy bulk density, (3) increasing proportion of resistant species, and (4) increasing tree size (Agee and Skinner 2005). We did not model surface fuel trajectories in this analysis, but accounted for surface fuel treatment cost and implicitly addressed surface fuels by developing a target canopy base height (CBH) metric (Keyes 2006, Keyes and O'Hara 2002). Each of these four dimensions of resistance was scored (0-3) to produce a component resistance metric (CRM). These were ultimately summed to calculate a composite resistance score (0-12) to integrate across these factors. Keeping large trees alive, harvesting and sequestering woody carbon in products, and utilizing residues for renewable energy all contribute to GHG mitigation, an important co-benefit.

To consider **target CBH**, all relevant timber litter and timber understory fuel models (Scott and Burgan 2005) were modeled in BEHAVE under a broad range of wind speeds and slopes to derive intensity and generate inputs for the van Wagner equation (van Wagner 1977) that calculates the target canopy base height required to prevent crown fire initiation. While these target CBHs vary with wind and slope, as well as fuel, we observed some clustering and natural breakpoints that suggested suitable thresholds for scoring this CRM: 0 for CBH < 7 feet, 1 for 7 ≤ CBH < 20, 2 for 20 ≤ CBH < 30 and 3 for 30 ≤ CBH.

Table 1—Silvicultural prescription parameters used to define 6 "improvement cuts" applied to multi-storied stands and 3 "commercial thins" applied to single story stands.

Treatment	Residual stand basal area or trees per acre (TPA) target	Max DBH (inches)	Min DBH (inches)	Understory Target TPA
Improvement cuts	80 to 100 ft^2	19-21, none	5-7	0 to 222
Commercial thins	150 ft^2	None	7	50
	90-194 TPA	None	5-7	20

We relied on the literature to score resistance conferred by **canopy bulk density** (CBD) as follows: 0 for CBD > 0.15 kg/m^3, 1 for 0.1 < CBD ≤ 0.15, 2 for 0.05 < CBD ≤ 0.1, and 3 for CBD ≤ 0.05. A stand scoring zero for this CRM has essentially no resistance to active crown fire propagation, while one earning a 3 not only has considerable resistance, but can grow for a while before resistance fades.

Western larch, ponderosa pine, Jeffrey pine, sugar pine, and red fir are considered fire resistant species in all 13 variants, and Douglas-fir in all except the Inland Empire, Blue Mountains and Eastern Montana variants. We calculated **resistant species proportion** (prop) as a fraction with numerator containing the basal area of all live trees of species that are considered fire resistant in that variant and denominator containing the basal area of all live trees. Scoring of this CRM was as follows: 0 for prop. < 0.25, 1 for 0.25 ≤ prop. < 0.50, 2 for 0.50 ≤ prop. < 0.75, and 3 for 0.75 ≤ prop.

Accounting for the tree size component of fire resistance, intended as a proxy for survival of live trees, was complicated by the simultaneous effects of size and species on survival. Mean DBH, height and crown ratio for all the trees in the FIA database were calculated, by species, size class and FVS variant to produce inputs for the First Order Fire Effects Model (FOFEM), version 6, which was used to predict mortality resulting from 6 and 8 foot flame lengths for each species-size class-variant combination. The species-size class-variant appropriate mean (of 6 and 8 foot flame length predictions) for each combination was applied to the trees per acre (TPA) represented by each live tree as a mortality factor, and these were used to expand tree volume (mortality TPA * volume) to mortality volume. Mortality volume was summed over all trees, then used to compute **survival proportion** as ((TPA*Volume) – mortality volume)/(TPA*Volume). Proportions were scored as follows: 0 for < 0.02, 1 for 0.02 ≤ prop. < 0.30, 2 for 0.30 ≤ prop. < 0.60, and 3 for 0.60 ≤ prop. This scoring awards a point for even very minimal proportional survival. When a stand contains trees that are of a size and species that result in 60 percent volumetric survival, this system considers the stand fully resistant with respect to this CRM.

These four CRMs were summed to produce a **composite resistance score** (CRS) that ranges from 0 to 12. This score can be calculated for pre- and post-treatment time points or for any other time point in the simulation. We can compare CRS at a particular time, or as a weighted average over a period of time, that results from one treatment versus another or to a grow-only scenario. In this way, treatment longevity can be explicitly considered in the analysis framework, and the effects of intentional management separated from changes that might occur anyway with natural succession in the absence of management.

Classifying Fire Vulnerability

Exploratory analysis of these calculated metrics (CRS and CRM) for thousands of stands revealed some distinctly different initial (pre-treatment) conditions that we believe are germane to identifying superior management alternatives. We constructed four bins, which we'll refer to as fire vulnerability classes (FVC), to partition the range of resistant species proportion, as this metric appears to strongly influence the potential for treatments to be effective (table 2). For example, a stand of pure white fir (FVC 4) cannot be immediately converted to a CRS score of 12 because its low resistant species proportion can't be changed without totally replanting the site. The FVCs also differ in terms of their resistance (as measured by mean CRS) and their prevalence in dry mixed conifer forests. Moreover, their potential for resistance improvement with management differs markedly, as seen for target CBH (fig. 2.). In stands with the lowest fire vulnerability (FVC 1), where CRS is high before any treatment, we see minimal improvement to that component resistant metric from applying restoration treatments. However, treating stands that have a high proportion of resistant species but lower scores for the other metrics (FVC 2) leads to outcomes of elevated target CBH scores that predict enhanced resistance relative to stands classified as FVC 3 or 4, perhaps because the latter contain shade tolerant species more likely to adversely influence this metric as regeneration commences.

Because every stand in a BioSum analysis is tied to a representative location on the ground, and the forest type, owner, and myriad site factors

Table 2—Pre-treatment fire resistance can be usefully classified or binned into fire vulnerability classes (FVCs) that partition the range of resistant species proportion

FVC	FVC description	Resistant species score	CRS Limit	Percent of forest	Mean CRS
1	High resistance sp. + high total score	3, ≥75% fire resistant spp.	≥ 9	19	10.1
2	High resistant sp. + low total score	3, ≥75% fire resistant spp.	< 9	10	7.3
3	Mod. resistant sp.	1 or 2, 25-75% fire resistant spp.	All values	33	7.4
4	Low resistant sp.	0, < 25% fire resistant spp.	All values	37	5.1

CRS=Composite resistance score.

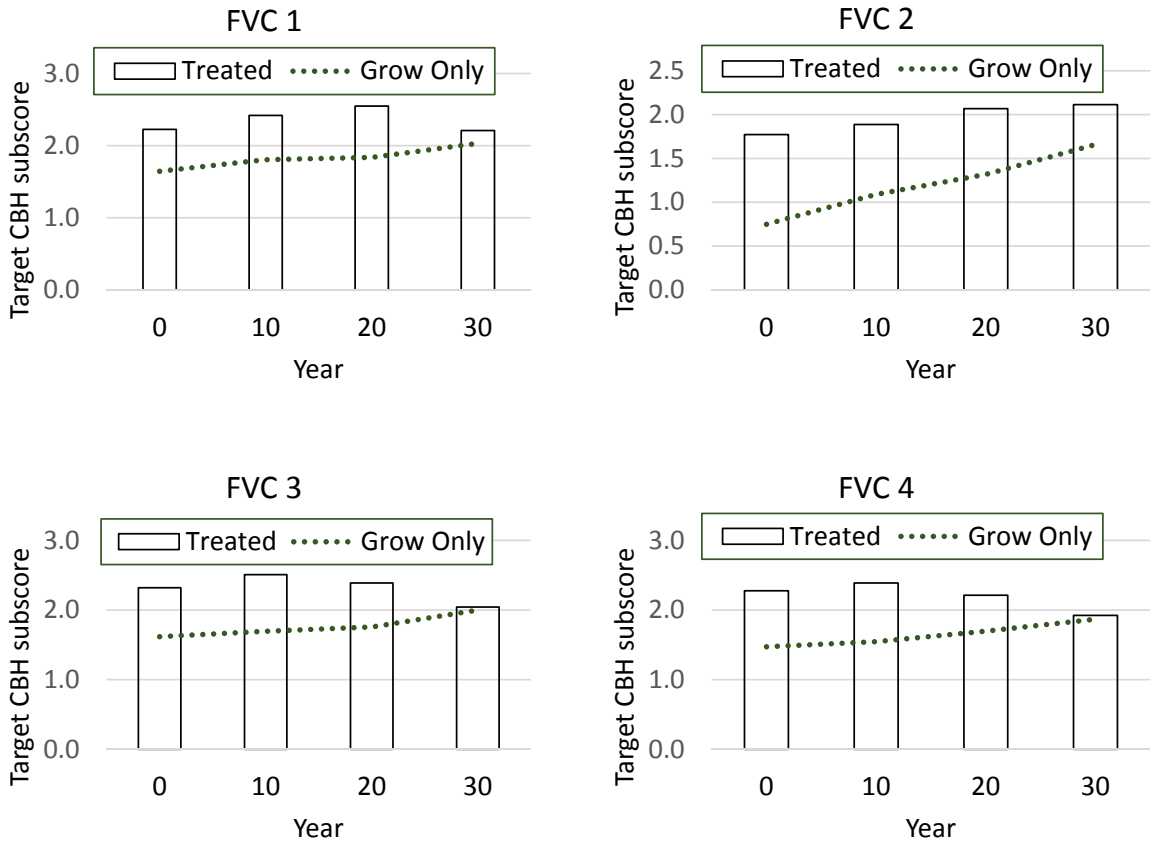

Figure 2—Mean target canopy base height subscore, where 0= less than 7 feet, 1=7 to 20 ft., 2=20-30 ft. and 3= greater than 30 feet., by fire vulnerability class (FVC), where FVC 1=high resistant species sub-score and composite resistance score, FVC 2=. high resistant species sub-score and low to moderate composite resistance score, FVC 3= moderate resistant species sub-score, and FVC 4= low resistant species sub-score, when most effective treatment was applied (hollow bars) and when no treatment was applied (dotted lines) over three decades.

associated with that location, it's easy to use these factors as a basis for summarizing any stand level metric collected by FIA or computed in FVS or FFE-FVS, or in this case, via FVC assignment derived from a complex resistance rating process that builds on attributes from those models as well as exogenously calculated information (on survival proportion). Figure 3 shows pre-treatment FVC distribution for dry mixed conifer forests to be highly varied across the National forests in the western portion of the study area, with Lassen having the lowest, and Siskiyou and Six Rivers the highest proportion of area with the highest level of resistant species proportion (FVCs 1 and 2). Reasons for these differences can be hypothesized and tested via analysis of the underlying inventory data.

Treatment Longevity

Comparing the average outcomes of implementing for each stand the restoration treatment that achieves the greatest increase in CRS over the grow-only at each time step confirms that the already high CRS-scoring stands in FVC 1 show less improvement over time when compared to the grow-only (fig. 4). Three decades after treatment, the gains in average resistance conferred by restoration relative to grow-only scenarios for stands in FVC 1 have completely disappeared. Additional work is underway in a related study to examine re-treatment efficacy and feasibility.

Treatment Economics, Effectiveness and Feasibility

A key BioSum strength is support for scenario analysis, considering, for example, alternative policies and constraints that govern which acres would be prioritized over the forested landscape, given the outcomes of restorations treatments and their net cost, as assessed via net revenue (NR). Four simple scenarios involving differences in the magnitude of the difference in scores (ScoreDiff) between the best restoration treatment and grow-only sequences and levels of treatment subsidy that can be contemplated, and considering only the ScoreDiff at year 1, were evaluated to produce the comparison of outcomes depicted in figure 5 with respect to area treated, mean net revenue and mean ScoreDiff. The scenarios are:

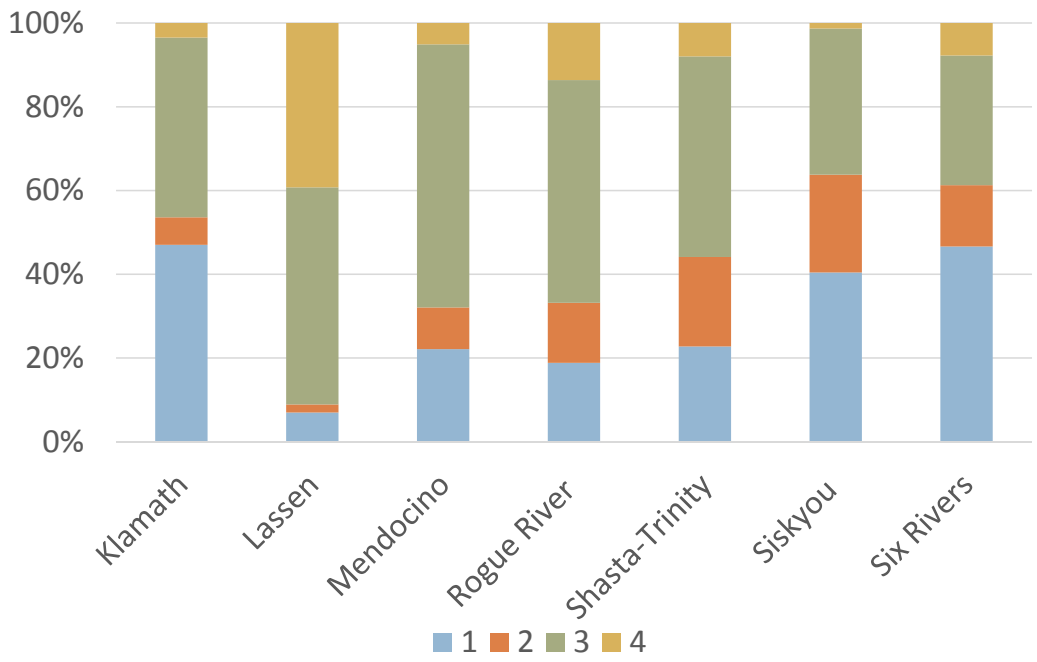

Figure 3—Distribution of forest area, as a percent of total area, by fire vulnerability class (FVC) for seven national forests in the western portion of the study area, where FVC 1=high resistant species sub-score and composite resistance score, FVC 2= high resistant species sub-score and low to moderate composite resistance score, FVC 3= moderate resistant species sub-score, and FVC 4= low resistant species sub-score.

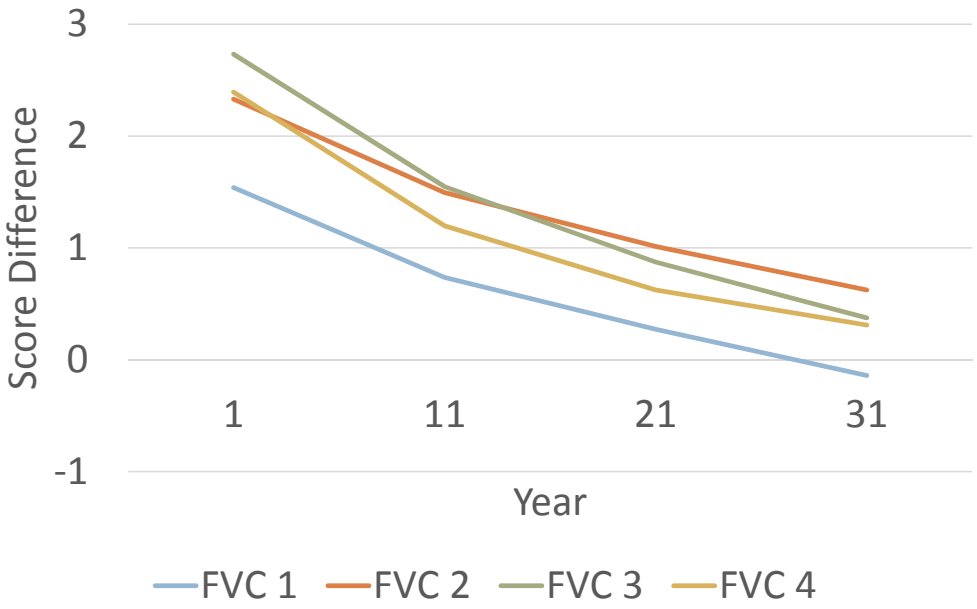

Figure 4—Mean fire resistance score difference in the 12-point scale composite resistance score, relative to a grow-only scenario, by fire vulnerability class (FVC) and decade, where FVC 1=high resistant species sub-score and composite resistance score, FVC 2= high resistant species sub-score and low to moderate composite resistance score, FVC 3= moderate resistant species sub-score, and FVC 4= low resistant species sub-score.

1. Score improves by at least 1 point (ScoreDiff>0, since scores are integers)
2. Score improves by at least 1 plus treatment pays for itself (ScoreDiff>0, NR >0)
3. Score improves by at least 1 and net treatment costs are between 0 and $500 per acre (ScoreDiff>0, NR 0 to -500)
4. Score improves by at least 3 and net treatment costs are between 0 and $500 per acre (ScoreDiff>2, NR 0 to -500)

Restoration treatment has the potential to at least somewhat increase resistance, at least initially, on approximately 17 million acres of dry mixed-conifer forest in this five State region; however, self-paying treatment is possible on only about half of that area (fig. 5A). As seen earlier, resistance improvement, as measured by ScoreDiff, in FVC 1 stands is somewhat less than for stands in the other classes (fig. 5B), and the mean improvement is somewhat less for stands where subsidy is required (NR of 0 to -500). However, for about a third of these stands, a ScoreDiff of 3 or greater can be attained, and at a unit cost about equal to the average for the full set of NR 0 to -500 stands, which suggests opportunities to prioritize—using the first available funds to treat acres with greater ScoreDiff. Most of the acres with negative net revenue would requires subsidies greater than $500 per acre (compare a sum of the 2nd and 3rd bars with the 4th in fig. 5A) to achieve a significant reduction in fire vulnerability.

Although most restoration treatments incur net costs, even after accounting for sales of wood produced, the revenue from those that produce positive net revenue is large enough that addressing all treatable acres would generate positive cash flow, except for stands in FVC 4. Unsurprisingly, limiting treatment to stands that pay for themselves generates much more revenue per acre, but treats much less area, though the improvement on acres that are treated is not dramatically different with or without such limits (fig. 5B, 5C). A caveat on the economic analysis is that only treatment and haul costs are considered; administrative and planning costs are not included in the estimates. It is hoped that implementation of BioSum would increase the transparency and accuracy of planning, with the potential to reduce planning costs.

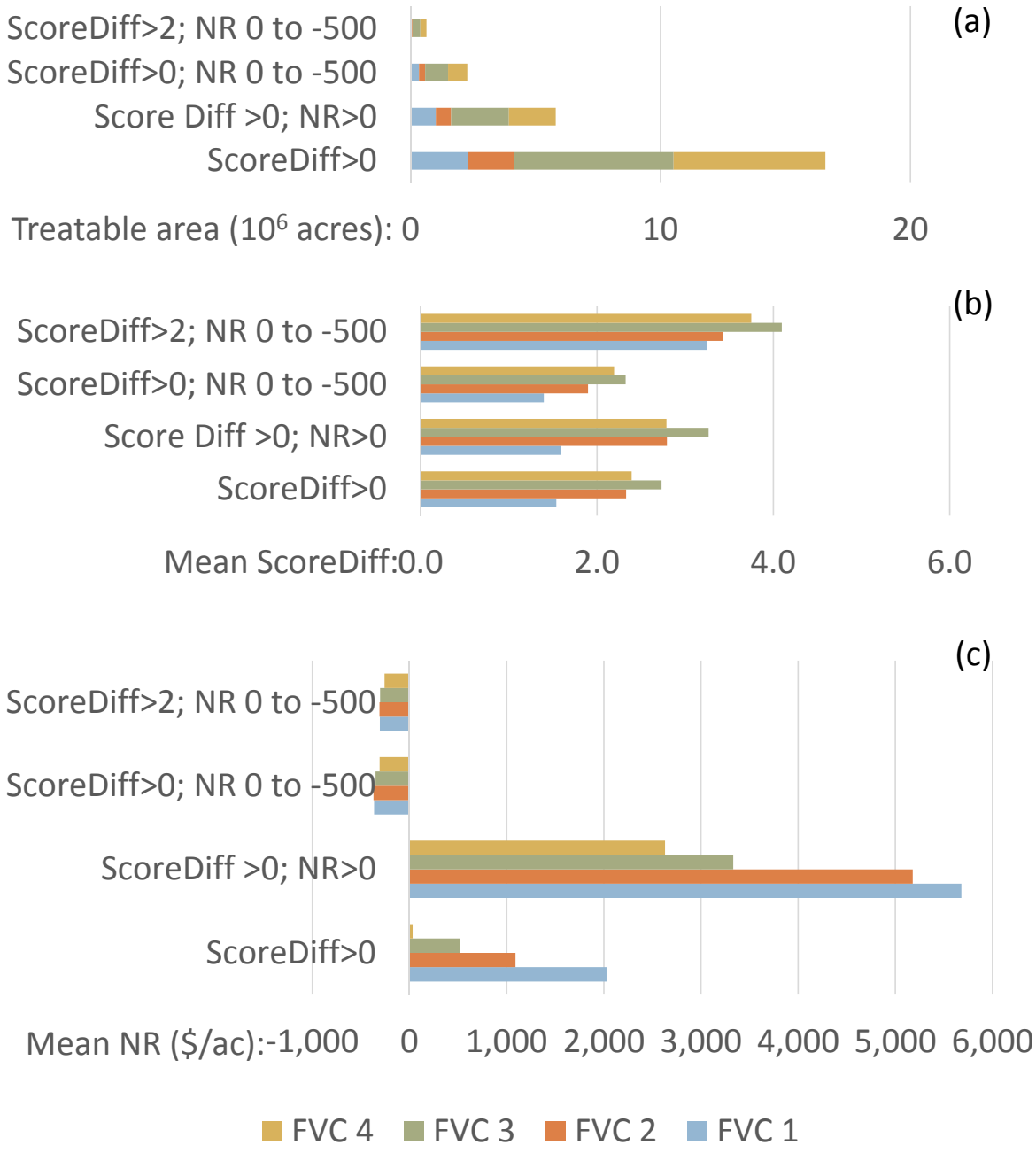

Figure 5—Area treated, in millions of acres (a); mean difference in composite resistance score (ScoreDiff) at year 1 between applying the most effective treatment and no treatment (b); and mean net revenue, in dollars per acre, of applying the treatment that generates the greatest increase in resistance score (c), by pre-treatment fire vulnerability class (FVC) under four scenarios: 1. Score improves by at least 1 point (ScoreDiff > 0), 2. Score improves by at least 1 and treatment pays for itself (ScoreDiff > 0, NR >0), 3. Score improves by at least 1 and net treatment costs are between 0 and $500 per acre (ScoreDiff > 0, NR 0 to -500), and 4. Score improves by at least 3 and net treatment costs are between 0 and $500 per acre (ScoreDiff > 2, NR 0 to -500).

MONITORING PROSPECTS

BioSum and the FIA plot network have potential utility for monitoring the outcomes of forest restoration implementation. BioSum analyses like this one can provide at least preliminary, model-based information about the likely outcomes of alternative management choices and about prospects for long-term success. However it is important to remember that, provided that the program remains funded, the FIA data will continue to roll in, so if implementation of those management choices produces substantial changes on the landscape, this becomes visible as the data updates and it will be possible to validate whether the forested landscape is changing as desired. If managed area is not large, there may be value for National forests in analyzing an overlay of treatment polygons in enterprise databases such as FACTS on FIA plot locations, provided that treatment polygons can be consistently populated and updated– something we have not yet found to be universally true.

AVAILABLE NOW

A forthcoming article (Fried and others 2017) more fully describes the BioSum framework and other examples of analyses conducted to date. This, and other BioSum related publications and the BioSum software and Users Guide, can be downloaded from http://biosum.info at no charge. FIA program data to feed BioSum can be downloaded from https://apps.fs.usda.gov/fia/datamart/datamart_access.html.

LITERATURE CITED

Agee, J.K.; Skinner, C.N. 2005. Basic principles of forest fuel reduction treatments. Forest Ecology and Management. 211(1-2): 83-96.

Barbour, R.J.; Fried, J.S.; Daugherty, P.J. [and others]. Potential biomass and logs from fire-hazard-reduction treatments in southwest Oregon and northern California. Forest Policy and Economics. 10(6): 400-407.

Bell, C.K.; Keefe, R.F.; Fried, J.S. 2017a. Opcost: an open-source system for estimating costs of stand-level forest operations. Gen. Tech. Rep. PNW-GTR-960. Portland, OR: U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station. 23 p.

Bell, C.K.; Keefe, R.F.; Fried, J.S. 2017b. Validation of the opcost logging cost simulator using contractor surveys. International Journal of Forest Engineering. 28(2): 73-84. DOI:10.1080/14942119.2017.1313488.

Daugherty, P.J.; Fried, J.S. 2007. Jointly optimizing selection of fuel treatments and siting of forest biomass-based energy production facilities for landscape-scale fire hazard reduction. Infor. 45(1): 17-30.

Fight, R.D.; Zhang, X. [and others]. 2003. Users guide for STHARVEST: software to estimate the cost of harvesting small timber. PNW-GTR-582: Portland, OR: U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station. 12 p.

Fight, R.; Hartsough, B.; Noordijk, P. 2006. Users guide for FRCS: fuel reduction cost simulator software. Portland, OR: U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station. 23 p.

Fried, J.S.; Christensen, G.; Weyermann, D. [and others]. 2005. Modeling opportunities and feasibility of siting wood-fired electrical generating facilities to facilitate landscape-scale fuel treatment with FIA BioSum. PNW-GTR-656. In: Systems Analysis in Forest Resources: Proceedings of the 2003 Symposium. Bevers, M.; Barrett, T.M. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 195-204.

Fried, J.; Jain, T.; Sandquist, J. 2013. Modeled forest inventory data suggest climate benefits from fuels management. Fire Management Today. 73(2): 11-14.

Fried, J.S.; Potts, L.D.; Loreno, S.M. [and others]. 2017. Inventory based landscape-scale simulation of management effectiveness and economic feasibility with Biosum. Journal of Forestry. 115: 249-257.

Jain, T.B.; Battaglia, M.A.; Han, Han-Sup. [and others]. 2012. A comprehensive guide to fuel management practices for dry mixed conifer forests in the northwestern United States. Fort Collins, CO: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station. 331 p.

Keyes, C.R. 2006. Role of foliar moisture content in the silvicultural management of forest fuels. Western Journal of Applied Forestry. 21(4): 228-231.

Keyes, C.R.; O'Hara, K.L. 2002. Quantifying stand targets for silvicultural prevention of crown fires. Western Journal of Applied Forestry. 17(2): 101-109.

R Core Team. 2016. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: https://www.R-project.org/. [Date accessed: Sept. 2, 2017].

Scott, J.H.; Burgan, R.E. 2005. Standard fire behavior fuel models: a comprehensive set for use with Rothermel's Surface Fire Spread Model. RMRS-GTR-153. Fort Collins, CO: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station. 72 p.

Vandendrieche, D. 2010. An empirical approach for estimating natural regeneration for the forest vegetation simulator. In: Proceedings of the 2009 National Silviculture Workshop. RMRS-P-61. U.S. Department of Agriculture Forest Service: 307-320.

Van Wagner, C.E. 1977. Conditions for the start and spread of crown fire. Canadian Journal of Forest Research. 7(1): 23-24.