Using the Fuels and Fire Effects (FFE) and Economic (ECON) Extensions to the Forest Vegetation Simulator (FVS) to Evaluate the Impacts of Silvicultural Regimes

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Abstract—The FFE and ECON extensions to FVS were used to evaluate the impacts of five silvicultural scenarios on a dry ponderosa pine (*Pinus ponderosa*) plantation and a moist, mixed-species stand. Scenarios ranged from no treatments to traditional thinning to thinning with prescribed fire management. Present net value (PNV), total cubic foot volume productivity, and fire hazard, defined by torching index, crowning index, and predicted fire type under wildfire conditions, were computed. Greatest PNV difference among all regimes was approximately $600 per acre at simulation end. Greatest difference in total cubic foot volume production among regimes at simulation end was approximately 2000 cubic feet per acre. Productivity was greatest for mechanical treatment only regimes. Regimes containing prescribed fire treatment generally had lower total productivity, with multiple fire treatment regimes generally producing less volume than single fire treatment regimes. Greatest difference in fuel concentration was approximately 45 tons per acre for the ponderosa pine plantation at 100 years. Surface fuel concentrations, for both fine fuels and total fuels, were consistently higher for the no treatment regimes for both stands, with marked increases occurring when stands reached 60 to 100 years old. Using the FFE and ECON extensions provides managers with quantitative measures for evaluating both the economic benefits and wildfire hazards of different silvicultural scenarios.

Several extensions to FVS (Stage 1973; Wykoff and others 1982) have been developed over the years to provide managers with quantitative information about forest management activities, beyond the basic dynamics of tree growth provided by FVS. The latest extensions are the Fuels and Fire Effects Extension (FFE) (Beukema and others 2000) and the Economic Extension (ECON) (Renner 2002, in preparation). The FFE is designed to simulate effects of fire on stand characteristics and stand development, and to simulate the effects of stand development and management actions on fuel dynamics, fire behavior, and fire effects. The FFE consists of three major modules: (1) snag module that monitors decay and fall down of snags, (2) fuels module that simulates accumulation and decomposition of surface fuels, and (3) fire module that simulates fire intensity, effects on trees, smoke production, and mineral soil exposure.

The ECON extension computes economic measures associated with stand management activities including present net value (PNV), soil expectation value (SEV), internal rate of return, benefit/cost ratio, value of reproduction, undiscounted cash flow, and the value of an existing stand. ECON allows for three types of economic analyses: (1) analysis of an existing stand over a finite investment horizon (PNV), (2) analysis of an infinitely repeating management regime (SEV), and (3) a combined analysis of an existing stand followed by application of an infinitely repeating management regime (PNVPLUS). ECON features include: (1) computation of harvest revenues based on either tree d.b.h. or log size, (2) evaluation of multiple rotation ages or harvest timings within a single FVS simulation via the PRETEND keyword, (3) full integration with FVS allowing for dynamic specification of management activities based on economic measures using the Event Monitor (Crookston 1990), (4) production of log stock tables with associated revenues, and (5) flexible specification of fixed and variable costs and revenues.

Case Studies

Two case studies illustrate the use of the FFE and ECON extensions in evaluating the impacts of silvicultural regimes. Five silvicultural regimes, including a no treatments option, were specified for each case study. Regime treatments, along with their associated economic costs and revenues, were provided by silviculturalists and fire management personnel currently involved in managing the stands. PNV, total cubic foot volume productivity, fuel profiles, fire-related mortality, and three measures of fire hazard rating were computed for each regime. The three fire hazard metrics used were: (1) torching index defined as the 20-foot wind speed (that is, wind speed at 20 feet above ground level) required to carry a fire from the ground surface into tree crowns; (2) crowning index defined as the 20-foot wind speed required to maintain an actively crowning fire, thereby killing all trees in the stand; and (3) predicted fire type under severe burning conditions (that is, "surface" fire when the fire is confined to the ground with no scorching of crowns, "passive" fire when the fire scorches and consumes groups of crowns resulting in scattered mortality, or "active" fire when the fire consumes all crowns within the stand resulting in

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Table 1—Silvicultural regimes for the ponderosa pine plantation. The stand was simulated beginning in year 2000 in order to include economic costs associated with stand establishment.

Year	Age	1a	1b	1c	2a	2b
2000	0	Plant	Plant	Plant	Plant	Plant
2020	20	Precommercial thin to 350 trees/acre (t/a); no residue treatment	Precommercial thin to 350 t/a; no residue treatment	No treatment	No treatment No treatment	No treatment
2030	30	No treatment	No treatment	No treatment	Throttle-back understory burn	Throttle-back understory burn
2060	60	Commercial thin to 130 sq ft + jack-pot fuel burn	Commercial thin to 130 sq ft; residue removed from stand	No treatment	Commercial thin to 130 sq ft + jack-pot fuel burn	Commercial thin to 130 sq ft; residue removed from stand
2120	120	Clear-cut	Clear-cut	No treatment	Clear-cut	Clear-cut

complete stand mortality). Prescribed fire treatment types used in the study were: (1) throttle-back broadcast burn, (2) low intensity "free to burn" broadcast burn, and (3) jackpot fuel burn. The throttle-back prescribed fire is a broadcast burn that affects the entire stand, with the fire confined to thin strips. The free to burn broadcast burn is a low intensity understory burn affecting the entire stand, while the jackpot fuel burn affects only concentrations of fuels within the stand.

Case Study 1 – Ponderosa Pine Plantation

The first stand used in the analysis was a ponderosa pine plantation with the following characteristics: located in Nez Perce National Forest, Idaho, 35 years old, *Pseudotsuga menziesii*/*Physocarpus malvacens* habitat type, 20 percent slope, southeast aspect, 4,500 feet elevation, 510 trees per acre, composed of 70 percent ponderosa pine, 20 percent Douglas-fir (*Pseudotsugamenziesii*), and 10 percent western larch (*Larix occidentalis*) on a trees per acre basis. The stand had no previous management treatments. The five silvicultural regimes applied to the stand are listed in table 1, and the input economic parameters used are listed in table 2.

PNV for each regime, displayed in figure 1, shows that the mechanical treatment only regime, 1b, generated the greatest PNV at simulation end, while the no treatment regime, 1c, had the lowest PNV. Regimes using prescribed fire treatments, 1a, 2a, and 2b, generated intermediate PNV values with slightly lower values for the regimes performing a jackpot fuel burn in 2060 (1a and 2a). Total cubic foot volume production, displayed in figure 2, shows that the mechanical treatment only regime, 1b, generated the greatest total cubic foot production, while the regime applying prescribed fire treatments at ages 30 and 60 years, 2a, was

Table 2—Input economic parameters for ponderosa pine plantation.

Economic parameter	Value
Discount rate	5.0%
Annual cost	$2.50/acre
Planting cost	$175.00/acre
Burn site prep cost	$200.00/acre
Precommercial thin fixed cost	$100.00/acre
Harvest variable cost	$25.00/mbf
Harvest fixed cost	$100.00/acre
Average harvest revenue	
Western white pine	$339.75/mbf
Western larch	$366.40/mbf
Douglas fir	$366.40/mbf
Grand fir	$339.75/mbf
Western hemlock	$339.75/mbf
Western red cedar	$366.40/mbf
Lodgepole pine	$339.75/mbf
Englemann spruce	$339.75/mbf
Sub-alpine fir	$339.75/mbf
Ponderosa pine	$384.00/mbf

mbf = thousand board-feet

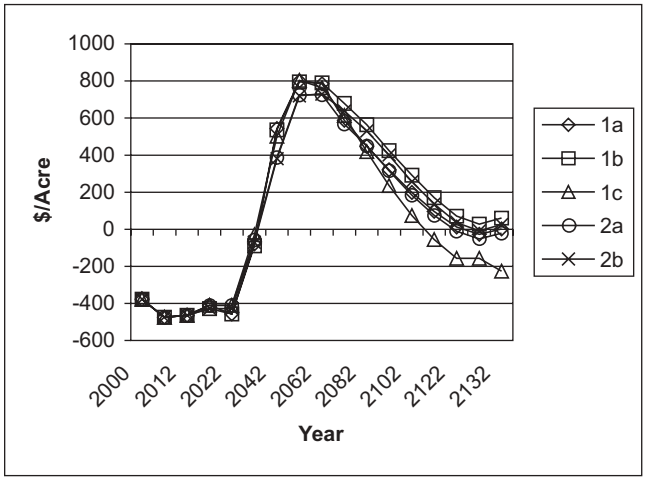

Figure 1—PNV for ponderosa pine plantation.

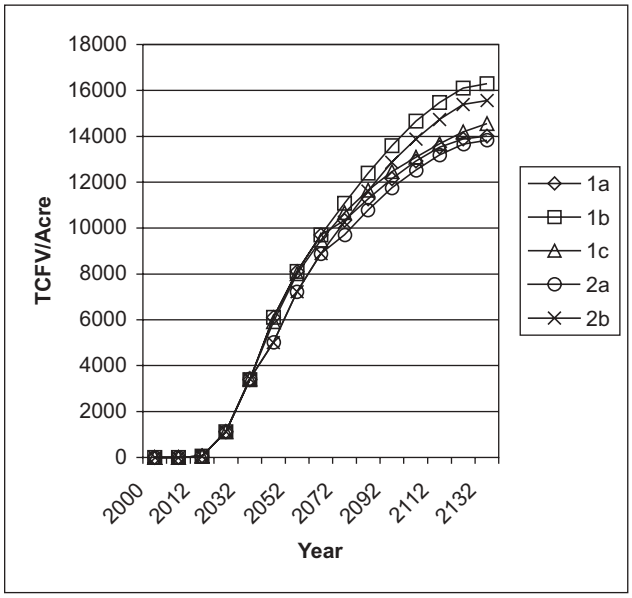

Figure 2—Total cubic foot volume production for ponderosa pine plantation.

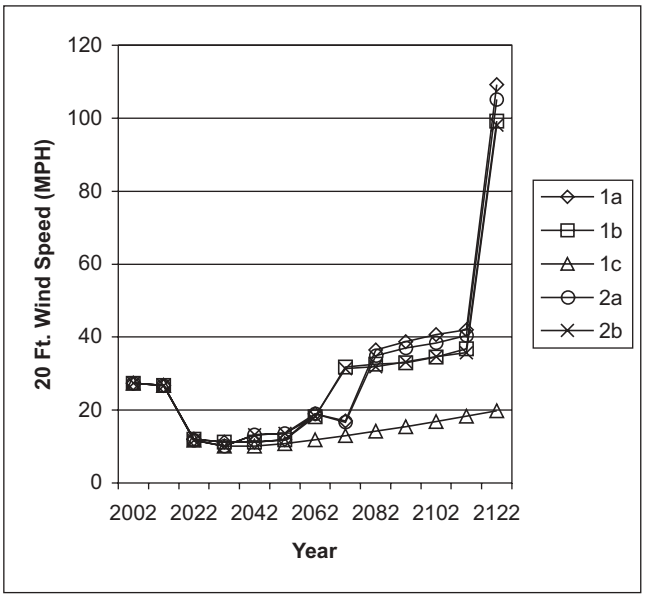

Figure 4—Crowning index for ponderosa pine plantation.

least productive. The no treatment regime, 1c, was intermediate in productivity. Although PNV and cubic volume differences among regimes were relatively small, greatest differences occurred between the no treatment regime and the more active management regimes.

Torching and crowning indexes for the ponderosa pine plantation are displayed in figures 3 and 4, respectively. Increasing values for both torching and crowning index represent *decreasing* wildfire hazard. Fire hazard decreased for all regimes during years 2022 through 2042 due to reduction of ladder fuels as a result of thinning and understory burning (fig. 3). However, regimes with mechanical treatment only at year 2020, 1a and 1b, resulted in a much larger increase in torching index in years 2032 through 2042 compared to regimes specifying fire treatments at year 2030 (2a and 2b). Wildfire hazard for the no treatment regime, 1c, was intermediate compared to the other regimes during this period and is most likely due to increased height to the base of crown that occurs as a result of self-pruning. Crowning index declined and remained low for all regimes between 2020 and 2050 in spite of the precommercial thinning/understory burn treatments at years 2020 and 2030 (fig. 4). This suggests that decreased stand density resulting from precommercial thinning/understory burn treatments was not sufficient to offset posttreatment growth and expansion of tree crowns. After 2060, however, thinning in all of the active management regimes substantially reduced crown fire hazard compared to the no treatment regime.

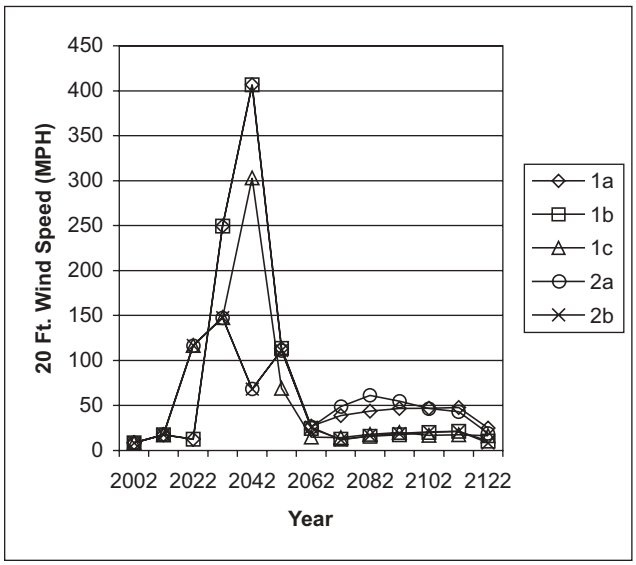

Figure 3—Torching index for ponderosa pine plantation. Values are identical for regimes 1a and 1b, and 2a and 2b, at year 2040.

Predicted fire type under wildfire conditions, defined as 30 m.p.h. winds under very dry moisture conditions, indicate all regimes were effective in reducing fire hazard between 2032 and 2052 as indicated by the transition from active to surface fire type (table 3). However, treatments at 2062 had a markedly different effect on the predicted wildfire type for the duration of the simulation. The no treatment regime, 1c, resulted in greater wildfire hazard as indicated by the active fire type. Regimes 1a and 2a, which utilized prescribed fire for treating fuels in 2062, provided the greatest reduction in hazard as indicated by the surface fire type. Regimes 1b and 2b, which specified commercial thinning at 60 years without prescribed fire, provided intermediate reduction in hazard rating as indicated by the passive fire type.

With the exception of the no treatment regime, 1c, PNV of the different silvicultural regimes varied little. Regimes

Table 3—Potential fire type under wildfire conditions for ponderosa pine plantation silvicultural regimes.

Year	Age	1a	1b	1c	2a	2b
2002	2	Active	Active	Active	Active	Active
2012	12	Active	Active	Active	Active	Active
2022	22	Active	Active	Surface	Surface	Surface
2032	32	Surface	Surface	Surface	Surface	Surface
2042	42	Surface	Surface	Surface	Surface	Surface
2052	52	Surface	Surface	Surface	Surface	Surface
2062	62	Active	Active	Active	Active	Active
2072	72	Surface	Passive	Active	Surface	Passive
2082	82	Surface	Passive	Active	Surface	Passive
2092	92	Surface	Passive	Active	Surface	Passive
2102	102	Surface	Passive	Active	Surface	Passive
2112	112	Surface	Passive	Active	Surface	Passive
2122	122	Passive	Passive	Active	Passive	Passive

that provided mechanical treatment only at age 60 years, 1b and 2b, resulted in slightly higher PNV values at the end of the simulation compared to regimes using a combination of commercial thinning and fire-based fuel treatments at age 60, 1a and 2a. This slight difference appeared to result from fire-induced mortality of larger, more valuable trees. PNV of the no treatment regime, 1c, was lower at the end of the simulation than other treatments, with an ending maximum difference of approximately $250 per acre among treatments. Total cubic foot volume productivity was also greatest for the mechanical treatment only regime, 1b. Regimes combining commercial thinning with fire-based fuel treatment at age 60 years, 1a and 2a, were least productive with the no treatment option, 1c, being intermediate in value.

Silvicultural regimes with slightly greater total cubic foot volume production and PNV values, 1b and 2b, also represented the scenarios of greater risk of loss under wildfire fire scenarios (passive versus surface fire type). Wildfire hazard risks were mixed, with the no treatments regime, 1c, having the greatest risk by all three measures—predicted wildfire type, torching index, and crowning index. While the use of prescribed fire as a treatment alternative in the early stages of stand development afforded no major differences in fire hazard risk compared to mechanical treatments, reduction in fire hazard was predicted in later years for the regimes that combined commercial thinning and fire-based fuel treatment at age 60 years, 1a and 2a.

Case Study 2 – Mixed-Species, Multistory Stand

The second case study was a mixed-species, multistory stand with the following characteristics: located near Colville National Forest in Eastern Washington State, approximately 60 years old, *Abies grandis/Clintonia uniflorum* habitat type, level (0 to 5 percent) slope, north aspect, 2,500 feet elevation, 335 trees per acre, composed of 50 percent lodgepole pine (*Pinus contorta*), 20 percent ponderosa pine, 20 percent western larch, and 10 percent Douglas-fir on a trees per acre basis. The stand was commercially thinned in 1990. The five silvicultural regimes applied to the stand are listed in table 4, and the input economic parameters are listed in table 5.

PNV was greatest over the simulation period for mechanical treatment only regimes 1a and 1d (fig. 5). PNV for the no treatment regime, 1c, was the lowest at the end of the simulation, while regimes 1b and 1e were intermediate in value. Regimes using prescribed fire, 1b and 1e, caused a reduction in economic benefit compared to regimes 1a and 1d that used mechanical only treatments. In addition, the regime specifying two prescribed fire treatments, 1e, registered a smaller PNV than the regime composed of one fire treatment, 1b. The effects of fire treatment on stand stocking may explain this trend, as fire-related mortality was often considerable even in larger diameter classes. Stocking reduction, particularly in the diameter classes that typically represent the highest economic values, would be expected to have such an adverse effect on economic value.

The mechanical treatment only regime, 1a, had the highest cubic foot volume productivity followed by the no treatment regime, 1c, and the mechanical treatment only regime 1d (fig. 6). Regimes applying prescribed fire treatments, 1b and 1e, were least productive, with the regime containing two fire treatments, 1e, registering the lowest total productivity at end of the simulation. The reduced volume in the

Table 4—Silvicultural regimes for the mixed-species stand.

Year	Age	1a	1b	1c	1d	1e
1990	60	Commercial thin to 300 trees/acre (t/a)	Commercial thin to 300 t/a + throttle-back understory burn	No treatment	Commercial thin to 300 t/a	Commercial thin to 300 t/a
1995	65	No treatment	No treatment	No treatment	Sanitation thin from below to 195 t/a	Sanitation thin from below to 195 t/a + low intensity broadcast understory burn
2010	80	Commercial thin to 110 sq ft	Commercial thin to 110 sq ft	No treatment	Commercial thin to 110 sq ft	Commercial thin to 110 sq ft + low intensity broadcast understory burn
2030	100	Clear-cut	Clear-cut	No treatment	Clear-cut	Clear-cut

Table 5—Input economic parameters for the mixed-species stand.

Economic parameter	Value
Discount rate	5.0%
Annual cost	$2.50/acre
Planting cost	$175.00/acre
Burn site prep cost	$200.00/acre
Precommercial thin fixed cost	$100.00/acre
Harvest variable cost	$25.00/mbf
Harvest fixed cost	$100.00/acre
Average harvest revenue	
Western white pine	$268.00/mbf
Western larch	$240.00/mbf
Douglas fir	$240.00/mbf
Grand fir	$200.00/mbf
Western hemlock	$200.00/mbf
Western red cedar	$200.00/mbf
Lodgepole pine	$200.00/mbf
Englemann spruce	$200.00/mbf
Sub-alpine fir	$200.00/mbf
Ponderosa pine	$285.00/mbf

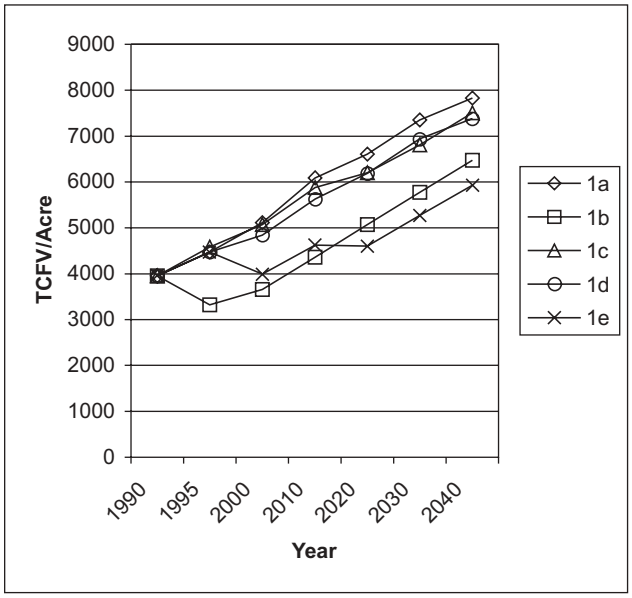

Figure 6—Total cubic foot volume production for the mixed-species stand.

prescribed fire regimes was the result of fire-induced mortality of larger trees.

Torching index initially declined for all regimes at year 2000 (fig. 7). The no treatment and mechanical treatment only regimes, 1a, 1c, and 1d, subsequently increased at year 2010 before declining again. Regimes using prescribed fire, 1b and 1e, remained low throughout the simulation. Crowning index increased for all regimes at year 2000, but then declined in future years. Decreases in crowning index were greater for regimes using prescribed fire, 1b and 1e, than for other regimes.

Predicted fire types under wildfire conditions for the mixed-species stand are listed in table 6. Wildfire conditions were defined as 30 m.p.h. wind speed under moist conditions. Treatments applied at stand age 60 to 70 years resulted in markedly different wildfire types. The no treatment regime, 1c, resulted in only surface fire conditions, while regimes that applied commercial thinning with no accompanying fire treatment, 1a and 1d, resulted in predictions of active crown fires. There were virtually no differences in fire hazard, however, at stand ages between 90 and 100 years. Regardless of silvicultural regime, active crown fires were predicted to prevail under severe burning conditions.

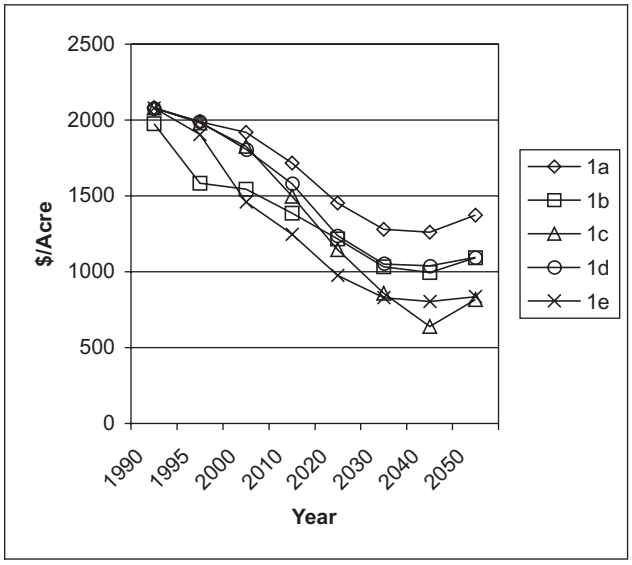

Figure 5—PNV for mixed-species stand. Stand establishment costs are not included.

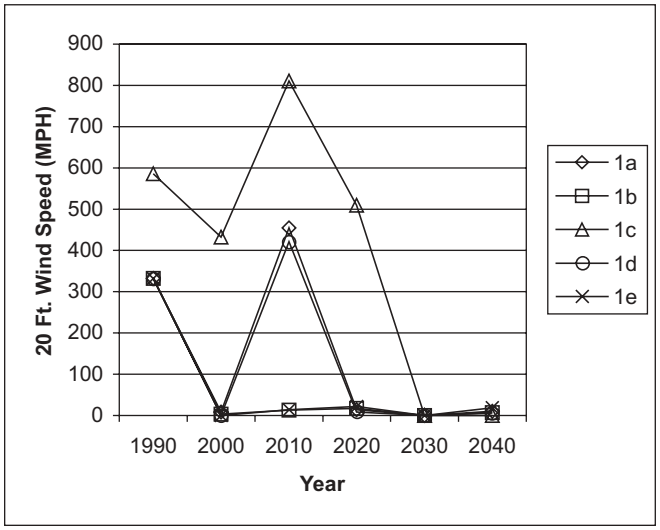

Figure 7—Torching index for the mixed-species stand. Values are identical for regimes 1a and 1b, and 1d and 1e, at year 1990.

Table 6—Potential fire type under wildfire conditions for mixed-species stand silvicultural regimes.

Year	Age	1a	1b	1c	1d	1e
1990	60	Surface	Surface	Surface	Surface	Surface
2000	70	Active	Passive	Surface	Active	Passive
2010	80	Surface	Active	Surface	Surface	Passive
2020	90	Active	Active	Surface	Active	Active
2030	100	Active	Active	Active	Active	Active

Fire hazard trends for the mixed-species stand, as expressed by torching index, were somewhat unexpected. Major reductions in fire hazard were observed for regimes using no treatment or mechanical only treatments at year 2010 (1a, 1c, and 1d). Hazards were significantly greater during the period between 2000 and 2020 for regimes containing prescribed fire treatments (1b and 1e). The rapid increase in fire hazard at year 2000 was the result of a large impulse of natural regeneration following the commercial thinning, with the resultant lowering of height to crown base to ground level and an increase in ladder fuels. The increase in torching index at 2010 for the mechanical treatment only regimes was likely due to the removal of understory ladder fuels at the time of thinning.

Crowning index increased in year 2000 as a result of thinning done in 1990. The thinning was effective in reducing crown bulk density and thus reducing the potential for crown fires within the stand (fig. 8). This hazard reduction was short lived for the single fire treatment regime, 1b, but was maintained for several decades for the two-fire treatment regime, 1e. Reduction in crown bulk density for regime 1e, 4.5 times lower than that for regime 1b, was apparently sufficient to provide a lower hazard level.

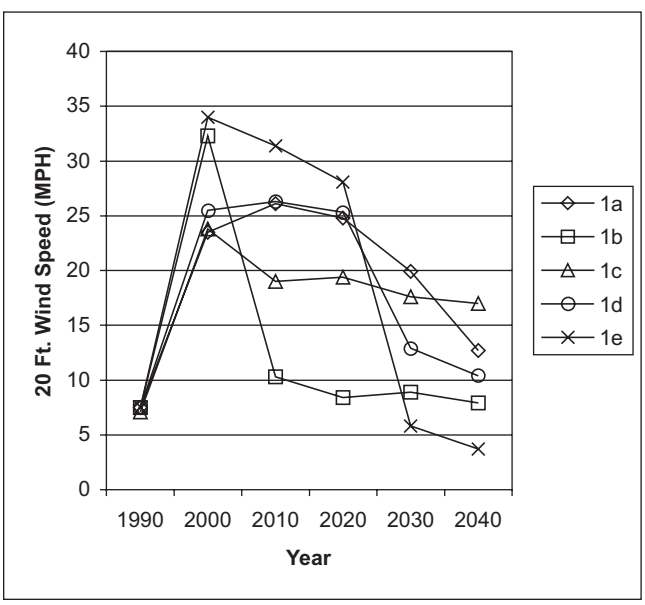

Figure 8—Crowning index for the mixed-species stand.

Discussion and Conclusions

Silvicultural regimes can have a significant effect on both the economic benefits and the fire hazard status of forest stands. The case study results presented here suggest a significant tradeoff exists between the economic benefits realized and the fire hazard risk associated with treating and maintaining a forest structure through time that provides those benefits. In the ponderosa pine plantation case study, there was little benefit in terms of fire hazard reduction from prescribed fire-based regimes early in the life of the stand. This effect appeared to be important, however, in the later stages of the stand's development. Reduction in fire hazard was associated with slightly reduced economic benefits as indicated by the lower PNV values for fire-related regimes. Differences and similarities in trends existed for the mixed species stand compared to the pine plantation. In the mixed-species case study, mechanical treatment only regimes, 1a and 1d, provided the largest PNV and total cubic foot volume production values. However, in the mixed-species stand, fire hazard reduction in response to treatment is accomplished only for initial treatments at ages 60 and 65, while subsequent fire treatment at age 80 provided no hazard reduction. The steady influx of natural regeneration in the mixed-species stand, along with its multistoried characteristics, showed that the use of fire as a tool for discriminating among tree classes and tree species is difficult. In both case studies the timing of fire treatments at specific points in the development of the stands appeared to be important in determining not only the economic benefits realized but also the susceptibility to catastrophic fire losses.

In any event, results from these analyses suggest that any reduction in fire hazard as a result of silvicultural treatment is short lived. This is consistent with the findings of Fiedler (Fiedler and others 2001) who observed that certain types of silvicultural regimes provided only a temporary reduction in fire hazard. Thus, management objectives calling for ongoing fire hazard reduction will likely entail repeated applications of fire as a silvicultural treatment. Managers considering a wide range of multiple-use objectives can use the FFE and ECON extensions to FVS to better evaluate the impacts of silvicultural scenarios on economic values and their effects on creating and maintaining a diverse forest structure capable of reducing wildfire risk.

Acknowledgments

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References

Beukema, S.J.; Reinhardt, E.D.; Kurz, Werner A.; Crookston, Nicholas L. 2000. An overview of the Fire and Fuels Extension to the Forest Vegetation Simulator. In: Neuenschwander L.F. and Ryan, K.C. (tech eds.). Proceedings from: The Joint Fire Science Conference and Workshop – "Crossing the Millennium: Integrating Spatial Technologies and Ecological Principles for a New Age in Fire Management." Vol. II. Boise, ID, June 15-17, 1999. University of Idaho and the International Association of Wildland Fire. pp. 80-85.

Crookston, Nicholas L. 1990. User's guide to the event monitor: part of Prognosis Model Version 6. Gen. Tech. Rep. INT-275. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 21 p.

Crookston, Nicholas L.; Beukema, Sarah; Robinson, Donald C.E. In prep. Chapter 3 – User's Guide. In: Reinhardt, Elizabeth, Crookston, Nicholas L. (tech eds). The Fire and Fuels Extension to the Forest Vegetation Simulator. Gen. Tech. Rep. RMRS-GTR-000. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Fiedler, Carl E.; Keegan, Charles E. III; Woodall, Chris W.; Morgan, Todd A.; Robertson, Steve H.; Chmelik, John T. 2001. A Strategic Assessment of Fire Hazard in Montana. Report submitted to the Joint Fire Sciences Program in cooperation with the U.S. Forest Service, Pacific Northwest Research Station. 33 p.

Renner, David L. In prep. User's guide to the ECON extension to FVS. On file with Research Work Unit 4155, Moscow Forestry Sciences Laboratory, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 53 p.

Stage, A.R. 1973. Prognosis Model for Stand Development. Res. Pap. INT-137. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 32 p.

Wykoff, W. R.; Crookston, N. L.; Stage, A. R. 1982. User's Guide to the Prognosis Model. Gen. Tech. Rep. INT-133. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 112 p.