Application of the Forest Vegetation Simulator in Evaluating Management for Old-Growth Characteristics in Southwestern Mixed Conifer Forests

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Abstract.—We used the Forest Vegetation Simulator (FVS) and GRAFFVS graphics display to investigate conditions associated with the stability of an old-growth stand and to evaluate the potential for two managed stands of contrasting but representative conditions to develop structures similar to the old-growth stand. Simulations indicate that the example old-growth stand can retain old-growth characteristics for up to 100 years in the absence of catastrophic disturbance. Modeling also indicated that silvicultural intervention could enhance the future old-growth potential of the two managed stands.

INTRODUCTION

Management for forest health concerns should maintain landscapes of appropriate mixes of cover type and seral stage distribution. Spatial patterns present on landscapes influence ecosystem processes that operate at landscape scales (Baker 1989; Burke 1989; Fahrig and Merriam 1994; Gilpin and Hanski 1991; Pastor and Post 1986; Risser 1990; Saunders et al. 1991; Turner 1987; Turner and Romme 1994). Significant alterations of landscape structure increase the potential to alter or disrupt these processes with serious ecosystem consequences. For example, when landscapes that are naturally heterogeneous in terms of distributions of cover types, structural conditions, and seral stages are converted to more homogenous conditions, the potential for catastrophic fire to occur at unnaturally large extents is increased (Turner et al. 1989; Turner and Romme 1994). Similarly, fragmentation of old-growth forests may affect processes associated with the viability of species that are dependent upon these habitats (Thomas et al. 1988).

The amount of old-growth forests in southwestern landscapes has been reduced in the last century and remaining old-growth is often in small, isolated fragments (Kaufmann et al. 1992). Species that are dependent on old-growth forests for habitat are susceptible to fragmentation due to loss of habitat, population isolation, and edge effects. It is therefore important for forest managers to determine the amount and spatial distribution of existing old-growth forests. Furthermore, it is critical to identify those stands that have the potential to become old growth within a management time frame to effectively manage landscapes for a desired pattern of future old growth. It may be necessary to employ vegetation management practices to enhance the potential for candidate stands to achieve a desired old-growth structure.

Our objectives are to 1) explore the potential for utilizing a simulation model and graphical tech-

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niques to identify stands that have the potential to become old growth within 100 years; and 2) use these approaches to evaluate the effectiveness of silvicultural treatments for enhancing the ability to achieve old growth structure within a 100 year time frame.

BACKGROUND

Assessments indicated that less than 2 percent of inventoried commercial forest lands on the Lincoln National Forest exhibit old-growth characteristics (USDA 1986a). This determination is based on a generic definition of old growth included in the Lincoln National Forest Plan (USDA 1986b). The Lincoln Plan calls for managing to have 7 percent of the Forest in an old-growth condition. To do this, managers must understand the complexity and variation associated with old growth across a range of environments. They must also determine appropriate and potential landscape distributions of the old-growth component.

The old growth definition used by the Lincoln National Forest in planning, inventory, and management efforts and cited in the Forest Plan (USDA 1986b) is:

> A stand that is past full maturity and showing decadence. Fifteen or more live trees per acre over 21 inches dbh and with 0.5 snags per acre over 21 inches dbh. Two or more canopy levels with overstory closure of 10–40%, usually with a shrub-sapling layer combined exceeding 70% closure. Logs obvious on the ground.

Ongoing research in the Sacramento Mountains is directed at testing the adequacy of this definition by studying the variation in and developmental processes of local old-growth mixed conifer forests. One objective of this effort is to predict those stand conditions that reflect a younger or managed stand's potential to attain old-growth characteristics. Identifying potential old-growth is important for replacing existing old growth that might be lost to disturbance or to increase the absolute amount of old growth on the landscape.

Human activities have significantly altered forest stand conditions and landscape structures in the Sacramento Mountains. The area has been intensively logged over the last century. The influences of logging combined with domestic livestock grazing and fire suppression have rescaled, both temporally and spatially, fire regimes and other natural disturbance processes. Little of the Sacramento Mountain landscape is in an old-growth condition and most of the landscape is in a much earlier stage of stand development. The overall diversity and pattern of seral stage distribution in the landscape is altered. Stand conditions are unnaturally dense and stagnated, and species compositions have been shifted. It is critical, then, to determine which stand conditions have the greatest potential as future old growth. Accomplishing this will allow for the determination of future old growth in a spatially explicit way for long-term landscape management prescriptions.

MODELING APPROACH

Simulation modeling provides an effective way for us to explore questions about the long-term future of forest stands. It is a logical way to approximate stand stabilities, stand trajectories, and potential old growth. We have used the Central Rockies Variant (Dixon 1991) of the Forest Vegetation Simulator, FVS, to project conditions in our stands. The FVS is an individual tree-based stand projection system that is widely used in the Forest Service (Wykoff et al. 1982). The Central Rockies Variant contains equations and relationships from the GENGYM model (Edminster et al. 1991), which is a variable density stand table projection system based on 1-inch diameter classes. This variant has been calibrated to Southwestern coniferous forests.

The GRAFFVS system was used for visual displays of simulation results. This data visualization program is an updated version of the program described by Shepperd (1995). Stand attributes of interest in our analyses which are easily simulated with FVS and illustrated by GRAFFVS include diameter distributions, basal area by species, tree density by species, large tree diameters and heights, and vertical canopy structure. Other old-growth attributes, including standing dead trees, coarse woody debris, canopy cover, and spatial heterogeneity will be addressed in future analyses.

We selected one stand, Peake Canyon, to serve as an example of an old-growth condition. This stand was measured in 1993 for several attributes of structure and composition and is considered to typify late seral potential of stands over much of the Sacramento Mountain landscape. The stand has never been logged, has at least one cohort of old trees, and has a spatial heterogeneity indicative of a stand maintained by small scale gap-phase processes. Basal area, large tree diameters, density of standing dead trees, vertical complexity of the canopy, and amounts of coarse woody debris all meet minimal levels of the old growth definition included in the Lincoln Forest Plan (USDA 1986b). It is beyond the scope of this analysis to address the suitability of the current condition of Peake Canyon as representative of a desired old-growth condition. However, we do recognize that the existing condition is probably heavily stocked in the understory and reflects an altered composition due to fire suppression over the last century.

To calibrate FVS to sites used in our analyses, we used data from Peake Canyon as input, grew the stand to 1995 as a starting point, and then projected the stand for 100 years. We assumed that the structural condition of Peake Canyon could remain stable through the next 100 years in the absence of catastrophic disturbance. Calibration consisted of making adjustments in the model to achieve stability. Stability was achieved by adjusting the recruitment of new stems and the mortality rates of small and very large trees to arrive at a diameter distribution in 100 years that is similar to the current conditions. No adjustment was accepted unless we felt that it was realistic given what is known about the biology and ecology of these forests. We incorporated the assumptions needed to achieve stability into each model run so that these conditions served as a baseline for all simulations. This allowed a uniform comparison of management options and disturbance scenarios.

Historical evidence suggests patterns of repeated, low intensity natural disturbances in these forests that did not result in complete stand replacement. Mean fire intervals of 10 years have been documented for the Peake Canyon stand (Huckaby and Brown 1995). We do not yet have a clear understanding of patterns of mortality in younger age classes, but we do know that older cohorts have experienced several fires as indicated by the fire history data. Western spruce budworm is another disturbance factor which has been studied in similar southwestern mixed conifer forests (Swetnam and Lynch 1989, 1993). These data provide support for exploring the range of conditions that might be expected at Peake Canyon under spruce budworm scenarios over the next 100 years. Results from the baseline and spruce budworm disturbance scenarios provide a reference point of variation in stand conditions for evaluating the old-growth potential of other stands.

Two stands, Sacramento Canyon and Apache Point, were used for the assessment of the potential for achieving old-growth structure. These stands were selected from the Lincoln National Forest RMRIS database to provide contrasting conditions and reflect characteristics typical of previously managed forests in the Sacramento Mountains. We selected stands with growth potentials similar to those of the Peake Canyon stand. Habitat type, site index, and elevation criteria were considered in matching stand potentials.

Sacramento Canyon has no documented management history but was apparently selectively logged earlier in this century. There is minimal evidence of logging in the current stand. The stand has a dense understory and may be representative of overstocked, stagnated conditions of many older stands in the area. Apache Point was thinned in the mid–1960's and then commercially thinned in the late 1980's. This treatment scenario is similar to that applied to many stands on the Forest in recent management history.

The assumptions established for baseline stability of the Peake Canyon stand were applied to each of the experimental stands. Each stand was grown for 100 years with no treatment and again under simple silvicultural prescriptions. Simulation results and graphical output were evaluated to assess the old-growth potential of each of the treated stands.

RESULTS AND DISCUSSION

Initial Stand Comparisons

Data for each stand were input into FVS and the stands were grown to 1995 as a starting point for old growth development projections. Stand attributes used for matching stand potentials are given in Table 1. Stand structures in 1995, the initial year of our 100 year projection, are given in Table 2. Basal area and quadratic mean diameter (QMD) are lowest and stem density is highest at Apache Point, which is the intensively managed stand. QMD is also low at Peake Canyon and Sacramento Canyon, reflecting a high density of small sized trees that may have increased with a decrease in post-settlement fire frequency. The QMD of the largest 10 percent of the trees on each site characterizes a difference among sites, indicating the greater proportion of large trees at Peake Canyon and Sacramento Canyon. Douglas-fir is the dominant species at Peake Canyon. Dominance is shared by Douglas-fir and white fir at the two managed stands. We assumed a maximum stand density index of 595 for Douglas fir and 845 for white fir at each site.

Peake Canyon Old-Growth

Several modeling steps or adjustments were required to approximate stabilization of baseline growth of the Peake Canyon stand over the 100 year projection period. Excessive aspen sprouting was reduced using the NO-SPROUT option. The NATURAL keyword was used to regenerate all species. It was necessary to reduce height growth of aspen to avoid excessively large trees at the end of the projection. The model appeared to be underestimating mortality for aspen trees and small trees of other species. We increased mortality of aspen over 16 inches dbh and we used a thinning option to reduce stocking of small trees and avoid severe stagnation. We based recruitment of young trees into the future stand on existing understory stocking, assumed a 20 year growth period to dbh, and assumed only 20 percent of the understory stocking would survive to reach dbh.

Diameter distributions at Peake Canyon approximated a Q of 1.2 in both 1995 and at the end of the projection period in 2095 (fig. 1). Basal area increased to just over 300 ft^2/acre in 2095, with Douglas-fir dominant throughout the projection period (fig. 2). GRAFFVS displays illustrate the species diversity and vertical canopy complexity of the stand in 1995 (fig. 3a) and tree growth to 2095 (fig. 3b).

Table 1.—Attributes of Peake Canyon, Sacramento Canyon, and Apache Point stands used for evaluating site potentials.

	Elevation	Habitat Type	Site Index[b]
Peake Canyon	9000 ft	ABCO/QUGA[a]	84
Sacramento Canyon	9000 ft	ABCO/QUGA[a]	84
Apache Point	9100 ft	ABCO/QUGA[a]	84

[a]*ABCO/QUGA is the White fir/Gambel oak habitat type.*

[b]*Based on a reference age of 100 years (Edminster et al. 1991).*

Spruce Budworm in the Peake Canyon Old-Growth

We assumed 13-year budworm defoliation periods and 35 year intervals between outbreaks (Swetnam and Lynch 1989, 1993). For Douglas-fir and white fir, we assumed 10 percent topkill, 15

Table 2.—Initial conditions of Peake Canyon, Sacramento Canyon, and Apache Point based on FVS projections from the date of data collection to 1995.

					BA by Species	
	BA	Density	QMD	Large tree QMD[a]	PSME[b]	ABCO[c]
Peake Canyon	244	635	8.4	34.2	128	80
Sacramento Canyon	222	440	9.6	31.9	103	105
Apache Point	159	823	5.9	16.7	50	53

[a]*Large tree QMD is quadratic mean diameter based on the largest 10% of the trees.*

[b]*PSME is Douglas fir.*

[c]*ABCO is white fir.*

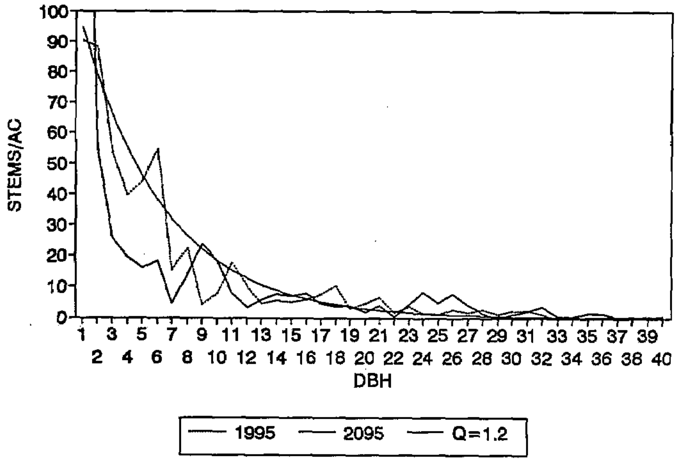

Figure 1.—Projected diameter distributions of the Peake Canyon old-growth stand with no treatment, 1995 and 2095.

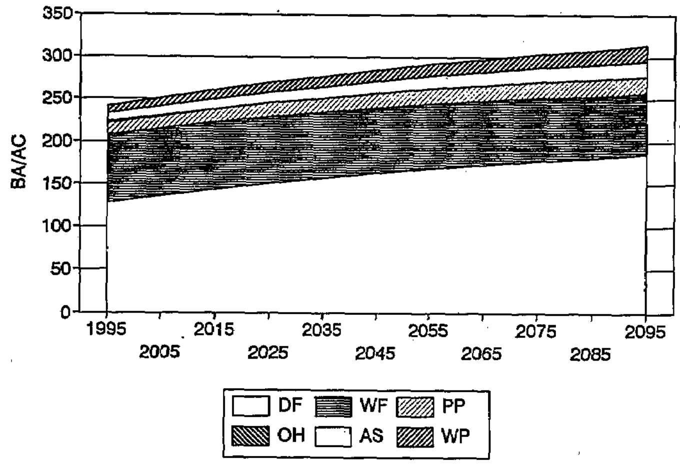

Figure 2.—Projected basal area growth of the Peake Canyon old-growth stand with no treatment. Projection period is 1995 to 2095. DF is Douglas-fir, WF is white fir, PP is ponderosa pine, OH is other hardwoods, AS is aspen, and WP is southwestern white pine.

percent mortality in the overstory, 50 percent mortality in dbh classes up to 5 inches, and 75 percent reduction in recruitment was associated with the outbreaks in our simulations (Lynch pers. comm.). In addition, growth was stopped during outbreaks in our simulations. The first budworm attack caused a reduction in stocking, but stand basal area recovered and increased after subsequent attacks (fig. 4).

Target Old-growth Conditions

Ranges of selected structural attributes, based on data from Peake Canyon in 1995 and on simulation results, are given in column one of Table 3 as targets for assessing the potential of previously managed stands in achieving old-growth conditions. Goals for old-growth include an uneven-aged diameter distribution with an approximate Q of 1.2, a large tree qmd ≥34 inches, dominance by Douglas-fir, total basal area ≥244, and multiple canopy layers.

Table 3.—Comparison of targeted old growth conditions and simulated structures with thinning of Sacramento Canyon and Apache Point in 2095.

	Old Growth	Sacramento Canyon	Apache Point
Total basal area (ft²/ac)	244–295	295	275
PSME[a] basal area	128–186	164	120
ABCO[b] basal area	50–80	82	87
Total stems/acre	635–754	293	431
PSME stems/acre	270	163	146
ABCO stems/acre	189	82	79
Large tree QMD[c] (in)	34–36	33	25
Diameter distribution (Q)	1.2	1.3	1.3
Canopy layers	4	2	2

[a]PSME is Douglas fir

[b]ABCO is white fir

[c]Large tree QMD is quadratic mean diameter based on the largest 10% of the trees.

Projections in Managed Stands

Assumptions for no treatment projections of Sacramento Canyon and Apache Point are identical to those used in the Peake Canyon stabilization projections. The current (1995) diameter distribution of Sacramento Canyon roughly approximates a Q of 1.3, with an overabundance of individuals in 2 inch and 8 inch size classes (fig. 5). When the stand is grown for 100 years with no treatment, the distribution shows marginal improvement and more closely approximates a Q of 1.3, the 2 inch peak has been shifted to 4 inches and has been reduced, and the 8 inch peak has been shifted to 12 inches.

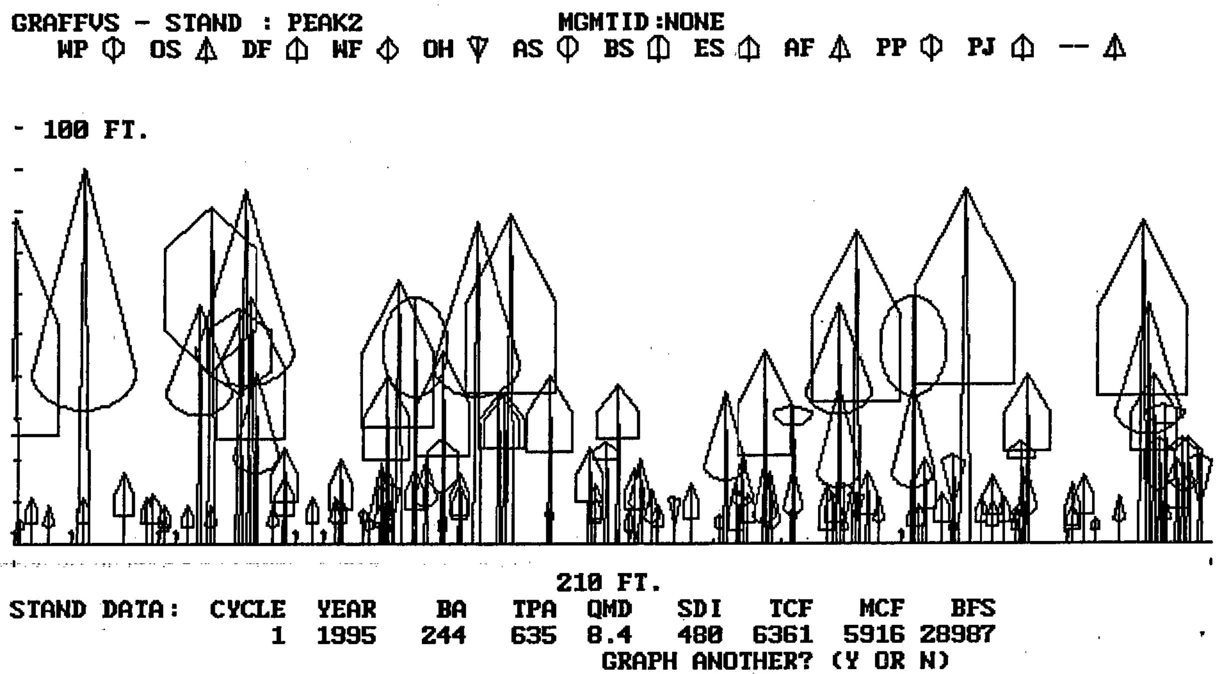

Figure 3a.—GRAFFVS display of the Peake Canyon old-growth stand with no treatment in 1995.

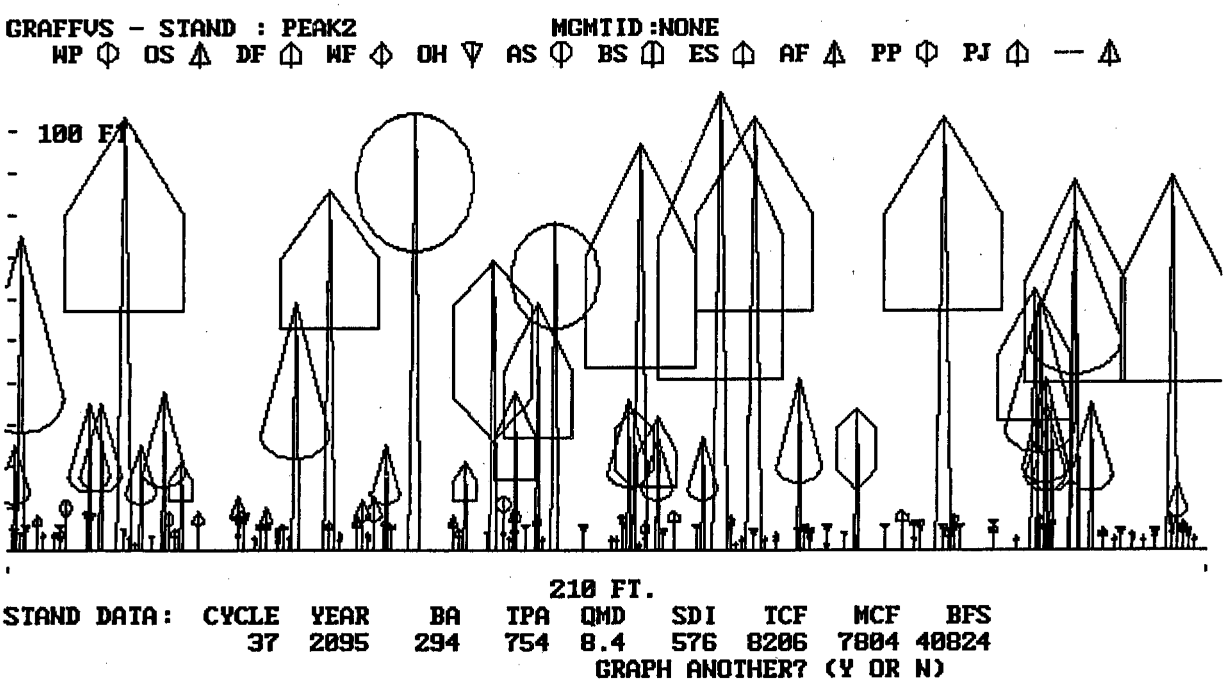

Figure 3b.—GRAFFVS display of the Peake Canyon old-growth stand with no treatment at the end of the projection period in 2095.

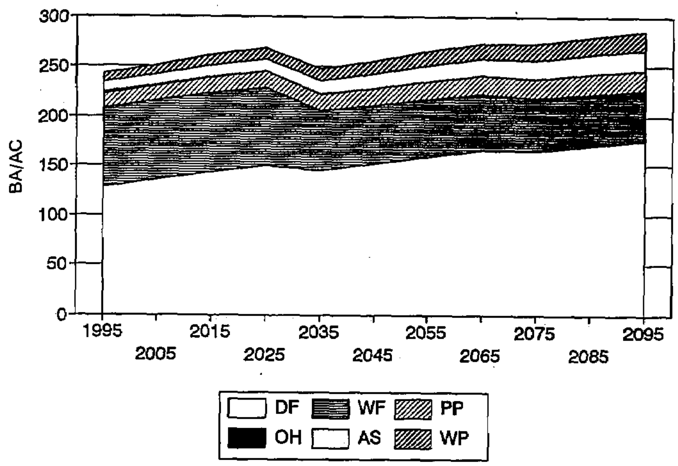

Figure 4.—Projected basal area growth of the Peake Canyon old-growth stand under a simulated spruce budworm regime. Projection period is 1995 to 2095.

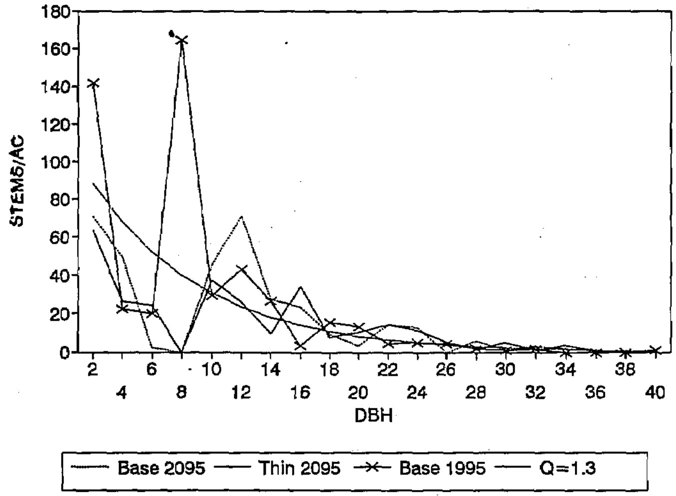

Figure 5.—Projected diameter distributions of Sacramento Canyon with no treatment, 1995 and 2095, and with simulated thinning, 2095.

To deal with these disproportions in the diameter distribution, which are largely white fir, we simulated thinning in Sacramento Canyon from below to remove excessive white fir stocking from the understory and to stimulate growth in larger diameter classes. The thinning treatment deals with disproportions in the diameter distribution and results in a better approximation of a Q of 1.3 by the year 2095 (fig. 5). Growth results in a large tree qmd closer to the target. In addition, thinning takes the stand to the targeted basal area and begins to correct the overabundance of white fir in the stand (fig. 6).

GRAFFVS displays (fig. 7a) illustrate that currently, Sacramento Canyon does not have the vertical canopy complexity, tree size, or species composition to match Peake Canyon (fig. 3a). Figure 7b suggests that, with thinning of understory white fir, problems of tree size and species composition are addressed but that the paucity of individuals in understory and seedling layers is still evident. Simulations suggest that our thinning treatment has not adequately promoted recruitment or achieved vertical complexity.

Apache Point has similar disproportions in the diameter distribution and has few trees greater than 25 inches in diameter in 1995 (fig. 8). When the stand is grown for 100 years with no treatment,

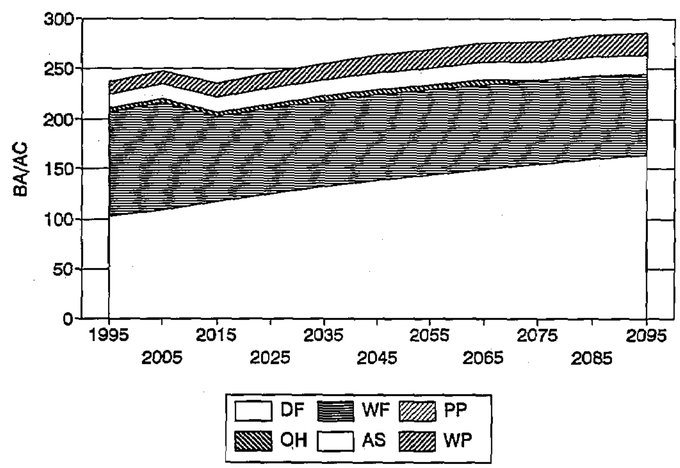

Figure 6.—Projected basal area growth of Sacramento Canyon with simulated thinning. Projection period is 1995 to 2095.

there continue to be major deviations from a Q of 1.2, disproportions in the diameter distribution, and an absence of diameters larger than 25 inches. We again applied a thinning from below, with over-represented diameter classes and white fir targeted for removal. This treatment improved some of the understory overstocking but did not result in the targeted Q of 1.2 and did not result in

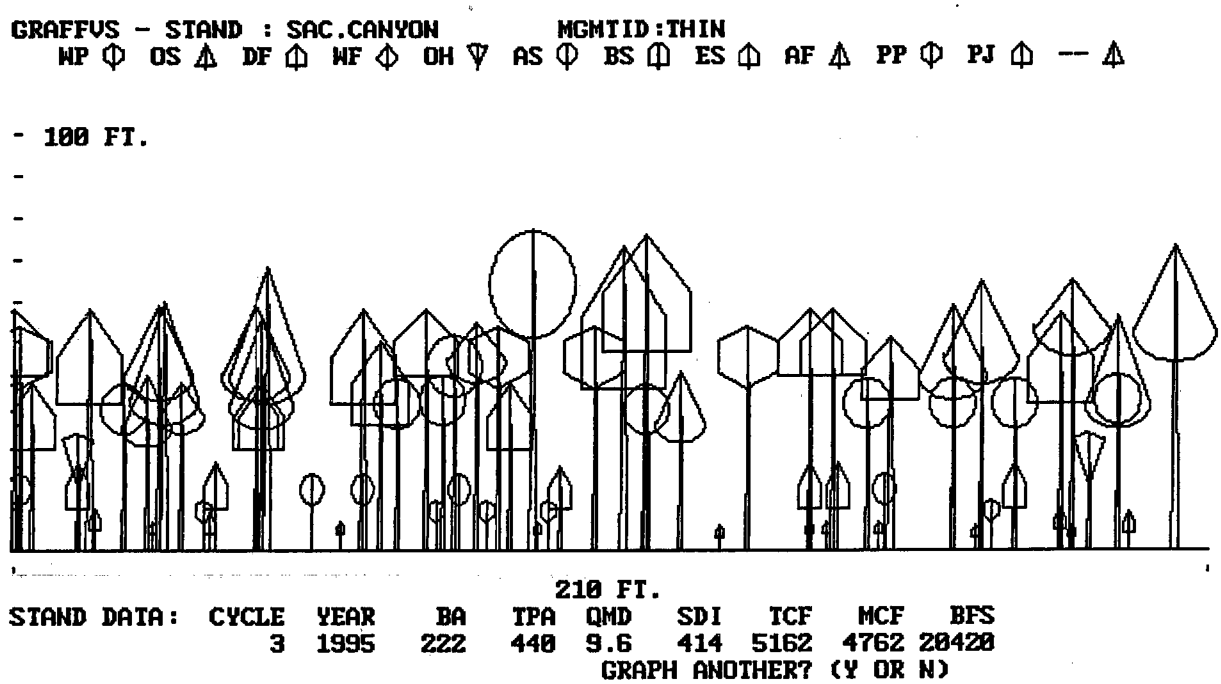

Figure 7a.—GRAFFVS display of Sacramento Canyon in 1995.

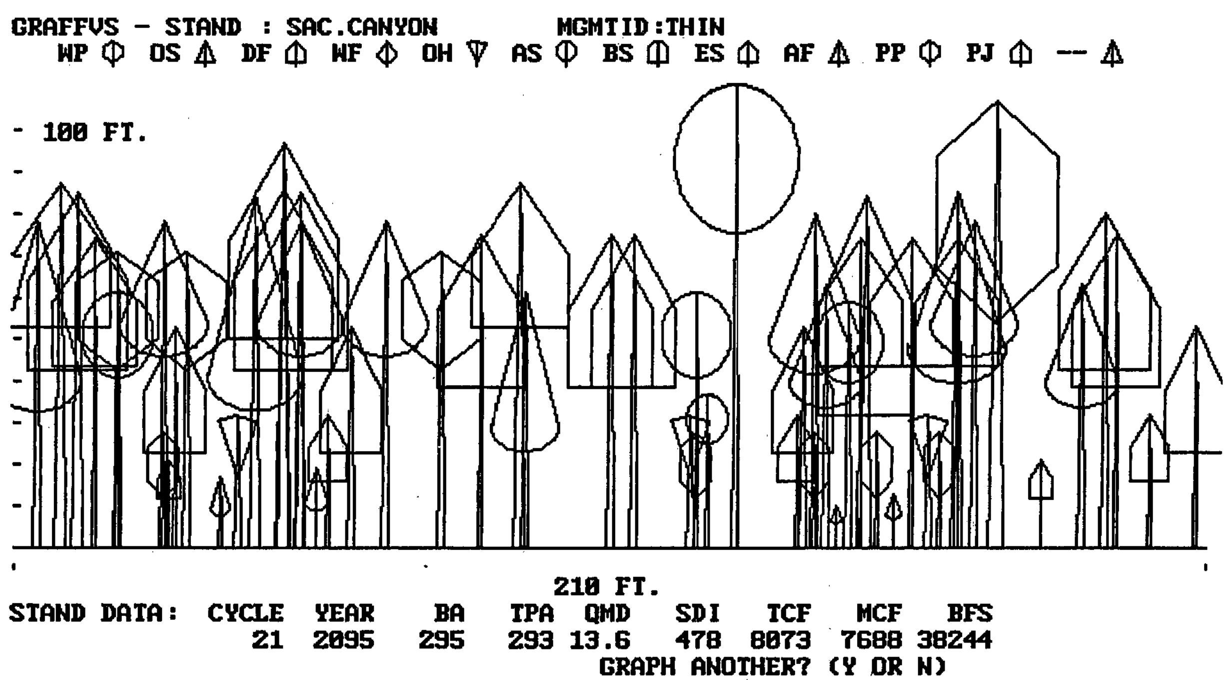

Figure 7b.—GRAFFVS display of Sacramento Canyon after simulated thinning, 2095.

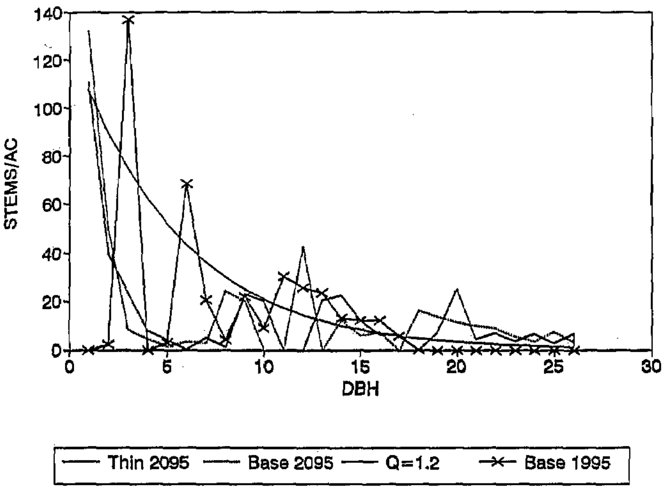

Figure 8.—Projected diameter distributions of Apache Point with no treatment, 1995 and 2095, and with simulated thinning, 2095.

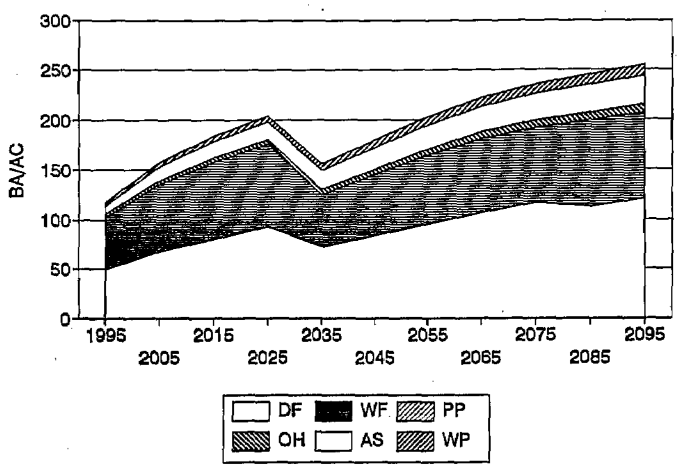

Figure 9.—Projected basal area growth of Apache Point with simulated thinning. Projection period is 1995 to 2095.

larger diameter individuals (fig. 8). Basal area has increased to just over 250 ft^2/acre in 2095, but it is still disproportionately high in white fir (fig. 9). GRAFFVS displays again illustrate lack of vertical complexity, overabundance of white fir, and smaller tree size at Apache Point when compared to Peake Canyon (figure 10a). Again, our thinning treatment was effective in dealing with disproportions in species composition and in stimulating growth, but did not achieved the vertical complexity represented by Peake Canyon (fig. 10b).

Simulations suggest that, with treatment, Sacramento Canyon has the potential to achieve some of the targeted old-growth structural attributes at the end of the projection period (Table 3). However, the diameter distribution does not yet approximate the Q of 1.2 and the vertical canopy complexity has not reached four identifiable layers. Projected conditions at Apache Point are not yet old growth, although some of the structural targets are achieved (Table 3). White fir basal area is still high, canopy complexity is low, and large tree qmd is low when compared to target conditions.

CONCLUSIONS

Adjusting the mortality and recruitment in FVS projections allowed us to achieve stability in the Peake Canyon old growth stand in the absence of catastrophic disturbance over the next 100 years. Existing and future conditions of Peake Canyon as well as projections of the Peake Canyon stand under a simulated spruce budworm regime provide a range of target conditions for evaluating old-growth potential of two previously managed stands. Target conditions were not achieved in either of the two stands under simulations with no treatment. In the Sacramento Canyon stand, we found that a simple silvicultural prescription began to promote a stand structure similar to the old-growth target. There is also opportunity for additional treatment to achieve the structural complexity targeted. In the Apache Point stand, we found that our prescription would not approximate target conditions within the projection period.

We found certain aspects of the small tree model of FVS to be problematic in application to our stands in the Sacramento Mountains. For example, FVS did not deal effectively with Gambel oak, which occurs on all of the sites that we modeled. We encountered difficulties with oak becoming large trees, inadequate oak mortality, and extreme competition by oak after disturbance. There is a need to strengthen the assumptions associated with the small tree model in FVS to more appropriately deal with recruitment, growth, and mortality of this component of the forest. Information is needed on the ecology of oak as well as other hardwoods in the range of environments in these Southwestern mixed conifer forests.

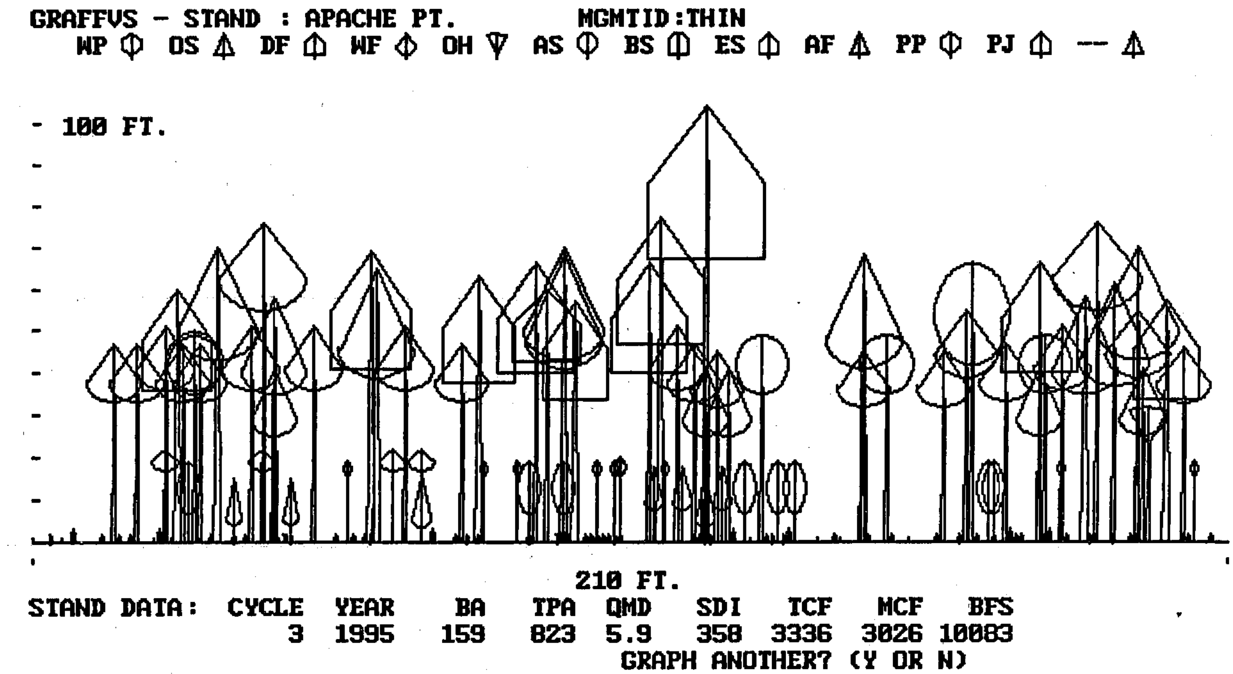

Figure 10a.—GRAFFVS display of Apache Point in 1995.

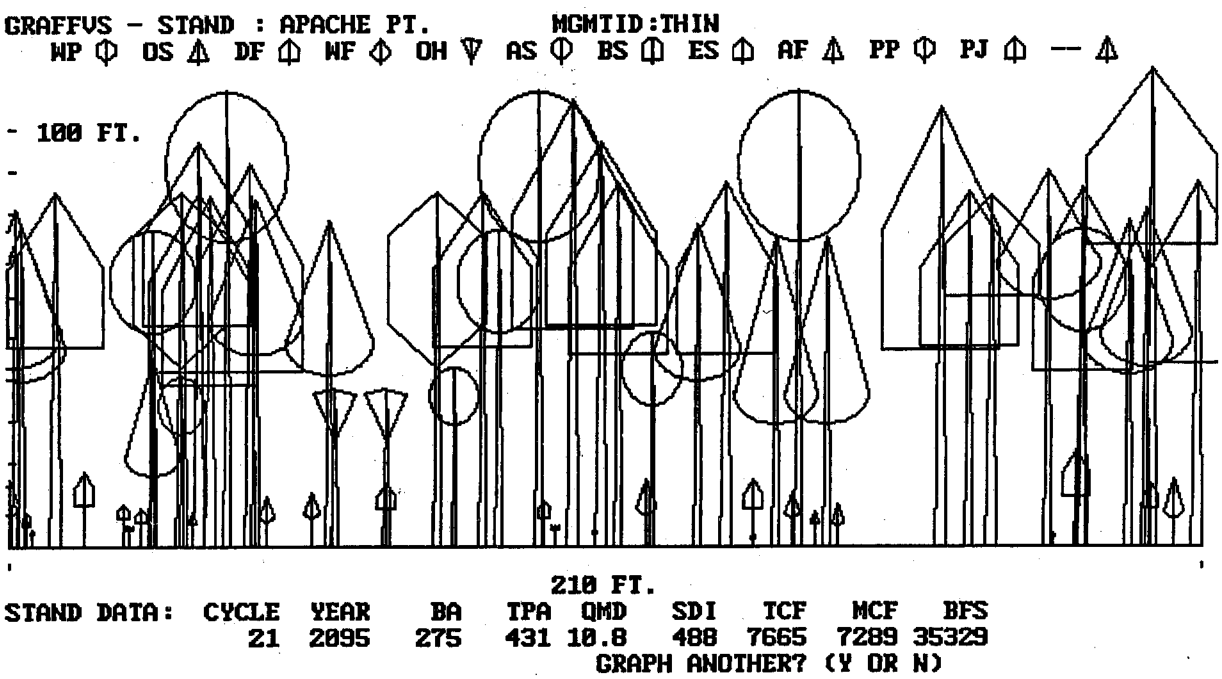

Figure 10b.—GRAFFVS display of Apache Point after simulated thinning, 2095.

However, FVS does offer the opportunity to explore ecological questions about these forests in addition to the more traditional growth and yield questions usually addressed. The model helped identify existing stand conditions that have old-growth potential. Clearly, there is an opportunity to address the question of potential old-growth in the Sacramento Mountains by investigating the full range of existing stand conditions, environments, and natural disturbance scenarios and making future projections using simulation modeling. A desirable goal for future work would be to couple FVS with GIS data from the Forest for a spatially explicit, landscape scale analysis of potential future landscapes, including investigation into the influence of pattern of old-growth distribution on ecological processes.

Finally, our simulation analysis, which is preliminary in terms of addressing questions related to the potential for old growth, indicates that there is a role for silviculture in generating future old-growth forests from previously managed stands. Our very simplistic prescriptions indicated that, in some situations, we could approach the structural targets within the projection period. Furthermore, the model helped identify existing stand conditions that do not appear to be suitable for reaching old-growth status. More complex silvicultural prescriptions should be applied in future simulations to effectively address appropriate vegetation management for the full range of structural attributes associated with these old-growth forests.

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