Photos by Steven Sesnie

Using History to Plan the Future of Old-Growth Ponderosa Pine

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ABSTRACT

Historical forest records, combined with the Forest Vegetation Simulator and a geographic information system for a land planning area on the Kaibab National Forest in northern Arizona, can suggest management approaches to restoring old-growth forest structures. Our analysis indicated that although more than 50 percent of ponderosa pine stands in the planning area are at or near an old-growth stage, they are at historically high tree densities. Stand-replacing wildfires have recently burned some old-growth stands. Silvicultural methods to restore desired old-growth structure and reduce fire danger can be evaluated with easy-to-use forest simulation models and validated with available historical and ground truth data.

Keywords: fire; GIS; silviculture

Environmental histories can help determine the role of common forest disturbances and changing conditions (Agnoletti and Anderson 2000). Farrell et al. (2000) suggest that a more profound understanding of site history and assessment of past management activities enhance our understanding of ecosystem processes. We present a case study of a Forest Service planning area on the Kaibab National Forest in northern Arizona, where maintaining remnant old-growth forests is a priority *(fig. 1),* and suggest an adaptive management approach that uses a history of management and historical information to develop new land management options.

Federal planning documents, inventory data, photographs, reports, and other records in the Southwest contain both quantitative and qualitative descriptions of forest conditions dating back to 1909. The Kaibab Forest Reserve was established in 1893; it became the Kaibab National Forest in 1908, and the Grand Canyon National Park was sectioned off in 1919. Management emphasis was on game and livestock. Deer hunting was banned during the 1920s until the herd overran the range and then declined between 1924 and 1929. Timber harvests were small and averaged less than 1 million board feet per year, mainly for local consumption and construction materials.

From 1948, when the first timber management plan for the North Kaibab was drafted, until 1982, timber harvests averaged 34 million board feet a year of mainly ponderosa pine *(Pinus ponderosa),* covering 10,000 to 20,000 acres annually. Annual removals greatly increased in the late 1970s. In 1982 severe wildfires, large-scale pine defoliation by insects, extensive tree disease issues, and dense forest regeneration prompted a switch to more intensive even-aged management systems. Administrative policy emphasized multiple use, and annual harvests ranged between 55 million and 70 million board feet, covering slightly more than 12,000 acres per year on average.

Today there is a scarcity of areas resembling forest conditions prior to Euro-American settlement; only 5 to 10 percent of the ponderosa pine cover type in the Southwest region is characterized as old-growth forest (Bailey and

Above left: **A recent human-caused fire within the Forest Service planning area consumed most of the trees. *Right:* Ponderosa pine stands on the Kaibab Plateau, where fires have been suppressed for many years, are now crowded with young trees.**

Ide 2001; Southwest Forest Alliance 2001). These stands contribute to biodiversity, social values, and scenic and recreation opportunities (Kaufmann et al. 1992).

USDA Forest Service (1996) forest plan amendments for Arizona and New Mexico state that no less than 20 percent of large forest planning areas will be retained as old-growth habitat. Yet most such planning areas on southwestern national forests contain less, largely because of a century of timber harvesting. Since fire suppression began in the 1880s, wildfires have played a lesser role in determining forest structural features (Manday and West 1980), although recent large fires in the West attest to the changing character of disturbances. With fewer old-growth stands and high fire risks, management planning requires estimating future was well as existing old-growth stand conditions. Identifying stands with high potential for developing desired old-growth characteristics thus becomes important.

Old-growth ponderosa pine forests are defined as late-successional stands with such distinctive features as large, old-aged trees and abundant snags in patchy distributions (Moir 1992). The expected physical characteristics (USDA Forest Service 1996) often vary with local site conditions, disturbance patterns, and forest management histories—including fire suppression, livestock grazing, and wildlife management as well as timber harvesting. Even ponderosa pine stands with little apparent human intervention have undergone changes. Although ponderosa pine stands were once considered to regenerate only sporadically, with few individuals or groups of trees surviving frequent ground fires (Pearson 1950), now dense stands of young trees are common in the understory. It is evident that old-growth ponderosa pine conditions are often dramatically different than those encountered by settlers little more than 100 years ago.

Forest landscapes on the Kaibab Plateau reflect a history of shifting management objectives; however, the plateau has maintained a larger proportion of old-growth stands because of its relatively short logging history *(fig. 2).* Public concern for protecting these forests prompted the Forest Service to create old-growth conservation areas for each forest type on the Kaibab National Forest in 1991. Silvicultural treatments can be applied within such conservation areas only to enhance their long-term viability as old-growth habitat. However, without a system for assessing future stand and landscape conditions, management activities are often deferred.

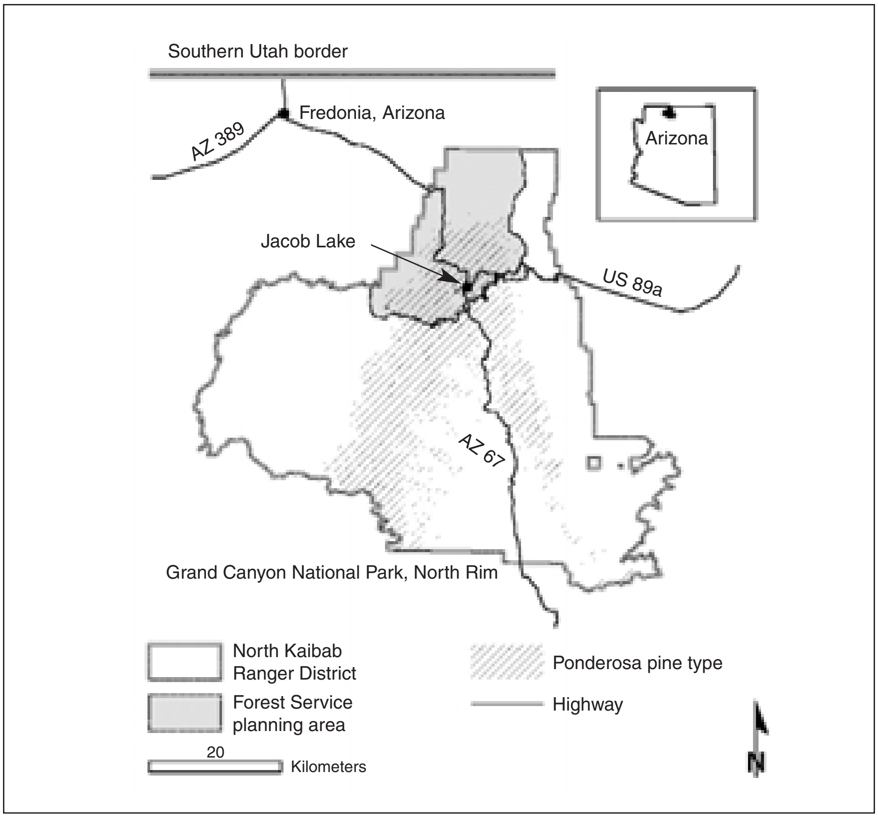


Figure 1. **A map of the study location and extent of the USDA Forest Service planning area on the North Kaibab Ranger District, Kaibab National Forest, Arizona.**

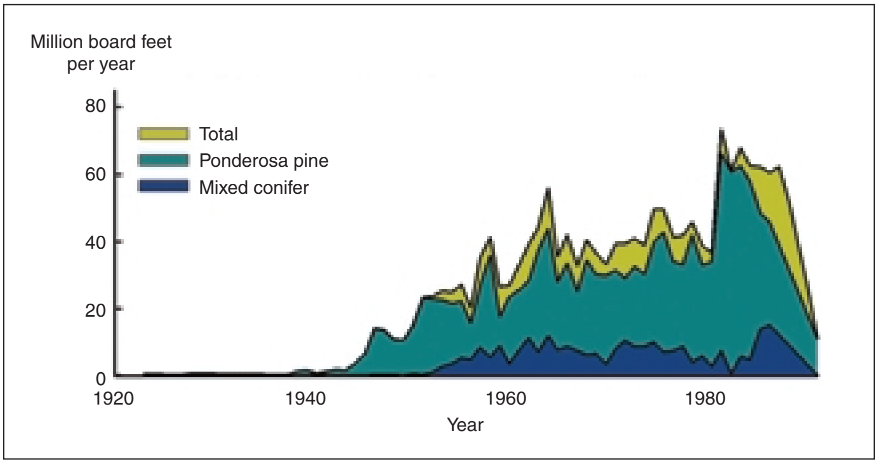


Figure 2. **Annual total board feet of timber harvested from ponderosa pine and mixed conifer forests on the Kaibab Plateau from 1923 to 1993.**

Methods

Measures to identify and monitor old-growth forest conditions at multiple

Using Historical Information

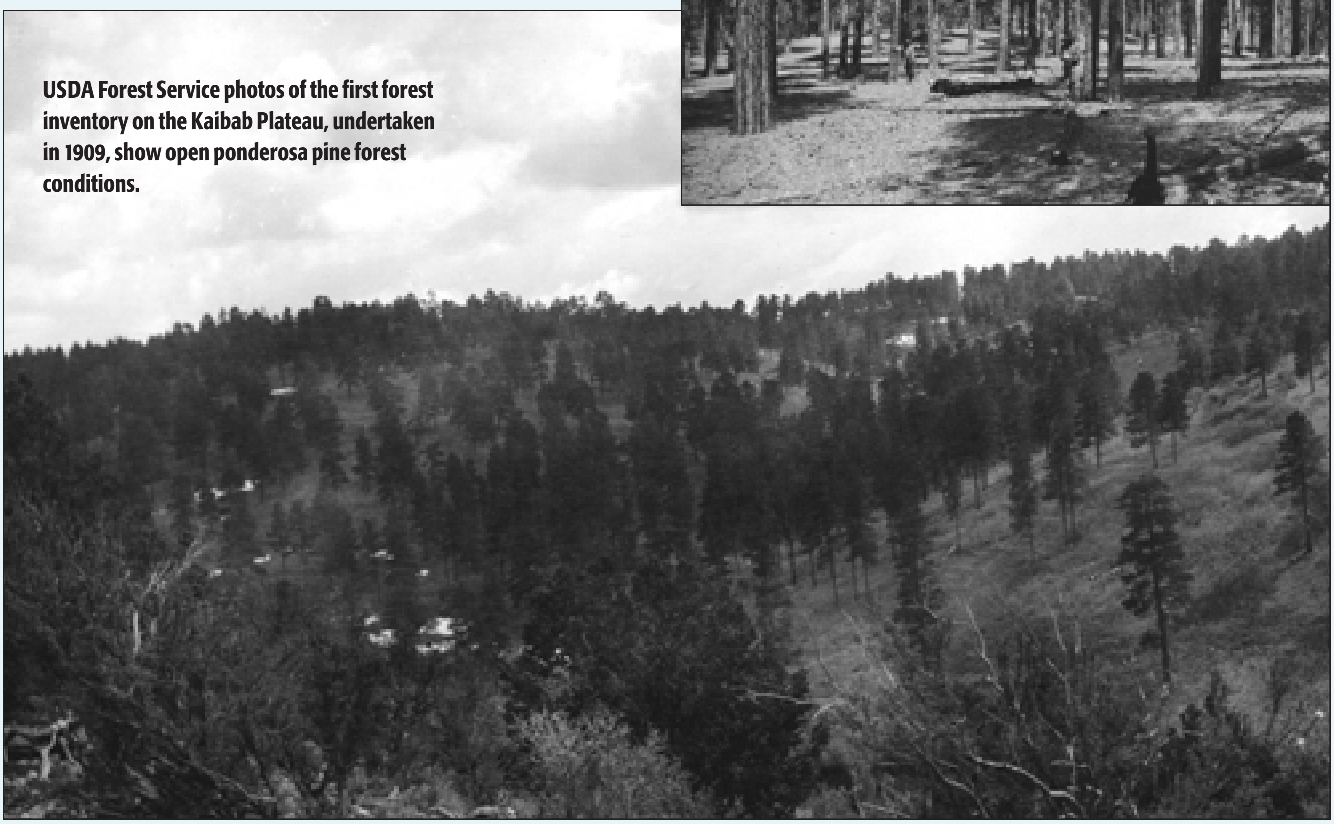
There is no standard method for incorporating historical observations of forest structure into forest planning and decision making. Forest inventory data have been collected at various scales and sampling intensities on nearly every western national forest. In some cases, original field data are no longer available and are only summarized in average stand tables or timber volume atlases. Procedures for collecting quantitative forest data have changed considerably since the first North Kaibab inventory was conducted in 1909 (Lang and Stewart 1910).

Nevertheless, several sources of historical information proved useful. Timber planning documents, photographs, and nearly a century of forest inventory records identify significant changes. Forest descriptions, stand table summaries, and photos accompanying the 1909 inventory show open stand conditions within pure ponderosa pine and bunchgrass forests. This was before timber management but after some three decades of livestock grazing and resultant fire regime disruption.

The 1909 inventory provided tree volume estimates from a 5 percent strip cruise for each quarter-section of forestland with commercial timber species (equivalent to an 8-acre plot per 160-acre quarter). This extensive inventory covered most of the Kaibab Plateau for both ponderosa pine and mixed conifer forests, but original plot data could not be located. Forest inventory records indicate that only trees greater than 18 inches dbh in the ponderosa pine type were measured. Volume calculations were based on the Woolsey (1911) equations from the Tusayan National Forest on the south rim of the Grand Canyon (Ellenwood 1994).

A separate survey of all trees taller than 3 feet was conducted to estimate tree diameter distributions and construct average stand volume tables (Graves 1906; Woolsey 1911). However, North Kaibab stand tables were more comparable to those from inventories taken in the “maximum stand” from several other national forests in Arizona and New Mexico, conducted in 10-acre plots for stands then considered at maximum tree density for ponderosa pine (Woolsey 1911). Trees greater 18 inches dbh for the North Kaibab 1909 stand table were nearly 70 percent of the average maximum density for southwestern plots reported by Woolsey (1911). Thus, we believe that the 1909 stand table for the North Kaibab is representative of late-successional ponderosa pine forests on the Kaibab Plateau c. 1900.

The 1909 tree diameter distributions were compared with continuous forest inventory points measured in 1955, 1966, 1977, and 1982 from areas with little or no timber harvesting. These data indicate a trend toward much higher stand densities in all but the largest size class. Although sampling methods differed greatly over time, these figures suggest that long-term changes observed in other southwestern forests (Covington and Moore 1992; Covington et al. 1997) are also true on the Kaibab Plateau.



USDA Forest Service photos of the first forest inventory on the Kaibab Plateau, undertaken in 1909, show open ponderosa pine forest conditions.

Photos courtesy of Kaibab National Forest Supervisor's Office

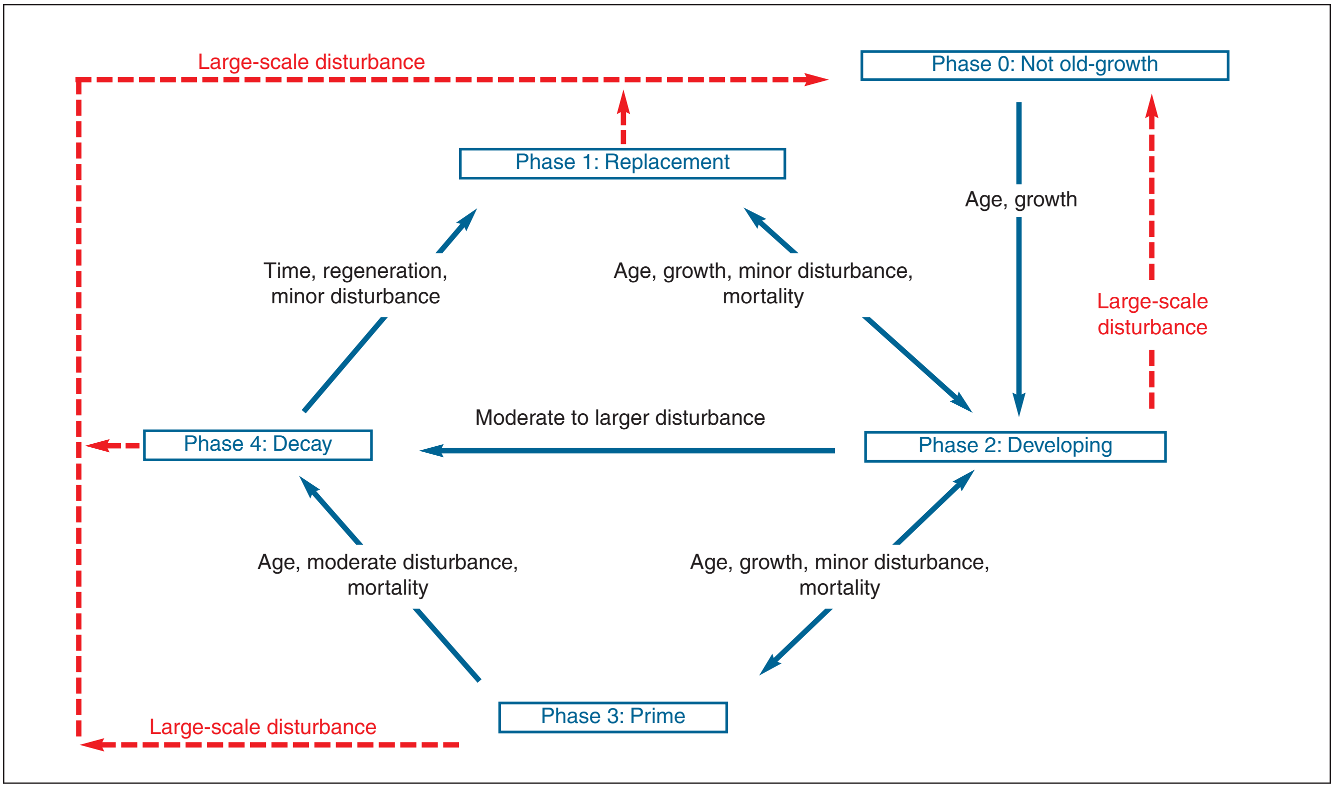


Figure 3. **A conceptual model of ponderosa pine old-growth phases and potential factors influencing transition between the phases. Note that a phase 0 stand cannot develop into phase 1 because important old-growth components, such as downed logs recruited from later stages, would not be present.**

scales are a prerequisite for making specific management recommendations (Franklin and Spies 1997; Hemstrom et al. 1998). We therefore initiated a pilot study to assess historic structural changes for a 30,000-acre ponderosa pine forest within the North Kaibab Ranger District's Jacob-Ryan Ecosystem Management Unit. Our objective was to consolidate contemporary and historical forest information to (1) classify old-growth ponderosa pine structure, (2) compare current old-growth stands with former forest conditions, and (3) identify management histories leading to today's old-growth and other structural conditions.

We used the Forest Vegetation Simulator (FVS) and its graphical interface SUPPOSE (Crookston 1997) to pose standard management questions and silvicultural options. FVS outputs were linked to an ArcInfo geographic information system (GIS) through a Microsoft Access database to monitor landscape planning alternatives and simulate forest successional stages (Teck et al. 1996). The Central Rockies FVS features the empirically derived GENGYM (Edminster et al. 1991) individual tree growth-and-yield model developed from study plots in Arizona and New Mexico national forests. Plot data were collected from a range of stand conditions, including even- and uneven-aged stand structures of pure ponderosa pine and mixed conifer forests of ponderosa pine, Douglas-fir *(Pseudotsuga menziesii),* white fir *(Abies concolor),* Engelmann spruce *(Picea engelmannii),* blue spruce *(Picea pungens),* aspen *(Populus tremuloides),* southwestern white pine *(Pinus strobiformus),* and corkbark fir *(Abies lasiocarpa var. arizonica).* FVS can simultaneously process up to 1,000 stands and is therefore useful for analyzing large areas (Peng 2000). It has also been recommended as an ecosystem forecasting tool capable of monitoring long-term ecosystem processes (Teck et al. 1996).

An old-growth working group comprising university professors and students, USDA Forest Service managers, state and federal wildlife biologists, and Arizona environmental advocates used stand inventory records and information in the literature to develop an old-growth stand dynamics model (see "Using Historical Information"). Qualitative and quantitative definitions were used to identify a range of forest structural conditions leading to and away from late-successional or old-growth ponderosa pine. We started with the qualitative definitions in *table 1* (p. 44). A simple forest succession model identified factors that influence old-growth development and transitions between each development phase *(fig. 3).*

Successional pathways identified by Moir and Dieterich (1988) and structural features noted by Kaufmann et al. (1992) and Popp et al. (1992) for southwestern ponderosa pine were incorporated into the stand dynamics model using five variables available in current forest inventory data:

- Large trees for the dominant species and site conditions.
- Snag size and number.
- Stand density indicators (trees per acre, tree diameter distributions, basal area).
- Site history.
- Site productivity (site index).

Stand conditions based on quantitative indices for each phase were refined with the help of Forest Service silvicul-

Table 1. Narrative descriptions of ponderosa pine old-growth phases for the Kaibab Plateau.

Phase 0: Not old-growth	Historically forested but without remnant large trees or standing snags. Commonly resulting from disturbances such as severe wildfires, windthrow, salvage logging, or previous intensive logging practices.
Phase 1: Replacement	Regeneration or secondary forest ("blackjack" pine) is ecologically dominant and affect the site more than remaining old-aged trees. A remnant of the large-tree component still exists.
Phase 2: Developing	Dominant cohort is 150-year-old trees (16 to 20 inches dbh). Yellow bark pines develop within this phase, codominating with older blackjack pines, and dominating at the end of the phase.
Phase 3: Prime	The largest trees dominate the group or stand. Yellow bark pines have large, wide red-yellow plates and large limbs. Large trees dominate the total basal area. Multiple ages and multiple canopies are desirable. Large live trees outnumber large dead trees. Desired distribution of large snags and dead and down material is present.
Phase 4: Decaying	Death and decay dominate the ecological process and peak during this phase, with fewer large live trees than in phase 3. Smaller trees may be developing in the understory. Disturbances such as dwarf mistletoe, insects, and fire may significantly affect the larger-tree component. Phase 4 occurs at the group (<1 acre) to stand scale and larger areas, depending on the level of disturbance.

Table 2. Quantitative indices adapted to the Forest Vegetation Simulator for estimating old-growth phases as successional trends.

Old-growth phase	Site index	Trees ≥18 inches dbh per acre	Trees ≥30 inches dbh per acre	Basal area (ft^2 per acre)	Snags ≥18 inches dbh per acre
0	≥55	<4	—	<20	—
	<55	<4	—	<20	—
1	≥55	≥4, <12	—	≥20, <60	<4
	<55	≥4, <9	—	≥20, <60	<4
2	≥55	≥12	—	≥60	—
	<55	≥9	—	—	—
3	≥55	≥16	≥1.5	≥60	2
	<55	≥12	≥1.0	—	1
4	≥55	≥4, <12	—	≥20	≥4
	<55	≥4, <9	—	≥20	≥4

turists and agency wildlife biologists. Thus, values for stand variables incorporate expert knowledge, historical forest inventories, and tree data. These sources of quantitative information served as baseline values to develop algorithms for four old-growth development phases that were programmed for FVS succession simulations using keyword functions (Teck et al. 1996). The COMPUTE keyword allowed us to summarize stand inventory data and generate each stand development phase using logical "if/then" or "greater/less than" statements according to our quantitative criteria *(table 2)* at the end of each 10-year FVS growth cycle (Crookston 1997). A fifth phase, 0, comprised stands under even-age management or having undergone intense disturbance such that they would require perhaps 150 years to become old-growth.

FVS model extensions can test management alternatives and incorporate common forest disturbances, such as pest outbreaks (Johnson 1997) and natural or prescribed fire (Beukema et al. 2000). The "Fire and Fuels" extension (Beukema et al. 2000) and SNAGSUM keyword allowed us to calculate the number of snags per acre for each phase at a height (25 feet) and diameter (>18 inches dbh) considered important for wildlife habitat. We used snag numbers in combination with other structural attributes to identify only phases 3 and 4. Separate quantitative site indices were used for high and low sites (breakpoint of 55), although only 3 percent of the ponderosa pine cover type within the planning area was considered low, according to inventory data and site index estimated from tree core samples (Mathiasen et al. 1987).

Forest Service inventory data for 479 ponderosa pine stands were used to generate present old-growth phases with FVS and project them into the future. Model output was linked to the GIS database to develop preliminary land-cover maps. We compared each stand phase with ground reference data collected in the field for 342 stands to test the performance of the model. Forest Service silviculturists reviewed stand summary data from the latest inventories and conducted walkthrough surveys to verify each stand's phase according to *table 1* and *2* criteria. We used standard error matrices (contingency tables) and agreement statistics to judge accuracy (Congalton and Green 1993). Percentage agreement and Cohen's Kappa coefficients (Agresti 1996) were calculated to validate the phase model for identifying present stand conditions.

Forest management regimes were compared with the five phases to identify management activities leading to each old-growth phase condition. The three most common management regimes found in the Forest Service planning area were categorized as follows:

- *Moderate to no harvest:* unharvested or selectively logged stands removing less than 50 percent of the basal area during initial harvest between 1955 and 1979. Most stands had had understory thinning for trees less than 9 inches dbh at approximately 10-by-10-foot spacing between 1978 and 1983. Some prescribed burning had taken place since 1980.
- *Intensive harvest:* stands recently harvested (1987–90) using shelterwood seed tree, shelterwood removal,

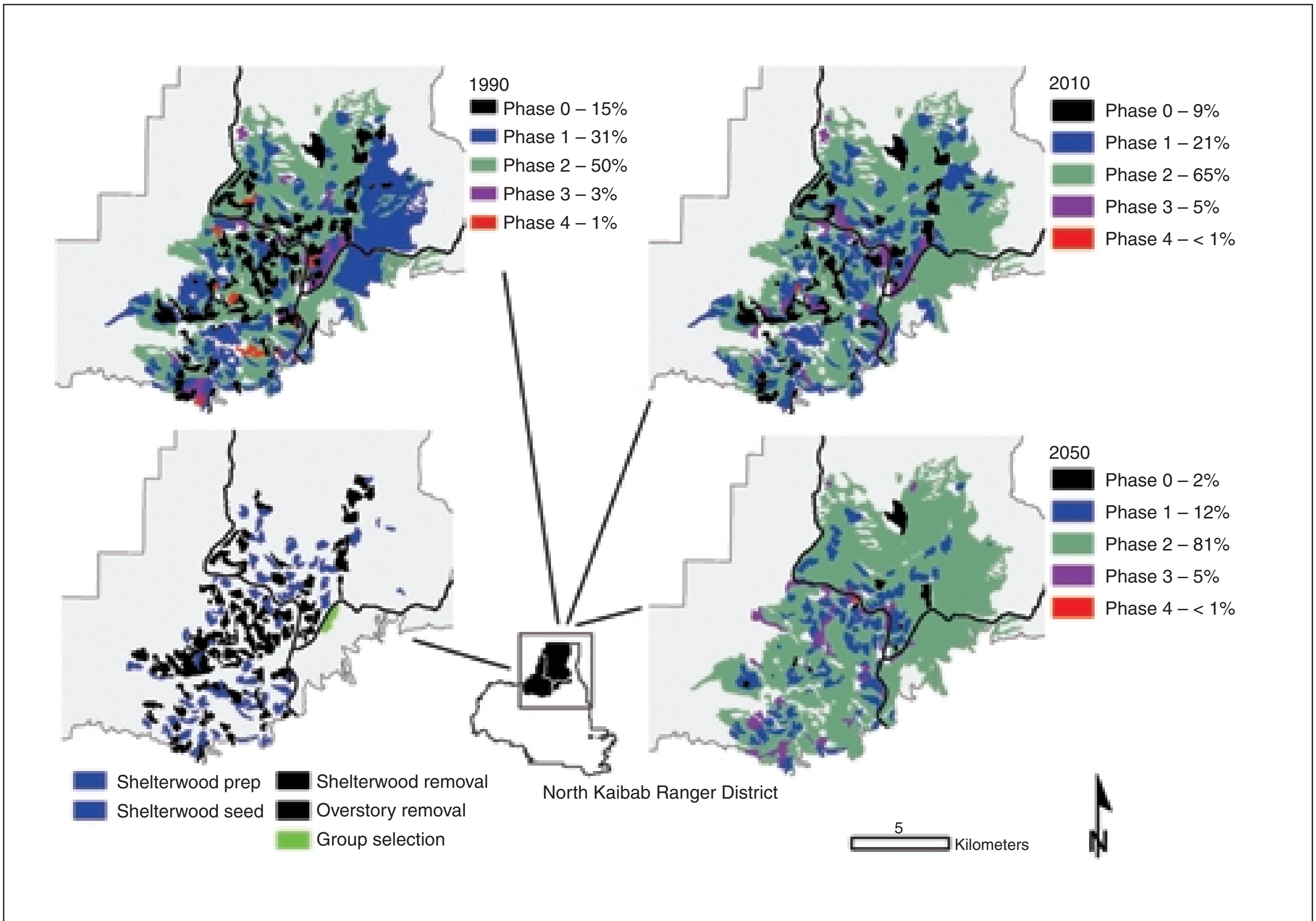


Figure 4. **An FVS simulation using the current stand inventory data with the phase model. The lower left map shows that many of the most recent harvest treatments (1986–91) correspond to phase 0 and 1 stands. Many of these are still phase 1 at year 2050. The large phase 0 area in 2050 is a lightning-caused burn encompassing 2,000 acres, from 1987.**

overstory removal, commercial thinning, salvage, and other silvicultural practices removing 50 to 90 percent of the basal area. Most stands had understory thinning between 1978 and 1983.

• *Unknown or other disturbance:* stands altered by fire, other disturbances, or harvest practices unaccounted for in the database.

Lastly, growth of ponderosa pine stands was simulated to 2010 and 2050 to estimate future old-growth phase conditions across the planning landscape. A "no management" alternative was used to generate baseline landscape conditions.

Results and Discussion

Phase accuracy and comparisons. Phase accuracy between the FVS model and ground reference data initially showed 56 percent accuracy and a Kappa score of 0.40, with the greatest discrepancy between phase 0 and phase 1. Eighty percent of the phase 1 stands misclassified by FVS had been harvested by shelterwood and overstory removals that left approximately 20 percent of the residual basal area for trees greater than 18 inches dbh. Such stands would require a long time to grow trees into larger-diameter classes *(fig. 4).* We therefore reclassified all stands with intensive harvest as phase 0 for mapping current phases. This improved classification accuracy to 70 percent with a Kappa score of 0.55. Reclassifying stands was unnecessary for simulation purposes, because many of the phase 1 stands simply remained at that phase for an extended time.

We considered classification errors between phase 2 and 4 stands the most significant source of error using the FVS model. Snag recruitment and fewer large live trees per acre were used to indicate decaying or declining phase 4 old-growth stands. Field-classified phase 4 stands with more than 10 large snags per acre but exceeding the maximum of 11 large live trees per acre were therefore classified by FVS as phase 2 developing old-growth stands. In all but five of the 16 stands classified as phase 4 in the field, 50 to 80 percent of the trees were infected with dwarf mistletoe tree disease. We believe that the field-based classifications correctly identified phase 4 conditions, with decline rather than old-growth development as the dominant ecological process. The maximum number of large trees per acre in phase 4 should perhaps be increased. We also observed that, for many stands field-classified as phase 3, an insufficient number of snags were recorded in the inventory data, and FVS therefore classified them as phase 2. Successional models may be sensitive to snags, given their patchy distribution within stands and their

Table 3. Percentage of the planning area within each old-growth phase and proportion within a particular management regime (n = 479 stands, 1990 inventory).

				Management regime (% of old-growth phase)		
Old-growth phase	Stands	Area	Management period	Moderate to no harvest	Intensive harvest	Unknown or other disturbance
0	102	15%	1982–91	—	92%	8%
1	131	31	1982–91	—	38	62
2	208	50	1948–82	95	5	—
3	23	3	1948–82	100	—	—
4	15	1	1982–91	—	74	26

potential to be underestimated by forest inventories. The same may be true for the largest-diameter trees. However, FVS appears adequate for simulating future stand conditions where growth is the dominant process. FVS may accurately identify declining phases once fully calibrated for such conditions as high levels of tree disease or larger numbers of snags when detected with forest inventories.

Old-growth then and now. Old-growth tree densities and distributions have changed markedly, based on past and present inventory data and 1909 photos of the Kaibab Plateau. Available data showed modifications in forest structure similar to those noted by other authors (Moir and Dieterich 1988; Covington and Moore 1992; Ellenwood 1994). Tree densities have increased dramatically. Trees smaller than 12 inches dbh were eight times more numerous per acre on average in 1990 than in 1909 across all old-growth phases generated by the FVS model. Old-growth phase 3 stands, considered the best approximation of classic old-growth conditions, had twice the average 1909 basal area within all tree diameter classes.

The area extent of the phases in 1909 is speculative at best: Only quarter-section volume summaries from the 1909 survey are available. By recalculating the 1990 inventory volumes using Woolsey's 1911 equations, Ellenwood (1994) found that 77 percent of the forests on the Kaibab Plateau had more than 125 percent of the 1909 volume summaries. We believe that volume comparisons made by Ellenwood (1994) reflect the high accumulation of tree basal area in many old-growth areas. However, developing phase 2 and late-successional phase 3 stands are now within a landscape of young, phase 0 and 1 stand structural conditions *(fig. 4).* Simulating landscape conditions 50 years forward showed that many of the most intensively harvested areas will be slow to attain phase 2 or 3 conditions.

Management regimes and old-growth phases. Old-growth phases created by particular management regimes *(table 3)* were associated with particular management periods and practices. The intensive harvests of the 1980s resulted in a majority of phase 0 and 4 conditions and 38 percent of the phase 1 stands. Most phase 1 and 4 stands had been harvested, and few large live trees and snags had been retained. It is likely that a number of phase 1 stands in the "unknown" category (62 percent) resulted from past selective logging that removed a large proportion of the basal area.

Phase 2 and 3 stands were almost exclusively the product of moderate or no timber management from 1948 to 1982. These stands had a large number of trees smaller than 12 inches dbh because of both selective logging and fire suppression with only light understory thinning—practices that allowed a disproportionate number of small and medium-sized trees to establish.

Wildfire accounted for greater than 7 percent of the planning area ponderosa pine stands within phases 0 and 1 mainly because of a single 2,000-acre stand-replacing fire. No fires were documented within phases 2, 3, and 4 stands, although field reconnaissance found that some prescribed burning or low-intensity wildfires have occurred within these stands.

Landscape conditions. Present landscape conditions are a mix of contrasting structural stages. Critics of the Forest Service have found intensive harvest practices undesirable because of the lasting effect on wildlife habitats. Indeed, landscape simulations *(fig. 4)* showed that many phase 0 and 1 stands remained in an early old-growth phase for the next 50 years. Yet high levels of dwarf mistletoe infestation and extensive pandora moth *(Coloradia pandora)* defoliation in 1981 were also considered undesirable by forest managers and other observers (Bennett et al. 1987). The peak forest densities shown by inventory data from 1982, along with heightened tree disease and insect levels, prompted even-aged management systems to reduce the number of old trees and mistletoe-infested stands, thought to be most susceptible to insect outbreaks (Wagner and Mathiasen 1985). A history of fire suppression and light selection harvests of merchantable timber led to the overly dense forest that had contributed to declining health.

Recommendations and Conclusions

Stands both with and without high levels of timber harvesting have undergone dramatic alterations on the Kaibab Plateau in response to a century of Forest Service decisionmaking. More trees now exist in our study landscape than perhaps ever before, especially in the diameter classes typically considered less than commercial size. Managers and others planning for the future of forests on the Kaibab Plateau (and elsewhere in the Southwest) may wish to review the history of these forests as they develop alternative silvicultural methods. Fire suppression, livestock grazing, and management practices favoring regeneration have all contributed to the overabundance of trees and, at times, the fragmentation of old-growth stands. Additionally, most of the prime old-growth stands (phase 3) are now those closest to the highways and have been left unharvested primarily for aesthetic purposes.

To maintain desired old-growth

functions, such as wildlife habitat, and as a structural component of the overall landscape, managers may wish to promote phase 3 conditions in other parts of the landscape. Many phase 2 stands could become phase 3 if the number of small-diameter trees and fire risks for selected areas were reduced.

Old-growth areas containing historically high tree densities and disease levels could benefit from active management. More extensive forest thinning and burning programs to reduce small-diameter trees are apparently long overdue. As early as 1948, managers recommended reducing overly dense regeneration that had developed in the absence of fire. Recent wildfires within the planning area and other parts of Kaibab Plateau have been predominantly stand-replacing rather than light understory fires. These conditions lend support for undertaking preemptive actions to reduce such risks while maintaining old-growth features.

In the absence of active management, less than 5 percent of the planning landscape will meet prime old-growth conditions in 50 years, according to FVS simulations. Silvicultural prescriptions that emphasize existing old-growth forest attributes, historical fire regimes, visual appeal, and wildlife habitat on the Kaibab Plateau will meet ecosystem and public values. An understanding of forest histories and application of decision support tools should lead to improved and more broadly accepted management practices in the future.

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