A.L. Sweitzer

Above: **Oxen logging on the San Juan National Forest, Colorado, 1910. Note the open, park-like forest conditions.**

Forest Restoration in Southwestern Ponderosa Pine

A field study on the San Juan National Forest focused first on restoring degraded ponderosa pine forests to ecological integrity and potential productivity, and second on maximizing returns from harvesting. Results show that if landscape-scale forest restoration has a future, sale design is critical. Managers who combine financially strong and weak units, design sales to reduce logging and prescribed burning costs, and take advantage of the fluctuating market for small material can achieve both ecological and financial objectives.

By Dennis L. Lynch, William H. Romme, and M. Lisa Floyd

Questions about operational forest restoration confronted us as we began our study in 1993, and we soon found we were not alone—foresters involved in restoration projects across the country were asking similar questions. Most cost-revenue information on small-diameter harvesting had come from either plots or just estimates. No one had addressed the revenues and costs associated with achieving ecological objectives in forest restoration at the project level. We work in the Southwest, but the questions transcend region:

Will good ecology naturally translate into good economics? What types of small-diameter products can be expected from restoration treatments? What are the actual costs and revenues for a restoration project? Can restoration projects pay their way or must they be subsidized? Can harvesting operations alone achieve restoration objectives? What combinations of harvesting and prescribed fire may be needed to achieve desired ecological conditions?

Much has been written about degraded ponderosa pine *(Pinus ponderosa)* forest stand structure and processes across the Southwest and the substantial differences between current forest conditions and those existing before the influx of Europeans (Cooper 1960; Covington et al. 1997; Dahms and Geils 1997; Fulé et al. 1997). In southwestern Colorado, fire history and stand reconstruction studies (Romme et al. 1999a) confirmed similar differences in conditions. Thinning to remove small-diameter trees, accompanied by prescribed fire, has been suggested as a means of restoring structure and processes to degraded forest systems (Sackett et al. 1993; Edminster

Prescribed burning is used to create openings on the San Juan National Forest, Colorado.

Right: **An area of severe crown scorch after prescribed burning but before spring green-up.**

Center: **The same area one month later, after green-up; note the abundance of forbs and herbs in the understory.**

Far right: **The same area one year later.**

and Olsen 1995; Hardy and Arno 1996; Omi 1998). Since the start of our study, efforts have also been made to estimate the financial potential of restoration projects (Mirth and Larson 1997; Lynch et al. 1997; Scott 1998) but with varying results.

No one, however, had seen on-the-ground operational forest restoration. The Forest Service had offered traditional timber sales that included small-diameter material, but these sales consistently failed to attract bids. Small, scattered areas had been precommercially thinned using classical spacing guides. Prescribed fire had been used in open pine stands but not in high-density stands needing restoration. In the public involvement phase that preceded our study (Richard and Burns 1998), we learned that citizens were interested in the idea of forest restoration but uncertain what it might look like.

An Ecological Prescription for the San Juan Pine Zone

Retain large trees. Any trees 20 inches or larger in diameter should be retained. In stands with smaller trees, the largest trees should be retained in clumps. Large-diameter oak stems should be retained as clones.

Reduce tree densities. Pre-1900 levels were approximately 40 to 50 trees per acre, but future mortality and ingrowth should be considered.

Use large trees to identify clumps. The largest trees in the stand should be used as a guide to the placement of clumps. Isolated large trees between clumps may be removed. Occasional clumps of small-diameter trees may be retained to provide variation.

Vary clump sizes. Clumps may vary from groups of six trees to as much as one-quarter to one-third acre in size, but considerable flexibility is possible.

Vary distances between clumps. The areas between clumps should be viewed as narrow glades and small openings with variation. Usually these should be 33 feet to 66 feet in width or 1 to 1.5 tree lengths across. They should exceed the lateral extent of crown and roots. Variation in opening size and shape is important.

Create openings. The purpose of openings is to provide for snow catch and sunlight to increase the component of grasses and forbs.

Manage fire. Gradually restore the fire regime to intervals of 10 to 20 years including summer burning. Protect large trees during burning. Try to reach light fuel beds that will be easy to manage even under wildfire conditions.

Provide for wildlife. Retain and create snags to increase this component of the stand. Clumps should include interlocking crown conditions for Aberts squirrels. Larger-diameter dead oak stems should be retained for songbirds.

The Dolores District Ranger of the San Juan National Forest, Montezuma County Commissioners, and Colorado Timber Industry Association formed the Ponderosa Pine Partnership in 1993 to learn how stands might be restored to the pre-1900 forest structure and processes suggested by Romme's studies. The partnership was also interested in improving a declining rural economy and maintaining traditional western lifestyles.

Romme provided a forest restoration prescription that called for retaining the largest trees and creating irregularly sized and shaped clumps interspersed with small openings and narrow glades (see "An Ecological Prescription for the San Juan Pine Zone"). Phil Kemp, of the Dolores District timber staff, translated this into a silvicultural marking guide for his crews. The district subsequently offered six units (totaling 549 acres) as a demonstration timber sale that was purchased by Montezuma County and subcontracted to local loggers associated with the Colorado Timber Industry Association. Carla Garrison, an employee of Montezuma County, acted as project coordinator for the partnership. Harvesting data were collected by Catherine Jones.

Although operational field studies reflect the real world, variables are hard

Photos by Dennis L. Lynch

to control, and not everything in this study went according to plan. However, information developed here may be useful to others contemplating forest restoration projects.

Ecological Prescription

The six experimental restoration units were representative of a 180,000-acre area in the San Juan National Forest near Dolores, Colorado. Elevation ranges from 6,500 to 9,500 feet, and substrate is primarily Dakota sandstone. This forest, nearly pure ponderosa pine, has been heavily utilized by humans throughout the past 125 years. Livestock grazing began in the 1870s, heavy logging occurred in the early 1900s, and fires have been excluded since the 1880s. In many areas there are now seven times more trees per acre than at the turn of the 20th century. Stands are more homogeneous (mostly in the 50- to 110-year age classes) and typically lack large trees and snags. Less than 20 percent of the stands have regeneration, understory plant diversity is limited, and fires are infrequent but potentially intense (Romme et al. 1999b). Overall biodiversity, ecological integrity, and productive potential may have been diminished, a situation that prevails elsewhere in the Southwest (Cooper 1960; Covington et al. 1997; Moir et al. 1997).

Ecological goals for this project included reducing risk of uncontrollable wildfires and insect outbreaks, stimulating growth of suppressed herbaceous plants, providing germination sites for pine seedlings, and increasing large living trees and snags for structural diversity and wildlife habitat (Covington et al. 1997; Hardy and Arno 1996; Romme et al. 1999a). Six specific ecological study objectives were identified:

1. Reduce current stand density to pre-1900 conditions.
2. Increase average stand diameters.
3. Increase crown base height (distance from ground to base of living crown) to reduce risk of catastrophic fire.
4. Reduce cover of woody plants and detritus (litter and woody debris).
5. Reduce downed woody fuels.
6. Increase cover and diversity of herbaceous plants and increase pine reproduction.

Methodology

Ecological monitoring and analysis. In June 1995, before treatment, we paced each stand (50 to 100 acres) and listed all vascular plant species present. We then established two permanent 100-meter transects through representative portions of each stand. To document vascular plant species present after treatment, we established 10-by-10-meter releve plots on both sides of the transect at the beginning and end of the transect, for a total of four plots per transect and eight plots per stand. We listed all vascular plant species within each plot and visually estimated cover and abundance using the Braun-Blanquet scale (Mueller-Dombois and Ellenberg 1974). We sampled all trees within a belt along each 100-meter transect. Before sampling, we selected an appropriate belt width, based on tree density, that would provide approximately 40 trees per transect. We recorded each tree species, diameter at breast height (dbh), crown base height, and condition (healthy, dying, or dead). The Forest Service measured tree density and basal area before and after treatment using stand examination techniques (USDA-FS 1999).

The point intercept method was used to evaluate percent cover of biotic and abiotic forest floor components. We sampled 25 point-frames (frequency frames) along each transect. Each frame was located randomly within sequential 4-meter sections of the transect. We established five lateral transects for planar intercept fuels sampling along each main transect, for a total of 10 planar intercept transects in each stand (Brown 1970).

In 1998, after treatment, all transects, belts, frames, and lateral transects were relocated and resampled. Using 1995 and 1998 data, we tested for significant differences in average stand dbh and crown base height by means of independent t-tests. We tested for significant effects on each cover component by means of ANOVA on arcsine-transformed data. Where the overall ANOVA model demonstrated significant differences between years or among stands ($p < 0.05$), we tested for significant differences in each stand using individual sample t-tests. Statistical tests were performed on transformed data, but results presented here are all untransformed means and standard errors. We tested for significant effects of year and stand on each fuel com-

Table 1. Stand characteristics. Four stands were treated and sampled for ecological objectives in this study in the San Juan National Forest, Colorado. Canopy species include ponderosa pine, aspen, and Gambel oak.

	A Thinned 1995	B Thinned 1995	C Thinned 1995	D Thinned 1995, burned 1996
Elevation (feet)	7,900	7,900	8,000	8,000
Substrate	Dakota sandstone, Mancos shale	Dakota sandstone, Mancos shale	Dakota sandstone, loess	Dakota sandstone, loess
Topography	Gentle northwest-facing slope	Gentle west-facing slope	Gentle west-facing slope on mesa top	Gentle west-facing slope on mesa top
Size (acres)	95	56	108	65
Posttreatment density in stems per acre (pine, all species)	28, 51	106, 106	49, 49	56, 56
Posttreatment basal area in square feet per acre (pine, all species)	50, 58	93, 93	58, 58	42, 42
Dominant ground layer plant species	*Bromus, Antennaria, Achillea lanulosa, Fragaria*	*Rosa woodsii, Achillea lanulosa, Wyethia arizonica, Potentilla*	*Quercus gambelii, Symphoricarpos, Amelanchier utahensis, Achillea lanulosa*	*Quercus gambelii, Carex geyeri, Wyethia arizonica, Poa fendleriana*

Table 2. Plant species richness (diversity) in experimentally treated stands in the San Juan National Forest.

Plant type	A Thinned 1995	B Thinned 1995	C Thinned 1995	D Thinned 1995, burned 1996
Woody species				
1995	9	8	9	8
1998	5	6	5	5
Forbs				
1995	32	27	30	23
1998	10	11	18	42*
Graminoids				
1995	4	2	4	2
1998	3	2	6	6*
Alien species				
1995	2	2	1	5
1998	1	2	2	3
Noxious weeds				
1995	1	1	0	2
1998	2	2	2	3
Total species				
1995	45	37	43	33
1998	18	19	29	53*

Values represent the number of species encountered within the entire 50–100 acre stand in 1995, and in eight 100-square-meter plots in each stand in 1998. Pairs of numbers are not directly comparable because of different sampling methods.

**Trends that appear biologically meaningful.*

ponent by means of ANOVA. Where the overall ANOVA model was significant ($p < 0.05$), we tested for significant differences between years in each stand using independent sample *t*-tests.

Harvesting and prescribed fire. Harvesting equipment typically used in this area might be described as "survival" technology—paid for and simple to repair. A history of inconsistent timber supply and stumpage pricing on national forest lands has discouraged local investment in new logging or milling equipment. Trees were therefore felled, limbed, and bucked manually with chainsaws; a John Deere 743 mechanical harvester assisted in two units. Slash was lopped and scattered to create a fuelbed for prescribed burning. Skidding was accomplished with either a JD 540 or CAT 518 rubber-tired, swinging grapple skidder. Skidders attempted to crush slash and small oakbrush *(Quercus gambelii)* to prepare a fuelbed, but larger oak clones were left intact for wildlife. Gentle terrain (typically flat with occasional 5 to 10 percent slopes) permitted easy construction of landings and short spur roads.

Logs were loaded onto conventional log trucks with a hydraulic knuckle boom loader and transported to various mills for processing into pine excelsior, waferwood for oriented-strand board, pulpwood, posts and poles, and sawn products. Haul distances were approximately 335 miles for pulpwood to Stone Container in Snowflake, Arizona; 160 miles for waferwood logs to Louisiana-Pacific in Olathe, Colorado; and 25 miles for excelsior logs, posts and poles, and sawlogs in Mancos, Cortez, or Dolores, Colorado.

As trees were cut, they were counted and sorted into 5–7.9-inch, 8–11 9-inch, and 12+-inch diameter classes. Skidded logs were also recorded by diameter class. Logs were separated by product and counted during loading.

Every truck was weighed. Samples were taken from logs and sample loads were scaled to determine weight-volume conversions.

Records for labor, equipment, fuel and fluid consumption, and hourly machine use were kept in a daily journal, and costs were calculated using methods described by Miyata (1980). Other costs included insurance, workers' compensation, FICA, bookkeeping, and office and administrative expenses. Revenues were recorded for each product sold by the logger.

Slash disposal and road rock replacement money was collected by the Forest Service along with stumpage. Prescribed burning was to be accomplished within one year after harvest of each unit. However, only two units were burned because of workforce and weather restrictions. One of these units was considered to have been satisfactorily treated to reduce fuels.

Results

Posttreatment ecological assessment. Ecological data from transects and plots were collected in four of the six treated stands. Basal area in all but one stand was reduced to 40 to 50 square feet per acre *(table 1)*. One stand was treated with an effective prescribed burn in fall 1996. This burn scorched foliage in nearly every tree, and in May 1997 the stand appeared visibly damaged. However, by July 1997 nearly all scorched trees had shed fire-killed needles and developed new ones. By summer 1998, fire-caused mortality of canopy trees was less than 5 percent. More than 95 percent of the trees sampled within belt transects in 1998 were classified healthy.

In three stands that were thinned but not burned, we documented fewer species of woody plants, forbs, and graminoids in 1998. This was largely a result of the smaller spatial area sampled for richness in 1998 (eight 100-square-meter plots versus the entire stand in 1995). In the thinned and successfully burned stand, however, we detected 20 more species in 1998 despite the smaller sampling area *(table 2)*. Especially striking was the increase in forb species. Grasses and sedges also increased, but woody species did not. There was a small increase in noxious weed species in all four stands, from 0 to 2 species in 1995, to 2 to 3 species in 1998, despite the smaller sampled area *(table 2)*. Litter depth increased in two thinned-only stands but did not change in other stands.

Table 3. Percent cover of biotic and abiotic ground layer components in 1995 (before treatment) and 1998 (after treatment) in four study areas in the San Juan National Forest.

	A Thinned 1995	B Thinned 1995	C Thinned 1995	D Thinned 1995, burned 1996
Forbs				
1995	24.6 (2.5)	29.4 (3.3)	11.2 (2.1)	7.8 (1.5)
1998	9.9 (1.3)*	12.8 (1.6)*	13.4 (2.4)	12.3 (2.2)
Grasses and sedges				
1995	6.1 (1.0)	11.1 (1.6)	8.4 (1.6)	0.9 (0.4)
1998	9.9 (1.6)	17.1 (2.8)	4.4 (1.2)*	1.2 (0.5)
Oak				
1995	0.64 (0.4)	0.0 (0.0)	8.5 (1.5)	13.6 (2.4)
1998	7.5 (2.3)*	0.1 (0.1)	23.3 (3.6)*	18.8 (4.0)
Snowberry				
1995	0.16 (0.16)	0.02 (0.02)	11.2 (2.8)	0.1 (0.1)
1998	0.0 (0.0)	0.64 (0.64)	6.2 (1.4)	0.16 (0.1)
Total herbaceous vegetation				
1995	30.8 (2.6)	40.5 (3.6)	30.9 (3.5)	8.6 (1.6)
1998	19.8 (2.3)*	30.5 (3.0)*	23.9 (2.7)	13.6 (2.3) (*p* = 0.07)
Total woody vegetation				
1995	1.36 (0.7)	0.9 (0.5)	22.2 (3.6)	29.5 (4.8)
1998	15.4 (4.7)*	0.4 (0.2)	49.7 (7.3)	38.4 (8.1)
Total detritus				
1995	68.3 (2.7)	52.9 (4.1)	54.9 (3.4)	74.6 (2.5)
1998	71.5 (2.8)	65.9 (3.0)*	46.1 (3.8) (*p* = 0.08)	59.5 (3.6)*
Bare ground				
1995	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
1998	0.8 (0.5)*	3.1 (1.0)*	3.2 (1.5)*	3.2 (1.5)*

**The difference between 1995 and 1998 is significant (p < 0.05). For marginally significant differences (p < 0.10), actual p value is given. Data were arcsine transformed for analysis, but values reported here are untransformed cover values: mean (standard error). N = 50 for each.*

Average stand diameters increased after removal of small material, from 2.8–5.8 inches in 1995 to 7.1–10.8 inches in 1998. However, average crown base height, which ranged from 14.4 to 22.3 feet, was not different after treatment in all stands.

In the three stands that were only thinned, the percent cover of herbaceous vegetation (forbs plus graminoids) was reduced in two stands, and percent cover of graminoids was reduced in a third stand. In the thinned and burned stand there was no change in forb or graminoid cover, but total herbaceous vegetation increased *(table 3)*.

Percent cover of oak and total woody vegetation increased in two thinned stands, but there was no change in cover of shrubs or total woody vegetation in other stands *(table 3)*. Percent cover of detritus increased marginally in two of three thinned-only stands. However, detritus was reduced in the thinned and burned stand. Percent cover of bare ground increased in all four stands, from zero in 1995 to 0.8–3.2 percent in 1998 *(table 3)*.

In thinned-only stands, fine fuels (1-hour and 10-hour timelag, both < 1 inch in diameter), important in fire spread, increased or were not different *(table 4)*. Heavy fuels (100-hour and 1,000-hour timelag, both > 1 inch in diameter), important in total heat release and fire persistence during rainy weather, also increased or did not change. In the thinned and burned stand, there was no change in either

Table 4. Dead woody fuels mass in 1995 (before treatments) and 1998 (after treatments) in four study areas in the San Juan National Forest.

Fuel type	A Thinned 1995	B Thinned 1995	C Thinned 1995	D Thinned 1995, burned 1996
1-hour timelag fuels (0–0.25 inch)				
1995	0.2 (0.009)	0.03 (0.01)	0.08 (0.02)	0.04 (0.02)
1998	0.16 (0.05)	0.21 (0.08)*	0.17 (0.04)*	0.1 (0.04)
10-hour timelag fuels (0.25–1 inch)				
1995	0.4 (0.5)	0.8 (0.3)	0.5 (0.2)	1.4 (0.4)
1998	1.4 (0.4)*	1.5 (0.6)	1.8 (0.3)*	1.1 (0.3)
100-hour timelag fuels (1–3 inches)				
1995	2.4 (0.65)	2.1 (0.5)	1.5 (0.5)	2.4 (0.7)
1998	4.7 (1.2)	8.1 (2.2)*	2.7 (0.7)	3.1 (0.8)
1,000-hour timelag sound fuels (> 3 inches)				
1995	1.2 (0.7)	5.1 (2.8)	3.2 (1.3)	3.9 (1.1)
1998	6.3 (2.4)*	12.0 (4.7)	4.6 (1.0)	2.7 (0.8)
1,000-hour timelag rotten fuels (> 3 inches)				
1995	0.35 (0.3)	3.7 (2.2)	1.4 (0.8)	1.1 (0.6)
1998	6.3 (3.6)	4.1 (1.7)	0.9 (0.5)	1.5 (0.9)
Total fuel mass (1,10,100, and 1,000 timelag fuels)				
1995	4.3 (1.0)*	11.7 (3.5)*	6.7 (1.7)	8.7 (1.8)
1998	19.0 (4.7)	26.1 (5.9)	10.1 (1.5)	8.4 (1.9)
Litter depth (cm)				
1995	1.8 (0.2)	3.7 (0.5)	2.8 (1.4)	3.3 (0.5)
1998	10.7 (1.8) *	18.4 (3.3) *	8.7 (2.0)	4.1 (0.9)
Duff depth (cm)				
1995	1.6 (0.2)	2.8 (0.7)	1.9 (0.5)	2.2 (0.5)
1998	0.2 (0.1)*	1.3 (0.3)	0.6 (0.2)	1.08 (0.3)

The difference between 1995 and 1998 is significant ($p < 0.05$). Results are reported as mean (standard error). N = 10 for all variables except duff depth and litter depth, for which n = 20. Fuel mass values are all tons per acre, where 1 ton = 2,000 pounds.

fine or heavy fuel loads.

Harvesting and burning results. In the five units for which we obtained meaningful financial information—the logger of one unit did not keep good records—a total of 31,163 trees were removed from 492.6 acres (an average of 63.3 trees per acre). Of the total trees removed, 13,468 trees (43.2 percent) were in the 5–7.9-inch dbh diameter class, 13,751 trees (44.1 percent) were in the 8–11.9-inch class, and 3,944 trees (12.7 percent) were in the 12+-inch class. A total of 6,075.8 tons of sawlogs, 7,254.71 tons of waferwood, and 1,047.15 tons of other products (posts and poles, pulpwood, and pine excelsior) were produced. This resulted in a total profit to the logger of $3,534 on gross revenues of $434,646, or less than 1 percent (0.81 percent) profit on gross revenue.

Profit came primarily from sawlog material. Smaller material—for wood products other than logs—typically resulted in financial losses. An experimental effort to develop pine excelsior as a product resulted in a loss. The logger sold pulpwood at breakeven on the landing to a trucker experimenting with back hauling to the pulp mill. The trucker's loss amounted to about $8 per ton. Posts and poles were essentially breakeven products. Waferwood logs resulted in consistent losses of $1.16 to $4.87 per ton.

Prescribed burning was estimated to cost $50 per acre in the unit that was effectively treated. About 50 percent of the cost had been collected as slash disposal money, with the balance covered by federal fuels reduction funds.

Discussion

Ecological effectiveness of the treatments. Thinning only and thinning plus burning were effective in reducing tree density and basal area (ecological objective 1) and increasing average stand diameters (objective 2). However, neither treatment effectively increased crown base height (objective 3).

Thinning only did not increase herbaceous plant cover or decrease cover of woody plants and detritus (objectives 4 and 5). It increased detritus, oak cover, and shrub cover in two stands and decreased herbaceous plant cover (forbs or graminoids or both) in all three stands. Reduction in herbaceous cover was probably not a decrease in herbaceous biomass because our sampling method, which measured relative percent cover, recorded only slash above herbs as detritus. Nevertheless, thinning only did not stimulate growth of suppressed herbaceous plants and did not lead to detectable changes in diversity or composition (objective 4). We conclude that aside from small increases in percent of bare ground, thinning treatments alone did not accomplish any changes in forest floor conditions specified in objectives 4 and 5, and in fact produced some undesirable changes (e.g., increased cover of woody vegetation and detritus).

In contrast, the thinned and burned stand showed a reduction in percent cover of detritus, a small increase in bare ground, and no change in percent cover of herbs or shrubs, but herbaceous richness increased substantially. The combination of thinning and burning thus accomplished some desirable changes included in objectives 4 and 5 and did not produce undesirable changes.

At least one component of fine woody fuels increased in thinned-only stands. Heavy fuels increased in two thinned stands. In contrast, there were no significant changes in any woody fuel components in the thinned and burned stand, probably because fire consumed some old detritus but logging added new material. Therefore, objective 6 was not accomplished in any stand.

It is apparent that thinning alone cannot restore the ecological structure and processes that formerly characterized ponderosa pine forests of the San Juan National Forest. In fact, thinning actually increased some problems (downed woody fuel loads, percent cover of detritus) and decreased herbaceous plant cover. However, we hypothesize that thinning alone may have reduced risk of crown fire by reducing total crown fuel mass and increasing space between crowns, even though it did not increase crown base height. Additions of slash, increased temperatures, and lower humidity in surface fuels as a result of opening the canopy may have increased potential spread rate and heat release of a surface fire. However, it is likely that the magnitude of these increases in potential surface fire severity is small.

Thinning plus burning was effective in stimulating suppressed herbaceous vegetation. This result is in contrast to experiences in Florida scrublands, where a single prescribed burn failed to produce any significant increase in herbaceous cover or diversity (Abrahamson and Abrahamson 1996). Thinning plus a single prescribed fire did not increase oak cover in our study, contrary to expectations (Harrington 1985). Oak cover increased in two thinned-only stands. Other shrub cover was not reduced in any stand.

Thinning plus burning did not effectively reduce downed woody fuels, but it is our judgment that risk of crown fire is lower than before treatment because the canopy is now less dense.

Our study confirms that ponderosa pine restoration must include both thinning and burning. Thinning alone was insufficient to accomplish the ecological goals we set. In fact, it could worsen or aggravate some problems. It is also apparent that a single prescribed fire is inadequate to reduce fuels that have not burned since fire was excluded from these stands and where new fuels are added by logging. However, a single fire can apparently stimulate renewed growth and diversity in suppressed herbaceous plants.

Financial considerations. Forest restoration projects can achieve ecological objectives and pay for themselves in southwest Colorado even with low-value material, but careful planning and execution are required. We want to emphasize that the ecological prescription always controlled the harvesting actions. In other words, we did not deliberately take sawtimber to subsidize products other than logs to make a unit profitable. Rather, we accepted for harvest whatever material was left after ecological objectives had been met.

Nevertheless, ecological decisions—to retain or remove either sawtimber or small-diameter trees—are also financial decisions that may determine sale viability. We found that to reach a breakeven point under market conditions existing during this study, harvested material had to approximate at least 40 percent sawtimber to 60 percent small material by weight. This would average six to eight sawtimber trees (12+ inches dbh) per acre with a volume of 12+ cubic feet per tree. The quality of 8–11.9-inch dbh material is very important. If it can be used as sawtimber, then the potential for profit increases. If it is poor quality and will become products other than lumber, the potential for loss increases. These findings can be used, along with an analysis of market conditions, to identify financially strong and financially weak units in this region.

Controlling harvesting costs is also critical. For example, loading and hauling costs constitute 50 percent of total harvesting costs for waferwood and are virtually fixed by product and haul distance. Given inconsistent timber supply, there is little incentive for loggers to invest in new equipment that would improve productivity. Therefore, cost containment in the other harvesting activities is needed to support profitability.

Market fluctuations are important. For example, after the study ended, waferwood prices rose from \$31–\$32 per ton to \$35–\$36 per ton. Such an increase would have created breakeven or better values for waferwood rather than losses. Sawtimber values would then increase profit margins instead of subsidizing small-tree removal. We estimate a potential profit of 7.3 percent on gross revenues under such market conditions. It is important to work toward profitability while achieving ecological objectives because breakeven projects do not spur investments to improve technology, create efficiencies, or develop value-added products.

In this area, about 50 percent of prescribed burning costs can be covered by slash disposal money collected from a sale. Considering the low profitability of these projects, it is unlikely that more money can be collected to cover all costs associated with prescribed burns. Managers should expect, therefore, that money for additional burns—necessary to achieve ecological objectives—will have to come from federal fuels reduction funds or other resource management funds.

If landscape-scale forest restoration has a future in southwest Colorado, two financial considerations are especially important. First, there must be a consistent supply of timber offered annually at prices that recognize the low quality of this wood and distances to processing plants. Second, sale design is critical to both ecological and financial objectives. Managers should carefully combine financially strong units with weak units, design sales to reduce logging and prescribed burning costs, and take advantage of markets when demand for small material is strong.

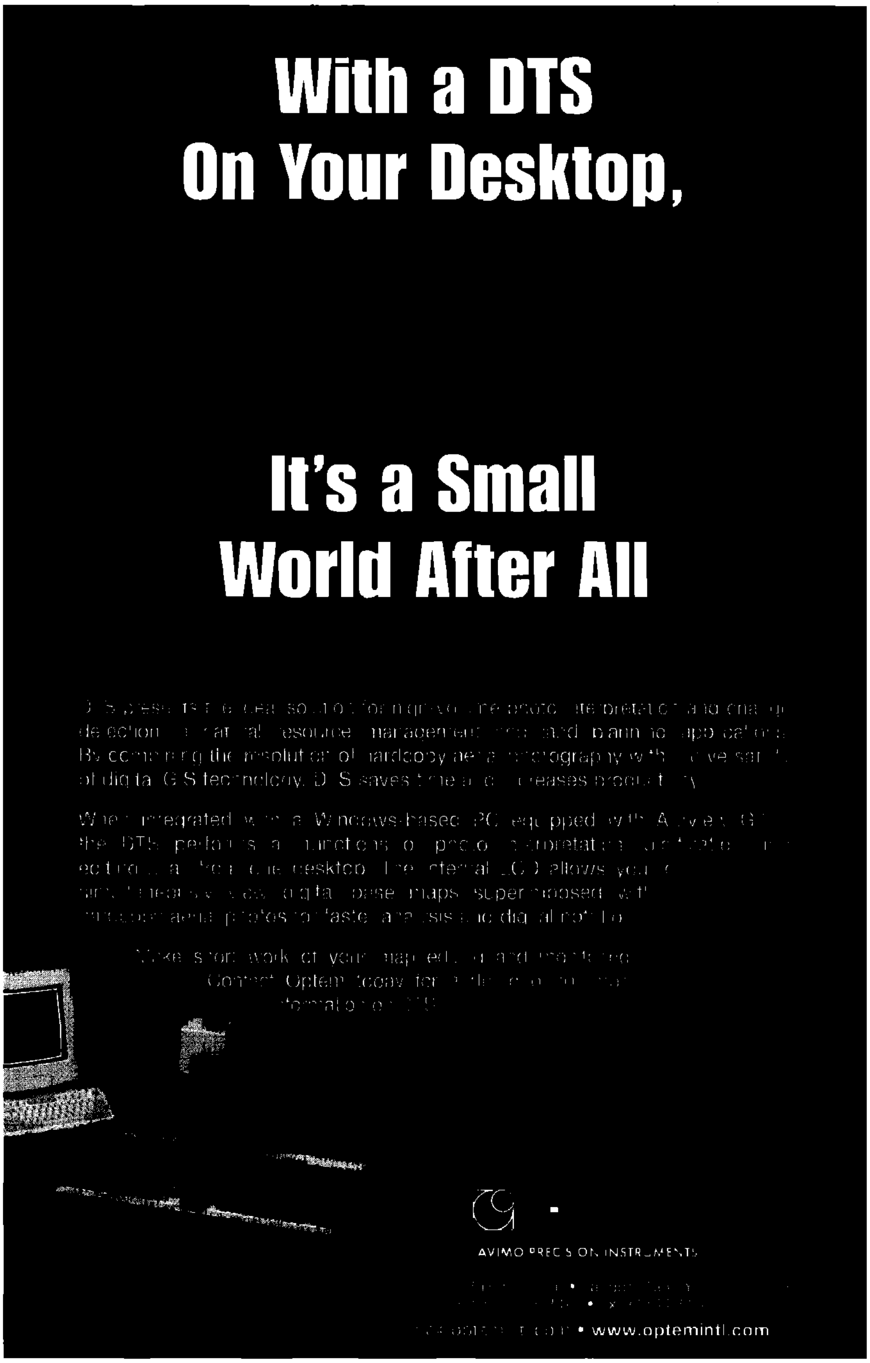
Conclusion

This project partially answered some of our questions. We discovered what products could be removed from forest restoration projects in the region, collected actual revenues and costs associated with the work, developed a means for estimating the financial potential of projects, confronted the reality that harvesting alone cannot achieve all ecological objectives, and found that single applications of prescribed fire will not completely treat these areas. We conclude that the general approach to ponderosa pine restoration, emphasizing thinning and burning, is ecologically and financially sound, but the details will make or break any individual project. Much remains to be done, however, and we will continue to develop expanded databases and monitor ecological results. Lastly, we received personal satisfaction from participating in this attempt to restore ecological balance to 549 acres of forest for the benefit and enjoyment of future generations.

Literature Cited

ABRAHAMSON, W.G., and C.R. ABRAHAMSON. 1996. Effects of fire on long-unburned Florida uplands. *Journal of Vegetation Science* 7:565–74.

BROWN, J.K. 1970. A method for inventorying downed



woody fuel. USDA Forest Service General Technical Report INT-16.

COOPER, C.F. 1960. Changes in vegetation, structure, and growth of southwestern pine forests since white settlement. *Ecological Monographs* 30:129–64.

COVINGTON, W.W., P.Z. FULÉ, M.M. MOORE, S.C. HART, T.E. KOLB, J.N. MAST, S.S. SACKETT, and M.R. WAGNER. 1997. Restoring ecosystem health in ponderosa pine forests of the Southwest. *Journal of Forestry* 95(4):23–29.

DAHMS, C.W., and B.W. GEILS, eds. 1997. An assessment of forest ecosystem health in the Southwest. General Technical Report RM-GTR-295. Fort Collins, CO: USDA Forest Service.

EDMINSTER, C.B., and W.K. OLSEN. 1995. Thinning as a tool in restoring and maintaining diverse structure in stands of southwestern ponderosa pine. General Technical Report RM-GTR-278. Fort Collins, CO: USDA Forest Service.

FULÉ, P.Z., W.W. COVINGTON, and M.M. MOORE. 1997. Determining reference conditions for ecosystem management of southwestern ponderosa pine forests. *Ecological Applications* 7:895–908.

HARDY, C.C., and S.F. ARNO, eds. 1996. The use of fire in forest restoration. General Technical Report INT-GTR-341. Fort Collins, CO: USDA Forest Service.

HARRINGTON, M.G. 1985. The effects of spring, summer, and fall burning on Gambel oak in a southwestern ponderosa pine stand. *Forest Science* 31:156–63.

LYNCH, D.L., L.W. STARNES, and C.S. JONES. 1997. Forest restoration in southwestern Colorado. In *Proceedings on forest operations for sustainable forests and healthy ecosystems*. Corvallis, OR: Council on Forest Engineering.

MIRTH, R., and D. LARSON. 1997. Potential for using small diameter ponderosa pine resources in Arizona (A feasibility study). Flagstaff: College of Engineering and Technology, Northern Arizona University.

MIYATA, E.S. 1980. Determining fixed and operating costs of logging equipment. General Technical Report NC-55. St. Paul, MN: USDA Forest Service.

MOIR, W.H., B. GEILS, M.A. BENOIT, and D. SCURLOCK 1997. Ecology of southwestern ponderosa pine forests. In *Songbird ecology in southwestern ponderosa pine forests: A literature review*, eds. W.M. Block and D.M Finch, 3–27. USDA Forest Service General Technical Report RM-GTR-292.

MUELLER-DOMBOIS, D., and H. ELLENBERG. 1974. *Aims and methods in vegetation ecology.* New York: John Wiley & Sons.

OMI, P.N. 1998. Concerning fire impacts on air quality and tradeoffs between wild and prescribed fires. Oversight hearing on regional haze. Subcommittee on Forests and Forest Health, US House of Representatives, July 16, 1998. Serial No. 105-100, p. 47.

RICHARD, T., and S. BURNS. 1998. Beyond "scoping" Citizens and San Juan National Forest managers, learning together. *Journal of Forestry* 96(4):39–43

ROMME, W.H., M.L. FLOYD, D. HANNA, and J.S. REDDERS. 1999a. Using historic disturbance regimes as a basis for mitigating impacts of anthropogenic fragmentation. In *Forest fragmentation in the southern Rocky Mountains*, eds. R.L. Knight, F. Smith, S Buskirk, W.H. Romme, and W.L. Baker. Boulder University Press of Colorado.

ROMME, W.H., H.D. GRISSINO-MAYER, M.L. FLOYD, and D. HANNA. 1999b. Landscape condition analysis for the South Central Highlands section: Ponderosa pine forests. Unpublished final report to the San Juan National Forest, Durango, CO.

SACKETT, S.S., S. HAASE, and M.G. HARRINGTON. 1993 Restoration of southwestern ponderosa pine ecosystems with fire. General Technical Report RM-247 Fort Collins, CO: USDA Forest Service.

SCOTT, J.H. 1998. Fuel reduction in residential and scenic forests: A comparison of three treatments in a western Montana ponderosa pine stand. USDA Forest Service Research Paper RMRS-RP-5

USDA FOREST SERVICE (USDA-FS). 1999. *Silvicultural examination and prescription handbook.* FSH 2409 26d.

Dennis L. Lynch (e-mail: denny@cnr colostate.edu) is forest products technologist, USDA Forest Service, Fort Collins, CO 80523, and professor emeritus, Department of Forest Sciences, Colorado State University; William H. Romme is professor, Biology Department, Fort Lewis College, Durango, Colorado; M Lisa Floyd is professor, Department of Environmental Studies, Prescott College, Prescott, Arizona. Funding: McIntire-Stennis Forestry Research Funds, Ford Foundation, San Juan National Forest, National Forest Foundation, and Colorado State University.