Forest Ecology and Management 114 (1999) 309–320

Understory structure by season following uneven-aged reproduction cutting: A comparison of selected measures 2 and 6 years after treatment

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Received 28 December 1997; received in revised form 28 May 1998; accepted 1 June 1998

Abstract

Rudis, V.A., Thill, R.E., Gramann, J.H., Picone, J., Kalidindi, N. and Tappe, P.A. 1999. Understory structure by season following uneven-aged reproduction cutting: a comparison of selected measures 2 and 6 years after treatment. For. Ecol. Manage. 1998. Deciding among cutting practices requires knowledge of forest structure, understory vegetation change, rates of recovery, and resource impacts. We used two field devices (a screenometer and a density board) and digital images of 35 mm photographs to compare measures and document the change in understory vegetation structure in forests following reproduction cutting disturbances. The study area, mostly 70-year old second-growth shortleaf pine–oak (*Pinus echinata–Quercus* spp.), had an average basal area of 26 m^2/ha. Treatments retained 13.8 m^2/ha in pine and three levels of hardwood basal area. The 21 m^2/ha treatment retained 33% hardwood basal area in a scattered condition. One 17 m^2/ha treatment retained 20% hardwoods in a clustered or grouped pattern, and another treatment retained 20% hardwoods scattered throughout. A fourth treatment retained no hardwood basal area. When compared with untreated (control) plots, vegetative screening increased on treated plots relative to untreated plots by degree of initial cutting disturbance. Both the screenometer and the density board readings distinguished between control and treated plots, but significant differences occurred by season, year, and height above ground. Digital information from scanned images yielded promising results by detecting significant differences in the amount of blue color intensity and the proportion of line objects. Color intensities were significantly different by season and year after treatment, that is, lowest in summer and highest in spring, and greater 2 years after treatment rather than 6 years after treatment. Results indicated that detection of disturbed conditions and recovery following disturbance varied with the scale and type of measurement. Each device estimated different structural dimensions. We concluded that assessment and modeling of understory structure, change, and recovery depended strongly on the cell size of the device used.

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0378-1127/99/$ – see front matter
PII: S0378-1127(98)00361-2

1. Introduction

In Jerry Franklin's opening address to the North American Forest Ecology Workshop, 24 June 1997, Raleigh, NC, he stated that there was very little known about forest vegetation structure, particularly understory vegetation, and its response following overstory management. To assess timber management impacts on other resource supplies, understory vegetation relationships must be quantified, yet much of the forestry literature focuses on overstory vegetation. The few that relate tree cover to understory vegetation address volume rather than structure (Conner and O'Halloran, 1986; Joyce and Mitchell, 1989) or infer causality from correlated relationships rather than tests of selected disturbances (e.g. Pearson and Sternitzke, 1974; Joyce and Baker, 1987; Rudis, 1990). Most understory evaluation relies on sampling at the time of maximum foliage development, that is, summer and on ocular estimates (Daubenmire, 1959; Pearson and Sternitzke, 1974; O'Brien and Van Hooser, 1983) that may not detect fine-scaled structural differences. Other measures use scaling devices with resource assessment objectives, for example, foliage density for determination of aesthetics (Rudis et al., 1988), range (Popham and Baker, 1987), recreational use (Nord and Magill, 1963; Rudis, 1985), and wildlife habitat (Nudds, 1977). Few procedures document change or compare devices over time, and none address ephemeral conditions or make remeasurements following partial cutting disturbances.

Our study describes vegetative screening following selected reproduction cutting practices. Vegetative screening included trees, shrubs, and herbaceous material. We estimated change relative to untreated (control) conditions. This study was a part of an effort to determine optimal measurement techniques to distinguish undisturbed from disturbed stands and to quantify a range of disturbances for inventory and monitoring assessments. This study was also a part of ongoing, interdisciplinary research investigation of aesthetics (Gramann and Rudis, 1994; Rudis et al., 1994; Kalidindi et al., 1996; Gritter, 1997), wildlife habitat, and selected reproductive cutting practices (Shelton and Murphy, 1991; Shelton and Baker, 1992).

To describe the status and change in vegetative screening, we used two field devices, a screenometer and a density board, and forest scene photographs. The screenometer (Rudis, 1985) provided human-scaled vegetative screening estimates for use in scenic beauty and visual quality assessments (Rudis et al., 1988; Ruddell et al., 1989). The density board (Nudds, 1977) provided vegetative screening estimates for wildlife habitat assessments. Scanned images of forest scenes provided digital information, for example, color, pattern, and object density, with the potential to index vegetation structure for an array of resource assessments.

2. Study area

Shelton and others installed plots in north-central Arkansas on the Ouachita National Forest's Winona Ranger District, near Lake Sylvia, on terrain with 10–20% slopes along an eastwest ridge ffrom 195 to 240 m above sea level (Shelton and Baker, 1992). Vegetation was second-growth shortleaf pine–oak (*Pinus echinata–Quercus spp.*) stands. *Quercus* dominants were *Q. alba*, with lesser amounts of *Q. stellata, Q. velutina, Q. marilandica*, and *Q. falcata*. They established four replicates of four hardwood treatments on 0.65 ha plots. Each replicate represented a unique topographic position (landform): three north facing positions (lower slope bench, middle slope, and upper slope) and another position facing south on an upper slope.

Initially with basal area 23–30 m^2/ha, Shelton and Baker (1992) assigned areas with treatments following a randomized complete block design. Their purpose was to assess uneven-aged cutting methods that selectively removed overstory hardwoods to regenerate pine and pine–hardwood mixtures. Each sample plot consisted of a 0.2 ha area within the center of each treated area (Shelton and Baker, 1992; Gramann and Rudis, 1994). We established four comparable control (*Cntrl*) plots that approximated the same landform after treatments had been implemented. In all there were 20 plots.

Treated areas designated by their basal area following treatment were 21 s – 21 m^2/ha: 33% basal area in hardwoods retained in a scattered distribution; 17c – 17 m^2/ha: 20% in hardwoods retained in a clustered distribution; 17 s – 17 m^2/ha: 20% in hardwoods retained in a scattered distribution; 14 – 14 m^2/ha: 0% hardwoods retained.

3. Methods

Treatments occurred in the 1988–1989 dormant season. Sampling began in the summer 1 year and 6 month following treatment and ended a year later. We repeated the sampling 4 years later. The 1990–1991 sampling was 'year 2' and 1994–1995 was 'year 6.' We sampled the proportion of view obscured by vegetative screening along a fixed azimuth and distance with two field scaling devices in summer and winter. We also photographed plots during summer, fall, winter, and spring.

3.1. Field measures

We used a 19×5 cm screenometer to gauge vegetative screening from a human-scaled perspective (Nord and Magill, 1963; Rudis, 1985). The sampled area was a view through a clear plastic viewpiece that was roughly a wedge beginning at eye level (1.7 m) outward along a 30° arc to a fixed distance from the viewer. Nord and Magill (1963) used 15 m as an optimal distance from the viewer. Other studies (Rudis, unpublished) noted that 15 m maximized interstand differences and minimized field costs. Modified to also address wildlife habitat interests, the screenometer used in this study distinguished vegetative screening in two zones, each with 9 sectors (Rudis et al., 1994). At a distance of 15 m from the viewer, a view through the lower zone of the screenometer was about 0.0–0.8 m above ground, and the upper zone was about 0.9–1.7 m above ground. Square dimensions of a sector cell was about 0.7 m^2 at 15 m from the viewer.

Screenometer means were from 12 views per plot for summer and winter for each survey year. Eight views began at the perimeter of the plot with azimuth pointed toward the center. Four views were from plot center with azimuth pointed toward the plot corners. Vegetative screening attributes included views dominated by screening from foliage and twigs (vegetation and stems <12.7 cm diameter at 1.4 m (dbh)) and tree boles (stems $\geq$12.7 cm dbh). For completeness, we also reported ANOVA in visual penetration (the absence of screening by tree boles, foliage and twigs, and non-vegetative screening (rocks, bare soil, and litter)). For this report, we focused only on the comparison of screenometer means in vegetative screening (foliage, twigs, and tree boles).

We used a 50×50 cm density board to gauge vegetative screening estimates by layer above the ground. The sampled area was roughly a view through a periscope to a distance of 15 m. Nudds (1977) indicated that 15 m maximized variation in foliage density estimates and minimized field costs. The target was a 16-cell black-and-white checkerboard. Means were from 12 samples for each season and survey year. Sampling occurred along marked transects systematically dispersed within each plot at four height zones 0.0–0.5, 0.75–1.25, 1.75–2.25, and 2.75–3.25 m above ground. Square dimensions of a density board cell was about 0.2 m^2 at 15 m from the viewer.

3.2. Image measures

Images from a camera with an f-1/2.8 lens were from permanently marked points. Eight views began at the perimeter of the 0.2 ha sample plot with azimuth pointed toward the center and photographed with focal length set at infinity. Plot views were in the foreground of each photograph. Ektachrome 35 mm color slide film, speed ISO 400, was push processed to ISO 800 to compensate for low light conditions. On average, picture-taking was over 3–4-day sampling period under clear-to-mostly-sunny skies. From the resulting photographs of acceptable technical quality, that is, no obvious distractions due to spectacular or aberrant lighting conditions, we randomly selected four images per plot for each season. These sampled images represented views of 20 plots, each from four different angles for each season. Each image used for year 6 was matched with the image having the same angle and season that we randomly selected in year 2.

A commercial vendor converted images from photographic slides to digital image files in photoCD (PCD) format, a proprietary format created by Kodak to archive high-quality photographs having a range of resolutions (Murray and Van Ryder, 1994). Kodak's 4× resolution, that is, 1536 by 1024 pixels, provided sufficient picture quality while minimizing memory storage requirements. Square dimensions of a pixel cell were roughly 8.3×10^{-8} m^2 at 15 m. Unlike the vegetative screening measurements, digitized attributes depicted in an image varied with distance from the viewer.

Due to proprietary copyright restrictions, we converted 4×-resolution PCD files into a publicly accessible portable pixel map (PPM) format (Murray and Van Ryder, 1994). From PPM-formatted files, we calculated the proportion of red, green, and blue color intensity values, and the proportion of short and long vertical line objects that made up each scene (Kalidindi et al., 1996). Intensity values ranged from 0 to 255 for each pixel, where 255, maximum color saturation. We subdivided intensity values by color into 100 'bins,' each 2.55 units wide, that is, 0.00–2.55, 2.56–5.10,. . ., 252.40–255.00. Mean intensity value by color was (sum of [midpoint of a bin unit]×[number of pixels in each bin])/(total number of pixels) where bin midpoints ranged from 1.275 to 253.7.

We used line objects as digital indices of forest structure. Conceptually, an image with a large proportion of long lines meant trees dominated the scene; a large proportion of short lines meant foliage and twigs dominated the scene. The procedure for line object detection was as follows: (1) convert color photographs to gray-scale, that is, black-and-white images, (2) use the Canny (1986) edge detection algorithm to convert these to line objects. The edge detection algorithm indicated an edge when the majority of three (or more) adjacent pixels reached a threshold difference, that is, gray luminance was dissimilar from adjacent pixels by 50% or more. To account for leaning trees, the algorithm was modified to accept five horizontally adjacent pixels. Technically, a line was a series of contiguous vertical edge pixels unbroken by 10 or more non-edge pixels.

A preliminary, ocular comparison of about 50 images (Kalidindi et al., 1996) suggested foliage and twigs corresponded to lines less than that of 25 pixel lengths, and tree stems corresponded to lines with 50 or more pixel lengths. Line length had the potential to be as much as 1024 pixels, that is, the maximum number of vertical pixels in an image. For each image, then, we had the total number of lines, and used the proportion of short (1–24 pixel length) lines to represent foliage and twigs, and the proportion of long (50–1024 pixel length) lines to represent tree stems.

3.3. Analysis

Analysis of variance in measurement device estimates used the general linear model (GLM) procedure (SAS, 1990). F-tests compared variance between fixed sources and the experimental design variance, and between the experimental design variance and the residual variance. We noted sources of significant ($p(F)<0.05$) differences. Estimated as proportions of the view, screenometer and density board readings were converted to arcsine square root for ANOVA. Vegetative screening means were transformed back to proportions for reporting purposes. Anticipating differences in vegetation phenology – and for images, ambient lighting and moisture conditions – we planned comparisons only among control and treated plot means by year and season. Planned comparisons between means employed t-tests ($p(t)<0.05$) and the least-squares means option (SAS, 1990).

4. Results

4.1. Field devices

Analysis of variance in screenometer readings revealed significant ($p(F)<0.05$) differences by year, season, zone, and treatment (Table 1). Among visual attributes, most significant differences were due to foliage and twig screening. Tree bole screening was not significantly different by zone.

Vegetative screening with the screenometer increased by year and was greatest in summer, but differed with respect to treatments by year, season, and height zone. In the summer of year 2, vegetative screening differences between treated versus control were apparent, regardless of zone. In the summer of year 6, differences by treatment were apparent. In the winter of year 2, differences by treatment were slight, but by year 6, treatments that removed hardwoods from part (17c) or all of the plot (14) had more screening than controls, regardless of height zone.

Analysis of variance among density board estimates showed significant differences by year, season, zone, and treatment (Table 2). Vegetative screening increased by year and was greatest in summer, but differed significantly by treatment. In summer, screening was significantly different from control plots above 1.7 m in year 2 and in the 2.75–3.25 m zone in year 6. Below 1.8 m in winter, significant differences were apparent only for the most extensive

Table 1
Degrees of freedom and mean square variance in visual attributes 0.0–1.7 m above ground by screenometer category, mixed pine–oak forests, Arkansas

Source	Degrees of freedom	Vegetative screening	Screenometer category		
			Tree boles	Foliage and twigs	Visual penetration
Landform	3	1999[a]	414[a]	2745	2042[b]
Zone	1	127,409[b]	0	146,904[b]	126,590[b]
Season	1	232,586[b]	531	277,042[b]	231,854[b]
Zone×season	1	2757[a]	544[a]	1739	2289[b]
Treatment	4	18,764[b]	5077[b]	31,183[b]	18,804[b]
Zone×treatment	4	5068[b]	19	5176[b]	4956[b]
Season×treatment	4	581	446[a]	1825[a]	610
Zone×season×treatment	4	566	12	497	462
Year	1	269,571[b]	3121[b]	246,203[b]	268,208[b]
Year×zone	1	2719[a]	1	5297[b]	2535[b]
Year×season	1	1433	4416[b]	3801[a]	1491[a]
Year×zone×season	1	5656[b]	46	7410[b]	4977[b]
Year×treatment	4	11,580[b]	628[b]	14,226[b]	11,499[b]
Year×zone×treatment	4	2505[b]	24	2861[b]	2799[b]
Year×season×treatment	4	4530[b]	145	4977[b]	4488[b]
Year×zone×treatment	4	1406	42	895	1583[b]
Experimental design	117	591[b]	137	725[b]	584[b]
Residual	1760	312	165	360	315
Total	1919				

Less than 0.5% of sample had non-vegetative screening. *F*-test significantly different: [a]$p<0.05$, [b]$p<0.01$.

Table 2
Degrees of freedom and mean square variance in vegetative screening with the density board, 0.0–3.5 m above ground, mixed pine–oak forests, Arkansas

Source	Degrees of freedom	Mean square variance
Landform	3	2774[a]
Zone	3	353,898[b]
Season	1	527,455[b]
Zone×season	3	35,523[b]
Treatment	4	12,185[b]
Zone×treatment	12	5493[b]
Season×treatment	4	4124[b]
Zone×season×treatment	12	606
Year	1	152,883[b]
Year×zone	3	4914[b]
Year×season	1	84,936[b]
Year×zone×season	3	11,238[b]
Year×treatment	4	8516[b]
Year×zone×treatment	12	1115
Year×season×treatment	4	1205
Experimental design	237	904[b]
Residual	3519	304
Total	3838	

F-test significantly different: [a]$p<0.05$. [b]$p<0.01$.

treatment in year 2, but apparent for most treatments (17s, 17c, and 14) by year 6.

In year 2, both the density board and screenometer failed to distinguish screening differences between the two 17 m^2/ha treatments: clustered (17c) and scattered (17 s) (Tables 3 and 4). Estimates below 1.8 m with the screenometer detected more screening in the 17c than 17 s treatment in the winter of year 6 (Table 3). Estimates in the 2.75–3.25 m zone with the density board detected less screening in the 17c than 17s treatment in the summer of year 6 (Table 4).

Comparison of means from the density board's lower zones (0.0–0.5 and 0.75–1.25 m) and the screenometer (0.0–0.8 and 0.9–1.7 m) indicated that both devices detected significant screening differences between plots with complete hardwood removal (14) and control plots in the summer of years 2 and 6 (Tables 3 and 4). Complete hardwood removal yielded 10–20% greater vegetative screening than control plots with either device. In winter, neither device detected significant screening differences between treated and control plots by year 2, but both did so by year 6.

Table 3
Average screenometer estimates of vegetative screening by height zone above ground, season, year, and treatment, mixed pine–oak forests, Arkansas

Height zone	Season	Year	Control	Treatment (residual basal area, m^2/ha)			
				21s	17c	17s	14
0.0–0.8 m			Percent				
	Summer	2	48.7 c	53.6 c	65.9 b	63.4 b	79.6 a
	Summer	6	73.2 d	79.4 cd	88.5 abc	84.7 b	94.1 a
	Winter	2	28.6 a	33.8 a	33.7 a	36.2 a	33.7 a
	Winter	6	44.6 cd	44.5 cd	63.4 b	52.7 c	88.7 a
0.9–1.7 m							
	Summer	2	48.8 a	32.7 b	29.6 b	29.9 b	34.0 b
	Summer	6	68.7 b	49.3 c	73.7 b	69.5 b	87.2 a
	Winter	2	25.9 ab	20.9 bc	15.7 bc	17.0 c	15.1 bc
	Winter	6	36.8 c	26.8 c	46.1 b	29.1 c	72.0 a
0.0–0.8 and 0.9–1.7 m							
	Summer	2	48.8 bc	43.1 c	47.7 bc	46.6 c	56.8 a
	Summer	6	71.0 c	64.4 d	81.1 b	77.1 b	90.7 a
	Winter	2	27.3 a	27.4 a	24.7 a	26.6 a	24.4 a
	Winter	6	40.7 c	35.6 c	54.8 b	40.9 c	80.3 a

s=scattered, c=clustered residual hardwoods. Averages by row with the same letter are not significantly different, $p(t)>0.05$.

A comparable ANOVA between the two devices used the two lower zones of the density board with the screenometer. Both analyses revealed significant differences by year, season, zone, and treatment (Table 5). Both the screenometer and density board estimates provided similar patterns in summer and winter when estimated by year and zone, but means were not the same (Fig. 1). Each device measured a different aspect of the scene, and each yielded different conclusions about the effect of selected treatments on vegetative screening.

Fig. 1 suggested a potential advantage of using a screenometer over a density board. Nearly equal screening in both upper and lower zones were characteristic of plots with no obvious recent disturbances. Rudis et al. (1994) also noted nearly equal summer screening with the screenometer by height zone above ground for randomly selected and not recently disturbed stands in another portion of the Ouachita National Forest. From our examination of year 6 results, vegetative screening between upper and lower zone also was indistinguishable for the most disturbed plots by year 6 following treatment. Screenometer zone differences might serve as indices of recent disturbance less than 6 years old. Caution is advised in extending this relationship to other forest types, however, as this study was restricted to pine–oak forest stands and only a few experimental treatments.

4.2. Image analysis

Analysis of variance showed significant differences by season and year for red, green, blue, and the proportion of short and long lines (Table 6). Color intensity, often associated with overall lighting conditions, was lowest in summer and highest in spring, and lower in year 6 than in year 2. Color intensity showed limited association with the ability to distinguish among treatments (Fig. 2).

However, differences by treatment were significant for the blue color intensity and the proportion of long lines (Table 7). Differences by treatment were not significantly different in year 6. Significant blue color intensity differences occurred between plots with reduced basal area. The mean proportion of long lines was greater in year 2 for both the clustered treatment (17c) and the treatment with all hardwoods removed (14). Differences in the pattern of relationships among treatments were similar in year 2 regardless of season (Fig. 3).

Table 4
Average density board estimates of vegetative screening by height zone above ground, season, year, and treatment, mixed pine–oak forests, Arkansas

Height zone	Season	Year	Control	Treatment (residual basal area, m^2/ha)			
				21s	17c	17s	14
0.0–0.5 m			Percent				
	Summer	2	65.2 b	65.3 b	85.6 a	87.2 a	93.2 a
	Summer	6	82.7 b	78.2 b	93.9 a	92.9 a	98.4 a
	Winter	2	30.6 c	32.0 bc	33.7 bc	34.8 bc	39.5 ab
	Winter	6	22.5 c	33.4 b	54.8 a	55.6 a	61.4 a
0.75–1.25 m							
	Summer	2	36.7 a	20.6 b	26.0 b	24.0 b	30.3 ab
	Summer	6	52.3 b	43.6 c	68.1 b	62.1 b	81.9 a
	Winter	2	17.7 ab	12.9 ab	9.5 b	14.5 ab	13.9 ab
	Winter	6	7.9 c	9.9 c	29.1 ab	23.3 b	28.1 ab
Lower zones 0.0–0.5 and 0.75–1.25 m							
	Summer	2	50.9 cd	43.0 e	55.8 bc	55.6 bd	61.7 a
	Summer	6	67.5 c	60.9 d	81.0 b	77.1 b	90.2 a
	Winter	2	24.1 a	22.5 a	21.6 a	24.7 a	26.7 a
	Winter	6	15.2 d	21.6 c	41.9 ab	39.5 b	44.7 ab
1.75–2.25 m							
	Summer	2	23.0 a	9.5 b	7.3 b	5.1 b	3.3 b
	Summer	6	44.3 b	21.9 c	46.0 b	41.8 b	55.5 a
	Winter	2	13.3 a	8.2 ab	5.3 b	10.8 ab	7.7 ab
	Winter	6	5.8 a	5.4 a	10.9 a	12.8 a	11.5 a
2.75–3.25 m							
	Summer	2	28.3 a	11.4 b	10.2 b	10.9 b	4.2 b
	Summer	6	50.1 a	23.7 cd	27.6 d	38.2 b	33.6 bc
	Winter	2	13.2 a	7.3 a	6.7 a	13.3 a	10.3 a
	Winter	6	4.7 b	6.6 ab	4.6 b	14.0 ab	4.5 b
Upper zones 1.75–2.25 and 2.75–3.25 m							
	Summer	3	25.6 a	10.4 bc	8.8 bc	8.0 bc	3.8 c
	Summer	6	47.2 a	22.8 c	36.8 b	40.0 b	44.5 ab
	Winter	2	13.3 ab	7.8 ab	6.0 b	12.0 ab	9.0 ab
	Winter	6	5.3 b	6.0 b	7.8 b	13.4 a	8.0 ab

s=scattered, c=clustered residual hardwoods. Averages by row with the same letter are not significantly different, $p(t)>0.05$.

5. Discussion and conclusions

Both the density board and screenometer characterized understory vegetation screening and detected structural differences caused by disturbances. The more hardwoods were removed, the more likely vegetative screening was greater by year 6 – relative to control plots. Both devices narrowly distinguished differences among treatments in the winter of year 2. Six years following disturbance, vegetative screening with field devices noted significant differences compared to control plots, a finding echoed by coincident studies of scenic beauty (Gritter, 1997). The finer-scaled data from digital images suggested no differences by year 6.

Advantages of the screenometer were its ability to distinguish screening differences (a) below 1.8 m between clustered and scattered hardwood treatments in the winter of year 6, and (b) among selected treatments in the summer of year 2. Advantages of the density board were its ability to characterize screening differences (a) below 1.8 m between control and treated plots in year 6, and (b) above 1.7 m. Conclusions about treatment differences varied by device and neither device was a substitute for the other.

Table 5
Degrees of freedom and mean square variance in visual attributes 0.0–1.7 m above ground by sampling device, mixed pine–oak forests, Arkansas

Source	Degrees of freedom	Mean square variance by device	
		Vegetative screening	
		Density board	Screenometer
Landform	3	912	1999[a]
Zone	1	384,050[b]	127,409[b]
Season	1	508,677[b]	232,586[b]
Zone × season	1	26,693[b]	2757[a]
Treatment	4	19,289[b]	18,764[b]
Zone × treatment	4	2718	5068[b]
Season × treatment	4	1375	581
Zone × season × treatment	4	300	566
Year	1	91,521[b]	269,571[b]
Year × zone	1	8516[b]	2719[a]
Year × season	1	17,263[b]	1433
Year × zone × season	1	21,299[b]	5656[b]
Year × treatment	4	5962[b]	11,580[b]
Year × zone × treatment	4	1516	2505[b]
Year × season × treatment	4	1442	4530[b]
Year × zone × season × treatment	4	2382	1406
Experimental design	117	1193[b]	591[b]
Residual	1760	297	312
Total	1919		

F-test significantly different: [a]$p<0.05$, [b]$p<0.01$.

Table 6
Degrees of freedom and mean square variance in image measures, mixed pine–oak forests, Arkansas

Source	Degrees of freedom	Mean square variance				
		Color			Line density	
		Red	Green	Blue	Short	Long
Landform	3	1190[a]	443	119	153[b]	16[b]
Season	3	26,017[b]	27,931[b]	24,387[b]	1117[b]	133[b]
Treatment	4	614	741	706[a]	59	25[b]
Season × treatment	12	438	305	151	38	3
Year	1	34,618[b]	10,172[b]	39,974[b]	47	36[b]
Year × season	3	1436[a]	330	2972[b]	114[a]	8
Year × treatment	4	412	230	182	71	17[b]
Year × season × treatment	12	281	297	201	15	2
Experimental design	117	366[b]	369[b]	244[b]	31[b]	4[b]
Residual	479	134	117	61	21	2
Total	638					

F-test significantly different: [a]$p<0.05$, [b]$p<0.01$.

Digital analysis of forest scenes is in its infancy as a means to characterize forest structure and detect change following disturbance. More sophisticated approaches than described here, for example, conversion of the three primary color intensities of red, green, and blue into other hues, may be more

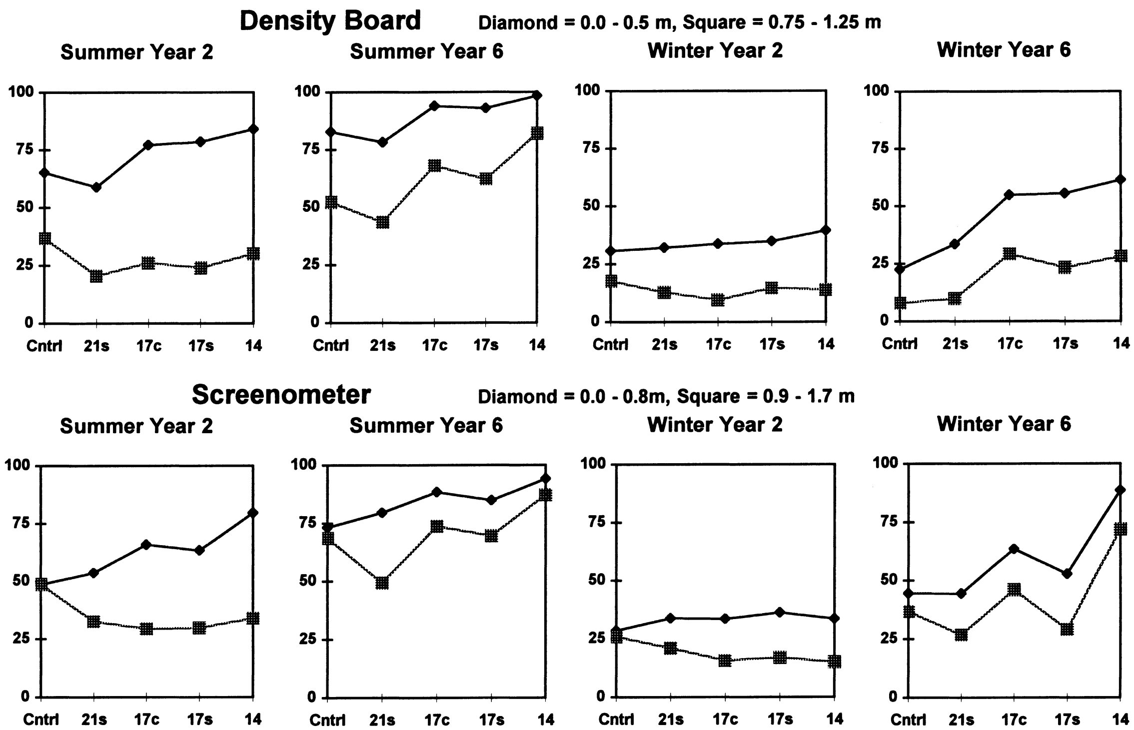

Fig. 1. Percent vegetative screening and treatment by scaling device, height zone above ground, season, and year following disturbance, mixed pine–oak forests, Arkansas.

effective in distinguishing color differences that relate to forest management-relevant treatments. From a different digitization process that examined only year 2 images, Yhang (1994) found that yellow was greatest for disturbed plots that retained hardwoods.

Color intensity and line objects used in this study were part of a pilot investigation of digital image indices. Images incorporated foreground views of treatments, but also captured uncontrolled differences, for example, ambient lighting, moisture, phenology, and background views. However, estimates of blue color intensity – presumably sky – were successful in distinguishing recently and extensively disturbed plots. The proportion of long lines distinguished recently disturbed plots from those with clustered and complete hardwood removal in year 2 and season was not a limitation. Image indices failed to distinguish among some treatments, however, and their ability to detect a significant difference was essentially lost by year 6.

Both field devices noted that the 17 m^2/ha clustered (versus scattered) hardwood removal yielded vegetative screening as intermediate between complete hardwood removal and control plots below 1.8 m. Image analysis noted that the clustered treatment yielded more long lines in year 2 than the scattered treatment. Screenometer-based vegetative screening averaged more screening, and 2.75–3.25 m layer with the density board averaged less screening, than the scattered treatment in the winter of year 6. A synthesis of structural differences relative to other resource values was incomplete as of this date, but preliminary findings suggested the clustered treatment yielded more pine regeneration (Shelton and Murphy, 1997) and higher ratings of scenic beauty (Gramann and Rudis, 1994; Gritter, 1997), compared with the scattered treatment.

Further analysis of structure with this extensive database should enable detection of additional image differences. In the winter of year 6, the 17 m^2/ha clustered treatment likely produced a larger disconti-

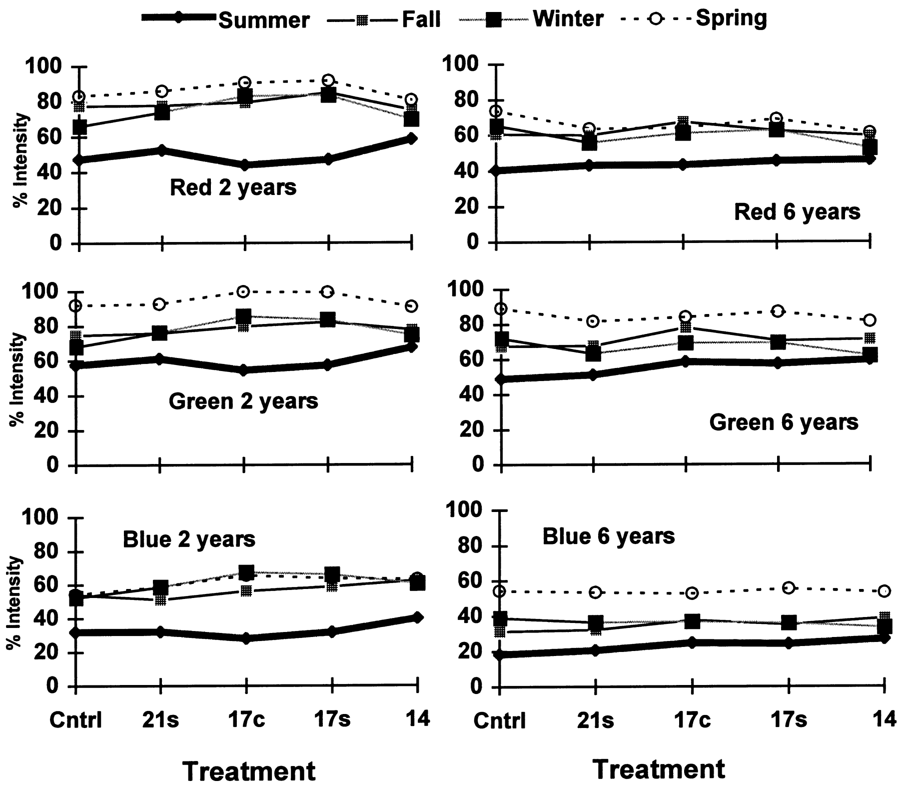

Fig. 2. Color intensity value and treatment by color, season, and year following disturbance, mixed pine–oak forests, Arkansas.

Table 7
Average image measures of color and line length by treatment and year, mixed pine–oak forests, Arkansas

Normalized color	Year	Control	Treatment (residual basal area, m^2/ha)			
			21s	17c	17s	14
Red	2	68.5	72.5	74.2	76.8	70.8
	6	60.1	55.6	58.9	59.8	54.8
Green	2	73.1	76.5	79.9	80.7	77.7
	6	69.5	66.0	72.6	71.2	68.7
Blue	2	48.2 b	50.1 b	54.3 a	55.1 a	56.5 a
	6	35.7 a	35.6 a	37.9 a	37.7 a	38.1 a
Short lines 1–24 pixels	2	71.5	71.1	69.1	70.7	68.6
	6	71.2	70.5	70.0	70.3	71.6
Long lines >=50 pixels	2	2.7 c	3.1 bc	4.2 a	3.5 bc	4.6 a
	6	2.9 a	3.1 a	3.5 a	3.2 a	3.0 a

s=scattered, c=clustered residual hardwoods. $p(F)>0.05$ for rows with no letter. Average by row with the same letter are not significantly different, $p(t)>0.05$.

nuity of objects, that is, seedling pines, than the 17 m^2/ha scattered treatment. Such a discontinuity may have been more readily reflected in vegetative screening averages from the screenometer than the density board because the screenometer had larger cell dimensions. The smaller length-and-width cell size of image mea-

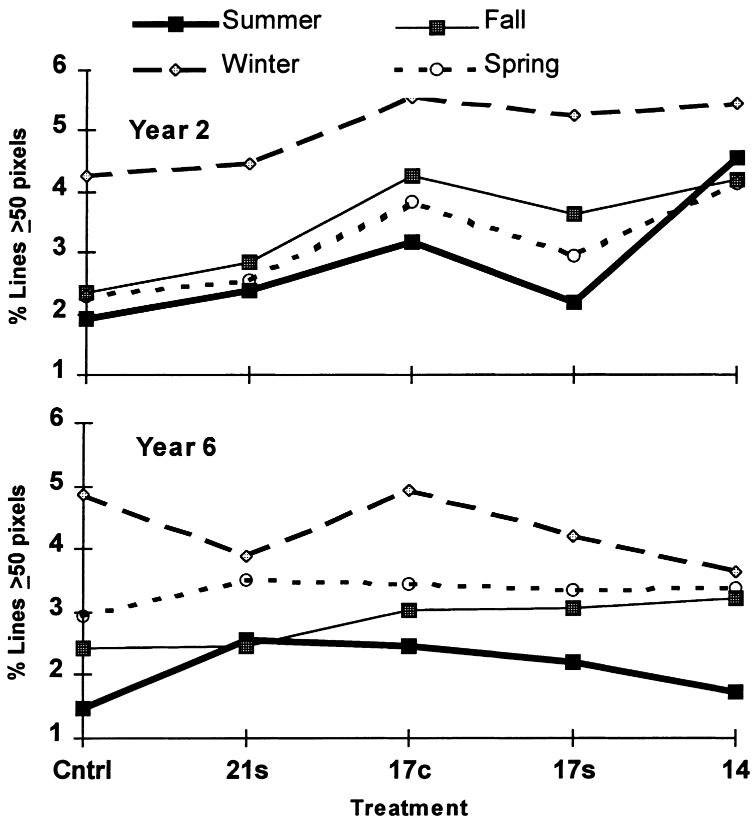

Fig. 3. Proportion of long (≥50 pixel) lines and treatment by season and year following disturbance, mixed pine–oak forests, Arkansas.

sures may have reduced chances for detecting large-sized discontinuities. One approach for image analysis is to modify cell size dimensions to detect larger objects or structures. Another is to model structural features with a wider array of objects than reported here, fit the model to a set of images with known or field-determined structural differences, and then test the model to determine how well it predicted structural differences with other image datasets.

We concluded that season and year following disturbance significantly affected detection of altered structure, that all devices had limitations, and that dimensions of measurement affected results. We suggest models developed and conclusions drawn about forest structure, change in structure, recovery following disturbance, and effects on associated resources will depend heavily on the cell size dimensions of the measurement device.

Acknowledgements

We thank Mike Shelton and Ouachita National Forest personnel for establishing the study site and providing silvicultural details. Mike Shelton also contributed constructive suggestions to an earlier draft. Financial support was provided by the authors' cooperating institutions and the Ecosystems Management Research Program administered by Jim Baker.

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