LANDSCAPE CHARACTERIZATION OF FOUR WATERSHEDS UNDER DIFFERENT FOREST MANAGEMENT SCENARIOS IN THE OUACHITA MOUNTAINS OF ARKANSAS

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Abstract—Recent changes in philosophy concerning forest management have focused attention on managing ecosystems at scales beyond the stand level. Properties of forested landscapes, such as patch size and shape, edge density, and interspersion have direct influences on flora and fauna. However, there is little information regarding spatial patterns and processes across large-scale landscapes. We quantified landscape characteristics for four watersheds in the Ouachita Mountains that represent different ownerships and management objectives. The watersheds included (1) an intensively managed landscape predominantly under forest industry ownership, (2) a landscape that has historically been managed under USDA Forest Service standards and guidelines, (3) a landscape composed of a mixture of forest industry and USDA Forest Service lands, and (4) a landscape that has received minimal management and now is largely mature forest. Using multi-temporal Landsat Thematic Mapper satellite imagery in conjunction with field-collected data, landcover classifications were developed. This information was incorporated into a geographic information system and landscape metrics were computed. Metrics such as mean patch size and density, edge density, and interspersion varied by watershed. Differences in watersheds at both the watershed and landcover class levels suggest that the dynamics of some ecological interactions are likely to also be different in each watershed. However, the interpretation of specific watershed characteristics is dependant on the particular phenomena being investigated. The quantified differences in landscape characteristics of each watershed provide important information that can aid in making management decisions in our ecologically and sociologically complex forests.

INTRODUCTION

Recent philosophical changes in natural resource management have focused attention on managing ecosystems at scales beyond the stand level. This emphasis has led to a heightened conceptual and theoretical understanding of landscape patterns and functions. Landscape patterns are influenced by the composition and development of vegetation following disturbances, as well as the juxtaposition of these disturbances (Oliver 1981). However, there is a lack of information regarding these patterns across large-scale landscapes (Soulé and Kohm 1989, Jeffers 1988).

Properties of forested landscapes, such as patch size, edge density, and degree of fragmentation have a direct influence on flora and fauna (Hagan and others 1997, Rolstad 1991, MacArthur and Wilson 1967). Thus, increased knowledge of these interactions is needed to make informed management decisions regarding ecologically and sociologically complex landscapes. However, before studies can address questions involving landscape functions, landscape structure must be quantified. Landscape-scale research currently being conducted in the Ouachita Mountains of Arkansas is addressing a myriad of questions concerning landscape interactions of flora and fauna (Fox and others, in press; Guldin, in press; Tappe and others, in press). This paper compares structural landscape characteristics for four watersheds in which these interactions are being studied.

METHODS

Study Areas

We quantified landscape characteristics of four watersheds included in the Ouachita Mountain Ecosystem Management Research Project described by Guldin (in press). The watersheds were located in the Ouachita Mountains in Garland and Saline counties north of Hot Springs, Arkansas. Each represented different ownerships and management objectives as follows:

1. Little Glazypeau (LG)—2,275 ha predominantly under Weyerhaeuser Company ownership and intensively managed for wood products
2. North Alum Creek (NAC)—3,961 ha with approximately equal mixtures of Weyerhaeuser Company and USDA Forest Service ownership. Weyerhaeuser Company lands were intensively managed for wood products and USDA Forest Service lands were managed under multiple-use standards and guidelines
3. Bread Creek (BC)—1,535 ha predominantly under USDA Forest Service ownership and historically managed under multiple-use standards and guidelines
4. South Alum Creek (SAC)—1,499 ha predominantly under USDA Forest Service ownership and historically received minimal management.

Inherent in the differing proportions of ownership and management objectives of each watershed was an implicit

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continuum of intensity of forest management activity. The highest intensity of forest management activity occurred on LG, followed in descending order by NAC, BC, and SAC.

Remote Sensing and Landcover Classification

A Geographic Information System (GIS) was utilized to help characterize the study areas. Delineated forest stand boundaries on each watershed represented discrete administrative management units and not necessarily unique landcover types. Thus, spectral landcover classes initially were identified based on Landsat Thematic Mapper (TM) data (30-m resolution, bands 1–7) using scenes from February, April, and July, 1995. The 21 bands (7 from each time period) were clustered using an isodata clustering algorithm (unsupervised classification) with a maximum-likelihood classification to create 255 spectral classes (Richards and Jia 1999).

Transects with 50-m radius plots spaced approximately 200 m apart were established in each watershed. Vegetation data were collected during May–August 1995 on a total of 524 plots: 124 plots in LG, 235 plots in NAC, 75 plots in BC, and 90 plots in SAC. Similar to a classification scheme used by Hagan and others (1997), each plot was placed into 1 of 5 forest composition classes, 1 of 3 canopy cover classes, and 1 of 3 tree height classes (table 1). This information was then used to categorize the unsupervised 255 spectral classes into 12 landcover classes (table 2). This process used both the spectral information obtained from the unsupervised classification and ancillary GIS layers obtained from the Natural State Digital Database (http://sal.uamont.edu/sal/nsdd/) at the Spatial Analysis Laboratory, University of Arkansas - Monticello. Landcover information was incorporated into a GIS, and watershed-level and landcover class-level indices were computed using Fragstats v.2.0 (McGarigal and Marks 1994). These indices included percent of a landcover class comprising a watershed, patch density (PD), (number per 100 ha), largest patch index (LPI), (percent of a watershed comprised by the largest patch), mean patch size (MPS) and coefficient

Table 1—Plot characteristics used to categorize an unsupervised spectral classification into landcover classes

Characteristic	Category	Value range
Forest composition (%)	Pine	≥ 75 pine
	Pine/hardwood	≥ 60 pine < 75
	Mixed	≥ 40 pine or hardwood < 60
	Hardwood/pine	≥ 60 hardwood < 75
	Hardwood	≥ 75 hardwood
Canopy cover (%)	Low	0–33
	Medium	34–75
	High	76–100
Tree height (m)	Low	0–7
	Medium	> 7–13
	High	> 13

Table 2—Landcover classes used to characterize four watersheds under different forest management scenarios in the Ouachita Mountains of Arkansas

	Forest characteristics		
Landcover type	Composition	Canopy cover	Height
Young, open pine	Pine	Low	Low
Thin, open pine	Pine	Medium	Medium
Dense canopy pine	Pine	High	Medium
Sparse pine	Pine	Low	Medium
Pine/hardwood	Pine/hardwood	Medium	High
Mixed forest	Mixed	High	High
Hardwood/pine	Hardwood/pine	High	Medium
Hardwood	Hardwood	High	Medium
Sparse hardwood	Hardwood	Low	Medium
Grass	Grass	NA	NA
Rock/road	Rock/road	NA	NA
Water	Water	NA	NA

NA = not applicable.

of variation (CV), edge density (ED), (m per ha), mean shape index (MSI), (mean perimeter-to-area ratio), mean nearest neighbor distance (MNN), (mean distance from a patch to the nearest neighboring patch of the same type) and CV, and McGarigal and Mark's (1994) interspersion/juxtaposition index (IJI), (extent to which patch types are interspersed).

RESULTS

Area Metrics

The four watersheds differed in their landcover composition (table 3). Landcover classes composed of ≥ 75 percent pine comprised 50.3 percent of LG, 28.7 percent of NAC, 15.8 percent of BC, and 1.2 percent of SAC. Proportions of pine/hardwood were approximately 1.5 times greater in SAC than in BC, 2 times greater than in NAC, and 4 times greater than in LG. Proportions of mixed forest were approximately 1.1 times greater in SAC than in BC, 1.5 times greater than in NAC, and 3 times greater than in LG. Within other landcover classes, proportions varied between watersheds by < 8.5 percent (table 3).

Overall, LPI was highest for SAC, followed in decreasing order by BC, NAC, and LG (table 4). The LPI varied < 4.7 percent within all landcover classes with the exceptions of dense canopy pine and pine/hardwood classes (table 4). The largest patch of dense canopy pine comprised a larger proportion of LG than it did in any other watershed (approximately 6 times greater than NAC, 9 times greater than BC, and 36 times greater than SAC). The largest patch of pine/hardwood comprised a larger proportion of SAC than it did in any other watershed (approximately 1.5 times greater than BC, 8 times greater than NAC, and 12 times greater than LG). Young/open pine in BC had notably higher LPI than in other watersheds.

Patch Metrics

At the watershed-level, LG had approximately 19 patches per 100 ha more than NAC, 24 patches per 100 ha more

Table 3—Percent and area of 12 landcover classes within 4 watersheds under different forest management scenarios in the Ouachita Mountains of Arkansas

Landcover class	Little Glazypeau	North Alum Creek	Bread Creek	South Alum Creek
	percent and area (*ha*)			
Young/open pine	11.2 (255.4)	7.4 (292.3)	11.4 (174.6)	0.5 (7.2)
Thin/open pine	11.0 (249.3)	13.2 (524.3)	2.7 (41.5)	0.4 (6.4)
Dense canopy pine	24.4 (554.2)	7.9 (314.0)	1.7 (26.9)	0.3 (4.8)
Sparse pine	3.7 (84.6)	0.2 (7.4)	0.0 (0.0)	0.0 (0.0)
Pine/hardwood	11.3 (257.5)	24.5 (970.8)	35.6 (546.8)	46.6 (698.2)
Mixed forest	9.0 (204.6)	19.0 (751.1)	25.8 (395.2)	27.8 (416.5)
Hardwood/pine	12.5 (284.1)	16.2 (639.5)	10.7 (164.3)	7.89 (118.3)
Hardwood	9.5 (216.7)	8.8 (347.7)	10.1 (154.8)	14.1 (212.3)
Sparse hardwood	6.4 (145.0)	2.8 (111.7)	2.0 (30.5)	0.5 (7.6)
Grass	0.6 (14.4)	< 0.1 (1.6)	0.0 (0.0)	1.79 (26.7)
Rock/pavement	0.4 (8.4)	0.0 (0.0)	< 0.1 (0.1)	0.1 (1.2)
Water	< 0.1 (0.4)	< 0.01 (0.2)	0.0 (0.0)	0.0 (0.0)
Total	100.0 (2,274.8)	100.0 (3,960.6)	100.0 (15,34.7)	100.0 (1,499.2)

Table 4—Patch density and largest patch index for four watersheds under different forest management scenarios in the Ouachita Mountains of Arkansas

Landcover class	Patch density and largest patch index			
	Little Glazypeau	North Alum Creek	Bread Creek	South Alum Creek
	- - - - - - - - - - - - - - *no./100 ha and* (*percent*) - - - - - - - - - - - - - -			
Young/open pine	11.08 (2.52)	6.54 (1.01)	1.43 (7.18)	0.47 (0.43)
Thin/open pine	14.29 (1.33)	6.34 (4.39)	6.45 (0.48)	0.27 (0.25)
Dense canopy pine	4.26 (7.16)	4.67 (1.17)	1.82 (0.76)	0.67 (0.20)
Sparse pine	1.63 (1.83)	0.03 (0.19)	— —	— —
Pine/hardwood	9.32 (3.31)	9.85 (4.91)	8.21 (22.02)	9.07 (39.34)
Mixed forest	14.29 (0.63)	15.07 (1.03)	14.6 (3.96)	17.01 (2.53)
Hardwood/pine	16.66 (1.07)	17.24 (1.31)	19.68 (0.49)	16.61 (0.56)
Hardwood	9.63 (1.47)	7.47 (3.54)	11.01 (4.94)	13.07 (5.59)
Sparse hardwood	10.38 (1.50)	7.75 (0.17)	7.04 (0.17)	2.8 (0.04)
Grass	1.71 (0.13)	0.3 (0.01)	— —	0.47 (1.70)
Rock/pavement	0.84 (0.12)	— —	0.07 (0.01)	0.07 (0.08)
Water	0.09 (0.01)	0.03 (< 0.01)	— —	— —
All classes	94.18 (7.16)	75.28 (4.91)	70.31 (22.02)	60.49 (39.34)

than BC, and 33 patches per 100 ha more than BC (table 4). PD for young per open pine was highest in LG, followed in descending order by NAC, BC, and SAC. PD was also highest in LG and lowest in SAC for thin/open pine, with NAC and BC having similar PD. Within other landcover classes, PD varied among watersheds by < 8 patches per 100 ha.

Overall, SAC had a MPS 0.23 ha larger than BC, 0.32 ha larger than NAC, and 0.59 ha larger than LG (table 5). MPS followed a similar pattern for the pine/hardwood class. MPS for dense canopy pine followed a reverse pattern, with LG having the largest MPS, followed in decreasing order by NAC, BC, and SAC. Young/open pine in BC had notably higher MPS than in other watersheds.

Overall, relative variability of MPS was greatest for SAC, with MPS CV approximately 1.5 times greater than that for BC, and 2 times greater than that for NAC and LG (table 5). MPS CV followed a similar pattern for the mixed forest class. MPS CV for young/open and dense canopy pine in LG, followed a reverse pattern, with LG having the largest MPS CV, followed in decreasing order by NAC, BC, and SAC.

Edge and Shape Metrics

At the watershed-level, LG had approximately 11 m per ha more edge than NAC, 19 m per ha more edge than BC, and 34 m per ha more edge than SAC (table 6). ED followed a similar pattern for all landcover classes composed of ≥ 75 percent pine, with LG having, on average, approximately 19 m per ha more edge than NAC, 41 m per ha more edge than BC, and 56 m per ha more edge than SAC. Pine/hardwood and mixed forest classes followed a reverse pattern. ED of the pine/hardwood class in SAC was approximately 21 m per ha more than in BC, 50 m per ha more than in SAC, and 77 m per ha more than in LG. ED of the mixed pine forest class in SAC was approximately 4 m per ha more than in BC, 35 m per ha more than in SAC, and 80 m per ha more than in LG.

Table 5—Mean patch size and coefficient of variation for four watersheds under different forest management scenarios in the Ouachita Mountains of Arkansas

Landcover class	Mean patch size and coefficient of variation			
	Little Glazypeau	North Alum Creek	Bread Creek	South Alum Creek
	ha and percent			
Young/open pine	1.01 (525.43)	1.13 (381.24)	7.94 (292.19)	1.03 (216.41)
Thin/open pine	0.77 (371.89)	2.09 (585.17)	0.42 (207.58)	1.6 (89.82)
Dense canopy pine	5.71 (389.99)	1.70 (285.52)	0.96 (240.71)	0.49 (180.53)
Sparse pine	2.29 (314.38)	7.38 (0.00)	— —	— —
Pine/hardwood	1.21 (462.00)	2.49 (523.14)	4.34 (701.76)	5.13 (980.97)
Mixed forest	0.63 (215.20)	1.26 (263.06)	1.76 (298.34)	1.63 (270.75)
Hardwood/pine	0.75 (304.52)	0.94 (339.43)	0.54 (194.65)	0.47 (213.04)
Hardwood	0.99 (341.98)	1.17 (721.50)	0.92 (641.86)	1.08 (562.32)
Sparse hardwood	0.61 (491.84)	0.36 (189.24)	0.28 (151.95)	0.18 (77.37)
Grass	0.37 (147.58)	0.14 (79.35)	— —	3.83 (231.59)
Rock/pavement	0.44 (145.21)	— —	0.09 (0.00)	1.17 (0.00)
Water	0.18 (< 0.01)	0.18 (0.00)	— —	— —
All classes	1.06 (561.47)	1.33 (531.84)	1.42 (811.96)	1.65 (1,205.51)

Overall, MSI was similar for all watersheds (table 6). No consistent trends in MSI were observed at the landcover class level.

Nearest Neighbor and Interspersion Metrics

Overall, MNN was similar for all watersheds (table 7). Likewise, no consistent trends in MNN were observed at the landcover class level. However, SAC had a notably higher MNN than other watersheds for both the thin/open (averaging approximately 675 m more) and dense canopy pine (averaging approximately 227 m more) classes.

Overall, relative variability of MNN was greatest for LG, followed by SAC (table 7). MNN CV for LG and SAC were approximately 1.5 to 2 times greater than those for NAC and BC. No consistent trends in MNN CV were observed at the landcover class level. However, SAC had a notably higher MNN CV for both the hardwood pine and hardwood classes, each averaging approximately 1.5 times greater than in other watersheds. The MNN CV for the young/open pine class in BC also had a notable CV, averaging 1.5 times greater than in other watersheds.

At the watershed level, the interspersion of available patch types is about 75 percent of the maximum possible equitable distribution in LG, whereas NAC and BC are at about 65 percent and SAC is below 50 percent (table 8). The IJI is < 50 percent for the pine/hardwood and mixed forest classes in SAC, and > 80 percent for the young/open pine class in BC, the thin/open pine class in SAC, and the hardwood/pine class in LG.

CONCLUSIONS

Several landscape characteristics suggest a gradient of spatial heterogeneity represented by differing proportions of ownership, management objectives, and intensity of forest management activity. At the watershed level, PD, ED, and IJI all were highest for LG, followed in descending order by

Table 6—Edge density and mean shape index for four watersheds under different forest management scenarios in the Ouachita Mountains of Arkansas

Vegetation class	Edge density and mean shape index			
	Little Glazypeau	North Alum Creek	Bread Creek	South Alum Creek
	m/ha and (*percent*)			
Young/open pine	47.83 (1.28)	30.25 (1.26)	24.65 (1.51)	1.88 (1.19)
Thin/open pine	68.52 (1.36)	48.22 (1.45)	20.00 (1.23)	2.12 (1.55)
Dense canopy pine	59.94 (1.48)	31.66 (1.38)	8.02 (1.26)	1.80 (1.22)
Sparse pine	10.99 (1.32)	0.53 (1.93)	— —	— —
Pine/hardwood	54.44 (1.35)	81.21 (1.38)	110.37 (1.47)	131.28 (1.38)
Mixed forest	62.06 (1.34)	106.50 (1.49)	137.10 (1.58)	141.57 (1.50)
Hardwood/pine	80.07 (1.38)	94.89 (1.38)	76.59 (1.32)	55.24 (1.24)
Hardwood	42.87 (1.30)	31.09 (1.22)	37.59 (1.22)	59.34 (1.27)
Sparse hardwood	36.51 (1.23)	22.49 (1.22)	17.20 (1.16)	5.32 (1.11)
Grass	5.03 (1.24)	0.48 (1.07)	— —	3.44 (1.26)
Rock/pavement	2.31 (1.16)	— —	0.08 (1.00)	0.50 (1.66)
Water	0.16 (1.06)	0.05 (1.06)	— —	— —
All classes	235.36 (1.33)	223.68 (1.36)	215.80 (1.35)	201.25 (1.34)

NAC, BC, and SAC. Conversely, LPI and MPS were largest for SAC, followed in descending order by BC, NAC, and LG. These observed landscape characteristics suggest that the watersheds can be ranked in order of decreasing spatial heterogeneity as LG > NAC > BC > SAC.

For most landcover classes composed of ≥ 75 percent pine, larger, more dense patches were well interspersed in LG than in the other watersheds. Additionally, they comprised 50 percent of the area of LG. In contrast, larger pine/hardwood patches occurred in SAC, with the largest accounting for 39 percent of the watershed area. Mixed forest classes comprised > 25 percent of BC and SAC, where they also had their largest MPS and ED. However, interspersion was poor (< 50 percent) in SAC. Similar proportions and patch sizes of the hardwood/pine class occurred in all watersheds. The hardwood class comprised < 15 percent of all watersheds, but proportionally occurred most in SAC.

LG was characterized by a higher proportion of pine landcover classes, more and smaller patches, more edge, and higher interspersion than the other watersheds. SAC was characterized by a higher proportion of pine-hardwood and mixed forest landcover classes, fewer and larger patches, less edge, and lower interspersion than the other watersheds. The NAC and BC watersheds were intermediate in these measures and varied relative to the intensity of forest management. The differences in watersheds at both the watershed and class levels indicate that the dynamics of some ecological interactions are likely to also be different in each watershed. However, the interpretation of specific watershed characteristics is dependant on the particular phenomena being investigated.

Table 7—Mean nearest neighbor and coefficient of variation for four watersheds under different forest management scenarios in the Ouachita Mountains of Arkansas

Landcover class	Mean nearest neighbor and coefficient of variation			
	Little Glazypeau	North Alum Creek	Bread Creek	South Alum Creek
	m and (*percent*)			
Young/open pine	54.19 (77.49)	56.43 (76.22)	145.66 (113.87)	124.28 (72.33)
Thin/open pine	51.58 (73.43)	43.72 (63.62)	53.03 (61.16)	724.75 (89.97)
Dense canopy pine	54.34 (130.96)	53.99 (89.29)	98.94 (206.01)	305.45 (158.71)
Sparse pine	56.99 (106.15)	0.00 (0.00)	— —	— —
Pine/hardwood	62.14 (91.00)	46.75 (73.38)	41.16 (48.07)	41.20 (60.35)
Mixed forest	51.39 (87.56)	42.16 (76.77)	37.80 (71.43)	37.89 (47.87)
Hardwood/pine	45.66 (75.57)	46.04 (73.80)	50.52 (64.14)	65.84 (102.00)
Hardwood	67.59 (103.92)	83.72 (92.58)	72.62 (88.68)	60.57 (154.24)
Sparse hardwood	71.85 (84.18)	77.57 (96.95)	90.37 (72.56)	79.70 (109.69)
Grass	163.86 (122.83)	332.91 (111.72)	— —	206.77 (81.24)
Rock/pavement	190.53 (109.78)	— —	0.00 (0.00)	0.00 (0.00)
Water	4,185.62 (< 0.01)	0.00 (0.00)	— —	— —
All classes	63.10 (223.63)	54.70 (104.24)	57.70 (106.67)	60.90 (175.79)

Table 8—Interspersion/juxtaposition index for four watersheds under different forest management scenarios in the Ouachita Mountains of Arkansas

Landcover class	Interspersion/juxtaposition index			
	Little Glazypeau	North Alum Creek	Bread Creek	South Alum Creek
	percent			
Young/open pine	71.80	67.50	80.85	77.06
Thin/open pine	62.04	65.42	68.14	84.10
Dense canopy pine	56.45	52.76	64.39	68.12
Sparse pine	53.41	26.94	—	—
Pine/hardwood	67.77	57.36	49.46	44.32
Mixed forest	69.55	58.40	58.15	46.51
Hardwood/pine	81.85	66.61	62.39	60.09
Hardwood	74.01	61.88	73.42	50.95
Sparse hardwood	78.19	66.88	73.08	60.65
Grass	78.71	53.57	—	66.22
Rock/pavement	72.72	—	33.33	53.40
Water	44.92	19.57	—	—
All classes	75.26	66.53	64.37	48.78

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