IUFRO Landscape Ecology Conference, Sept. 26-29, 2006 - Locorotondo, Bari (ITALY)

Effects of the Sustainable Forestry Initiative on landscape pattern and processes

João C. Azevedo[1], X. Ben Wu [2], Michael G. Messina [3], Jimmy R. Williams[4] & Richard F. Fisher[5]

[1] Departamento Florestal e Centro de Investigação de Montanha (CIMO), Escola Superior Agrária, Instituto Politécnico de Bragança, Campus de Santa Apolónia - Apartado 172, 5301-854 Bragança, PORTUGAL – Phone: 351-273-303-200; Fax: 351-273-325-405; E-mail: jazevedo@ipb.pt; Web-page: http://www.esa.ipb.pt/~jazevedo/
[2] Department of Rangeland Ecology & Management, Texas A&M University, College Station, TX 77843-2126, USA – Phone: 1-979-845-7334; E-mail: xbw@tamu.edu
[3] Department of Forest Science, Texas A&M University, College Station, TX 77843-2135, USA – Phone: 1-979-845-2547; E-mail: m-messina@tamu.edu
[4] Texas A&M University, Blackland Agricultural Research Center, 808 E. Blackland Road, Temple, TX 76502, USA – Phone: 1-254-774-6124; E-mail: williams@brc.tamus.edu
[5] Department of Forest Science, Texas A&M University, College Station, TX 77843-2135, USA – Phone: 1-979-845-5033; E-mail: DickFisher@templeinland.com

Abstract

We used simulation modeling to study the changes in landscape pattern and function resulting from the application of the Sustainable Forestry Initiative (SFI) program in East Texas, USA. Changes in landscape structure were examined by comparing landscapes with different management histories. The effects of pattern on processes were analyzed considering vertebrate habitat quality and configuration and hydrological processes such as water and sediment yield. Landscapes managed according to the SFI program presented increased general fragmentation. The application of measures under SFI increased habitat diversity in the landscape as well as Habitat Suitability Index (HSI) values for most of the species. Habitat for species requiring large patches of mature forest was almost absent. Landscapes managed under the SFI program showed lower sediment yield at the watershed level than those under the non-SFI program due to higher channel erosion related to the absence of buffer strips in the non-SFI scenario.

Keywords: Sustainable forestry, landscape modeling, Habitat Suitability Index, Sustainable Forestry Initiative (SFI), East Texas.

1. Introduction

The North American forest products industry is currently following the standards of the Sustainable Forestry Initiative (SFI) launched by the American Forest and Paper Association in 1994. The SFI program includes measures that are relevant at the landscape level, namely limitation of harvest unit size, establishment of wildlife corridors, establishment of buffer zones along streams, and application of adjacency rules. Such measures might change existing pattern and function of forested landscapes but have not been sufficiently analyzed.

The objective of this work was to analyze the effects of the application of the SFI program in forested landscapes in East Texas both in terms of landscape pattern and function. Specifically we addressed the following questions: (i) did the SFI program change the pattern of intensively managed forested landscapes in East Texas? (ii) did changes in structure, if any, affect ecological processes at the landscape level in this region?

2. Methodology

2.1 Landscape structure

We compared three landscapes in East Texas with different management histories to analyze the effect of SFI on landscape pattern. One landscape (SFI) has been managed according to the SFI program since the beginning of the 1990's. Another landscape (IM) has been managed by the traditional intensive management in the area. A third landscape (EM) has not been managed for forest products. These landscapes are relatively similar in forest cover and in size, ranging from 4400 ha to 5100 ha. Loblolly pine (*Pinus taeda* L.) is the most important species in all three landscapes.

GIS coverages of the areas were developed for stand forest type (pine, hardwood and mixed) and age class (0-10 yrs, 10-40 yrs, >40 yrs). The landscapes were sampled based on small watersheds and landscape metrics quantified for each sample. The number of sample watersheds was 11 in SFI (mean=163.5ha), 14 in IM (mean=162.7ha) and 10 in EM (mean=149.1ha). Landscape metrics were calculated using FRAGSTATS (McGarigal and Marks 1995). The landscapes were compared based on univariate and multivariate statistical methods, namely analysis of variance (ANOVA and MANOVA).

2.2 Effects of landscape structure on function

We developed a methodology to model dynamics in landscape structure and biophysical processes at the landscape and stand levels (Azevedo et al. 2005a). HARVEST 6.0 (Gustafson and Rasmussen 2002) was used to simulate landscape structure dynamics and management. Forest stand processes were modeled with Compute P-Lob (Baldwin and Feduccia 1987) for planted even-aged loblolly pine stands; SouthPro (Schulte et al. 1998) for uneven-aged loblolly pine, hardwood, and pine-hardwood mixed stands; and the Forest Vegetation Simulator (FVS) (Donnelly et al. 2001) for hardwood stands managed by the clearcutting system. Habitat Suitability Index (HSI) models (Schamberger et al. 1982) were used to model vertebrate habitats, and the APEX model (Williams et al. 2000) to evaluate the effects of management on water yield and soil loss. The models were run independently from each other but in an integrated fashion, coordinated by a GIS.

Simulation studies were conducted for two scenarios: SFI - representing SFI measures relevant at the landscape level (Streamside Management Zones (SMZ) ≥30 m wide along streams, max. harvest unit size of 49 ha (pine) and 12ha (hardwoods), green-up interval of 3yr; and Non-SFI - representing a reference scenario where all these rules were absent. At the stand level management types considered were: 1) pine-clearcutting, 2) hardwood-clearcutting, 3) pine-selection, 4) hardwood-selection, and 5) pine-hardwood-selection. We ran HARVEST for 400 years for each scenario and five replicate runs.

2.2.1 Habitats

This study was conducted in a 5773-ha area located in Angelina County, Texas, USA, managed for industrial forestry. All vertebrate species potentially occurring in the study area (83 herps, 132 birds, 51 mammals) were grouped into guilds based on breeding and foraging requirements, according to a set of 42 binary variables. Cluster analysis was applied using the Ward's minimum variance clustering method with distances based upon Jaccard's coefficient of similarity (Lapointe and Legendre 1994). We selected eight guilds that met the requirements of this study. One species was selected to represent the general habitat requirements of each of the guilds and their habitat modeled with HSI models. Model variables were calculated mainly from data provided by the growth and yield models. We used the following models: American beaver (Allen 1983), American woodcock (Cade 1985), Pine warbler (Schroeder 1982a), Downy woodpecker (Schroeder 1982b), Barred owl (Allen 1987b), Wild turkey (Schroeder 1985), Fox squirrel (Allen 1982), and Gray squirrel (Allen 1987a). Five suitability classes were defined based upon HSI values: ”unsuitable” (HSI=0), ”low” ($0<HSI\leq0.25$), ”medium” ($0.25<HSI\leq0.5$), ”high” ($0.5<HSI\leq0.75$), and “very high” ($0.75<HSI\leq1$). At the landscape level, maps of suitability classes were generated and analyzed in terms of landscape pattern using landscape metrics. See Azevedo et al. (2006) for details on the methods.

2.2.2 Hydrological Processes

This study was conducted in an 1190-ha watershed, a part of the study area for the HSI model study. Soils are mainly Alfisols of the Diboll and Alazan series and Ultisols of the Rosenwall series. Slopes are usually gentle, 2% on average, 7% maximum. Subareas were created with elevation and hydrographic data and further subdivided to reduce variability in soil and cover. Forest stands were managed by individual operation schedules according to their composition and age. Plantation and harvesting year for each pine stand were defined according to the sequence of clearcuttings in HARVEST. Subareas files were built using soil and operation schedule file codes, area, channel length and slope, upland slope, reach length and slope, when applicable, as inputs. The model was run 30 years prior to the period of interest to allow stabilization of the system and stand growth. Weather data were generated by APEX based on parameters for Lufkin, Texas. The methods are presented in detail in Azevedo et al. (2005b).

3. Result and Discussion

3.1 Landscape Structure

MANOVA results revealed differences among landscapes with different management histories. Simultaneous confidence intervals (Bonferroni approach; 0.05 level) allowed the identification of factors that contributed most to the observed differences in the multivariate populations (Table 1). SFI and IM differed due to edges (extension or density), shape and core area. These factors seem also to have a great deal of interaction. The presence of buffer strips along streams with elongated shapes and curly edges were responsible for the differences observed. A large number of effects seem to be important in distinguishing between SFI and EM landscapes (Table 1) whereas SFI and EM share basically diversity and evenness.

The results suggest that the application of the SFI program causes fragmentation of the landscapes. Although fragmentation is often related to a particular organism or process, it can also be understood in a more general sense as the division of habitat into smaller pieces. The sustainable landscape (SFI) presents many more and smaller patches than the non-sustainable (IM) or reference (EM) landscapes. SFI presents the highest density of edges, a fact reflected by most of the variables that consider this attribute in their calculation. Fragmentation in primeval forests as a result of management or land use change is well known. The results of this work indicate that fragmentation results also from the application of sustainable forestry practices in intensively managed landscapes. This kind of process has been described previously (Hagan and

Boone 1997; Cissel et al. 1998) and riparian buffers seem to play a major role in the creation of fragmentation in these cases.

3.2 Habitats

At the landscape level HSI values for pine warbler were higher in the Non-SFI scenario than in the SFI scenario (Table 2). Habitat suitability was slightly higher in the SFI landscape for American beaver and American woodcock and much higher for wild turkey and fox and gray squirrel. Given the similarity among runs, differences between management scenarios were statistically significant ($P<0.001$; repeated measures ANOVA with management as a fixed effect and runs as random subjects). Landscape HSI values for barred owl and downy woodpecker were practically negligible in both scenarios.

In terms of spatial configuration the simulations in the SFI scenario resulted in two major habitat patterns (Azevedo et al. 2005a). Highly suitable habitat for American woodcock, fox and gray squirrel, and wild turkey was abundant in the SFI landscape, distributed by few patches spread over the landscape, with an extremely large edge length and few, small core areas, corresponding mostly to the SMZs network established in the SFI scenario. In the Non-SFI scenario the habitat for the same species was restricted to few areas. Another pattern in the SFI scenario was a fragmentation pattern observed for pine warbler. Comparatively to Non-SFI, it was comprised of more and smaller patches that were less aggregated, had more edges, less core area, but lower isolation. For barred owl and downy woodpecker quality habitat was extremely scarce for any of the management scenarios. In the case of American beaver, landscape metrics were very difficult to interpret and sometimes meaningless given the way HSI was calculated.

3.3 Hydrological Processes

SFI and Non-SFI management produced the same amount of surface runoff and water yield at the subarea and watershed levels (Table 3). In the SFI scenario runoff and sediment loss were lower in the buffer strips comprised of hardwoods than in the upper areas comprised of pine under the clearcutting system with slope being the major factor explaining these differences. Average sediment yield at the subarea level was approximately the same in both scenarios. The Non-SFI scenario showed, however, considerably more sediment yield at the watershed level than the SFI scenario (Table 3). The difference in watershed sediment yield resulted from the routing processes, mainly channel degradation. Sediment deposition occurred as well but it was similar between landscape scenarios whereas channel degradation was common in both scenarios but higher in the Non-SFI scenario. Channel degradation was responsible for the differences in watershed sediment yield between the two landscapes. Channel degradation occurred to a greater extent in the Non-SFI scenario that presented fewer buffer zones and also less fragmentation than the SFI landscape.

4. Conclusion

The results of this study indicated that recent changes in forest management caused landscape pattern to change. The SFI program, given the spatial constraints in terms of harvest size limits, buffer zones and green-up interval it imposes, caused the landscape to be generally more fragmented. Among the SFI measures tested in this study, the establishment of SMZs seems to play a major role in the structure of modified landscapes. Processes simulated indicated that changes in structure affect changes in function. There was an increase in habitat diversity in the SFI scenario at the landscape level. There was also a general increase in habitat suitability for the species considered. New habitat patterns emerged in the landscape, namely a more fragmented habitat for one species and habitats in a network configuration for five of the remaining species. Habitat for species requiring large patches of mature forest was almost absent in any landscape scenario. Landscapes managed under the SFI program showed lower sediment yield at the watershed level than those under the non-SFI program due to higher channel erosion related to the absence of buffer strips in the non-SFI scenario.

References

Allen, A.W., 1982. *Habitat suitability index models: fox squirrel*. USDI Fish Wild. Serv. FWS/OBS 82/10.18.

Allen, A.W., 1983. *Habitat suitability index models: beaver*. USDI Fish Wildl. Serv. FWS/OBS-82/10.30. Revised.

Allen, A.W., 1987a. *Habitat suitability index models: gray squirrel*. U.S. Fish Wildl. Serv. Biol. Rep. 82(10.135). Revised.

Allen, A.W., 1987b. *Habitat suitability index models: barred owl*. USDI Fish Wild. Serv. Biol. Rep. 82(10.143).

Azevedo, J.C., Williams, J.R., Messina, M.G., and Fisher, R.F., 2005b. Impacts of the Sustainable Forestry Initiative Landscape Level Measures on Hydrological Processes". *Water Resources Management*, 19: 95-110.

Azevedo, J.C., Wu, X.B., Messina, M.G., and Fisher, R.F., 2005a. Assessment of Sustainability in Intensively Managed Forested Landscapes: A Case Study in East Texas. *Forest Science*, 51(4): 321-333.

Azevedo, J.C., Wu, X.B., Messina, M.G., and Fisher, R.F., 2006. Effects of the Sustainable Forestry Initiative on the Quality, Abundance, and Configuration of Wildlife Habitats. *Journal of Sustainable Forestry*, 23 (1): 37-65. Pre-publication.

Baldwin, V.C. and Feduccia, D.P., 1987. *Loblolly pine growth and yield prediction for managed west gulf plantations*. USDA For. Serv. Res. Pap. SO-236, 27 p.

Cade, B.S., 1985. *Habitat suitability index models: American woodcock (wintering)*. U.S. Fish Wildl. Serv. Biol. Rep. 82(10.105).

Cissel, J.H., Swanson, F.J., Grant, G.E., D. H. Olson, S.V. Gregory, S. L. Garman, L.R. Ashkenas, M.G. Hunter, J.A. Kertis, J.H. Mayo, M.D. McSwain, S.G. Swetland, K.A. Swindle, and D.O. Wallin. 1998. *A landscape plan based on historical fire regimes for a managed forest ecosystem: the Augusta Creek study*. USDA For. Serv. Gen. Tech. Rep. PNW-GTR-422, 82 p.

Donnelly, D., Lilly, B. and Smith, E., 2001. *The Southern Variant of the Forest Vegetation Simulator*. Forest Management Service Center. Fort Collins, Colorado, 61 p.

Gustafson, E.J. and Rasmussen, L.V., 2002. Assessing the spatial implications of interactions among strategic forest management options using a Windows-based harvest simulator. *Comput. Electron. Agric.*, 33(3): 179-196.

Hagan, J.M. and Boone, R.B., 1997. *Harvest rate, harvest configuration, and forest fragmentation: a simulation of the 1989 Maine Forest Practices Act*. Report MODCF-97001, Manomet, Division of Conservation Forestry, Manomet, MA, 17 p.

Lapointe, F.J. Legendre, P., 1994. A classification of pure malt scotch whiskies. *Appl. Statist.* 43(1): 237-257.

McGarigal, K. and Marks, B.J., 1995. *FRAGSTATS: spatial pattern analysis program for quantifying landscape structure*.USDA For. Serv. Gen. Tech. Rep. PNW-GTR-351,122 p.

Schamberger, M., Farmer, A.H. and Terrell, J.W., 1982. *Habitat suitability index models: introducion*. USDI Fish and Wildl. Serv. FWS/OBS-82/10, 2 p.

Schroeder, R.L., 1982a. *Habitat suitability index models: pine warbler*. USDI Fish Wildl. Serv. FWS/OBS-82/10.28.

Schroeder, R.L., 1982b. *Habitat suitability index models: downy woodpecker*. USDI Fish Wildl. Serv. FWS/OBS-82/10.38.

Schroeder, R.L., 1985. *Habitat suitability index models: eastern wild turkey*. USDI Fish Wildl. Serv. Biol. Rep. 82(10.106).

Schulte, B.J., Buongiorno, J., Lin, C.R. and Skog, K., 1998. *SouthPro: A computer program for managing uneven-aged loblolly pine stands*. USDA For. Serv. Gen. Tech. Rep. FPL-112. 47 p.

Williams, J.R., Arnold, J.G. and Srinivasan, R., 2000. *The APEX model*. BRC Report No. 00-06. Texas Agr. Exp. Station, Blackland Research Center, Temple, TX. 121 p.

Table 1. Lower and upper limits of Bonferroni simultaneous confidence intervals for comparisons among the three landscapes based upon landscape metrics calculated in small watersheds. Underlined values indicate significant differences for the 95% confidence level.

	SFI- IM		SFI-EM		IM -EM	
Variable	lower	upper	lower	upper	lower	upper
Largest Patch Index (%)	-46.99	14.80	-67.58	-0.57	-49.72	13.77
Number of patches	-4.45	12.28	2.10	20.25	-1.34	15.85
Patch Density (#/100 ha)	-2.79	6.14	1.38	11.07	-0.04	9.14
Mean Patch Size (ha)	-9.22	4.46	-22.01	-7.17	-19.24	-5.18
Total Edge (m)	422.5	13949.9	6718.7	21388.3	-83.2	13817.8
Edge Density (m/ha)	21.0	71.0	57.7	111.9	13.1	64.5
Landscape Shape Index	0.06	2.77	0.46	3.39	-0.88	1.90
Mean Shape Index	-0.12	0.54	-0.04	0.67	-0.23	0.45
Area-Weighted Mean Shape Index	-0.04	2.06	-0.12	2.16	-1.06	1.10
Double Log Fractal Dimension	-0.01	0.29	0.03	0.36	-0.10	0.20
Mean Patch Fractal Dimension	-0.02	0.04	-0.01	0.05	-0.02	0.04
Area-Weighted M. Fractal Dimension	0.00	0.11	0.00	0.12	-0.05	0.06
Total Core Area (ha)	-61.45	1.01	-73.38	-5.65	-41.39	22.80
Number Core Areas	-2.66	6.03	-1.37	8.06	-2.81	6.12
Core Area Density (#/100 ha)	-0.82	3.31	-0.37	4.11	-1.50	2.75
Mean Core Area 1 (ha)	-6.99	1.31	-12.97	-3.97	-9.90	-1.37
Mean Core Area 2 (ha)	-28.74	8.72	-38.66	1.97	-27.59	10.91
Total Core Area Index (%)	-34.83	-4.46	-44.15	-11.22	-23.64	7.56
Mean Core Area Index (%)	-8.22	1.11	-15.43	-5.31	-11.61	-2.02
Shannon's Diversity Index	-0.31	0.47	-0.08	0.76	-0.14	0.66
Simpson's Diversity Index	-0.16	0.32	-0.07	0.45	-0.13	0.36
Modified Simpson's Diversity Index	-0.33	0.56	-0.15	0.82	-0.23	0.68
Patch Richness	-1.79	0.49	-1.10	1.37	-0.39	1.96
Shannon's Evenness Index	-0.13	0.45	-0.06	0.57	-0.20	0.40
Modified Simpson's Evenness Index	-0.17	0.51	-0.11	0.63	-0.26	0.44
Contagion (%)	-27.68	4.19	-36.69	-2.12	-24.04	8.72

Table 2. Summary of HSI values for selected species under Sustainable Forestry Initiative (SFI) and Non-SFI management scenarios. Values refer to a 30-year simulation cycle.

	SFI scenario				Non-SFI scenario			
Species	Mean	Min	Max	SD	Mean	Min	Max	SD
American beaver*	0.63	0.61	0.64	0.007	0.55	0.53	0.57	0.013
American woodcock	0.45	0.43	0.46	0.007	0.41	0.39	0.44	0.014
Pine warbler	0.19	0.15	0.23	0.027	0.23	0.17	0.28	0.033
Downy woodpecker	0.03	0.02	0.04	0.003	0.03	0.02	0.03	0.002
Barred owl	0.04	0.02	0.06	0.013	0.002	0.000	0.005	0.002
Eastern wild turkey	0.54	0.52	0.55	0.010	0.06	0.03	0.09	0.019
Fox squirrel	0.24	0.23	0.24	0.002	0.02	0.02	0.03	0.003
Gray squirrel	0.21	0.21	0.22	0.002	0.03	0.03	0.04	0.003

*Calculated for the area within buffers only

Table 2. Average annual precipitation, runoff and water and sediment yield in three APEX simulations.

Simulation	Precipitation (mm)	QSS (mm)	QSW (mm)	QTS (mm)	QTW (mm)	YS (t/ha)	YW (t/ha)
SFI							
1	1093.9	23.15	22.75	30.51	30.03	0.09	0.17
2	1056.0	17.97	17.62	23.21	22.78	0.08	0.16
3	1074.2	20.81	20.43	27.21	26.74	0.09	0.16
Average	1074.7	20.64	20.27	26.98	26.52	0.09	0.16
Non-SFI							
1	1093.9	23.10	22.90	30.27	30.00	0.09	0.42
2	1056.0	17.84	17.67	23.11	22.87	0.07	0.34
3	1074.2	20.80	20.62	27.15	26.89	0.09	0.38
Average	1074.7	20.58	20.40	26.84	26.59	0.08	0.38

QSS-average subarea surface runoff; QSW- average watershed surface runoff; QTS-average subarea water yield; QTW- average watershed water yield; YS-average subarea sediment yield; YW- average watershed sediment yield.