Chapter 14

The Role of the Sustainable Forestry Initiative in Forest Landscape Changes in Texas, USA

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Abstract We studied the changes in landscape pattern and function resulting from the application of the Sustainable Forestry Initiative (SFI) in East Texas, USA. Changes in landscape structure were studied by comparing landscapes with different management histories. A methodology to integrate landscape and stand pattern dynamics with processes was developed based upon modeling and simulation. The effects of pattern on processes were analyzed with this methodology considering the quality, quantity and configuration of vertebrate habitat and hydrological processes.

Comparisons among landscapes revealed that forest management has a strong influence on landscape structure. The SFI program has increased overall fragmentation with an increase in number of patches, length of edges and shape complexity and a decrease in patch size, and number and size of core areas.

Management according to the SFI program resulted generally in higher habitat suitability for many of the species analyzed and higher habitat diversity in the landscape. The SFI program induced fragmentation of the habitat of pine warbler and the establishment of narrow and elongated habitats in a network structure for most of the remaining species. Landscapes managed under the SFI program showed lower sediment yield at the watershed level than those under the non-SFI program due to lower channel erosion. The effects of the SFI program at the landscape level are related to the network of buffer strips.

In general we conclude that relevant measures at the landscape level improve the sustainability of forested landscapes in East Texas.

14.1 Introduction

The landscapes we see today are the outcome of the combination of natural, economical, and political elements acting through time. Before human expansion

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in North America during the Holocene, landscape change was driven by natural disturbances and climatic change. Growing populations modified considerably the structure and function of the landscape until the arrival of European settlers to the continent (Denevan 1992). Landscape change then became dominated by the expansion of agriculture (Meyer 1995) and later by growth of urban centers and infrastructure (Olson and Olson 1999). Forests decreased in area until the early twentieth century and have increased since then with the abandonment of agriculture and regrowth of cut areas (Meyer 1995).

In ancient forested landscapes recent change has been marked by intensive cutting and conversion of old growth into second growth forests (Ripple et al. 1991) as well as by fire suppression (Baker 1992). In East Texas, USA, the existing forested landscapes result mostly from reforestation campaigns that took place during the twentieth century and from natural establishment of forest in abandoned agriculture areas following the intensive exploitation of the nineteenth century. They are also the product of the forest management philosophy and practices followed during the past century.

Today, forest management is dominated by sustainable forestry. This concept, and the correspondent practice, was developed worldwide in the 1990s to integrate economical, environmental, and social objectives in forest management. It was strongly influenced by landmark events of the 1980s such as the World Conservation Strategy of 1980, The World Commission on Environment and Development Report ("Our Common Future") of 1987, and by the establishment of organizations such as the International Tropical Timber Agreement (ITTA), in 1983, and the Tropical Forestry Action Programme (TFAP), in 1985 (Upton and Bass 1996). After the UN Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992, sustainability of forests became a global goal. Two documents approved in the Rio summit, the "Statement of Forest Principles" and the "Convention on Biodiversity", defined broadly the concepts of actual sustainable forest management. International initiatives such as the Montréal Process in North and South America, Russia, Asia, and Oceania, and the Helsinki Process in Europe developed the criteria and standards for implementation of sustainable forestry at the national level.

In North America, forest sustainability has become the goal and the practice in public, nonindustrial private and industrial forests. The United States Department of Agriculture Forest Service, the Canadian Forest Service and the State and Provincial Forest Services adopted sustainable forestry concepts and practices in national and state forests in the US and Canada. Several programs are available to nonindustrial private forest owners such as the American Tree Farm System, the Forest Stewardship Program, and Green Tag Forestry, among others. The forest products industry follows mainly the standards of the Sustainable Forestry Initiative (SFI). This program was launched in 1994 by the American Forest and Paper Association (AF&PA) based upon the initial SFI Principles and Implementation Guidelines. In 1998 SFI became an industry standard and in 2001 a certification scheme. It has been a fully independent forest certification program since the beginning of 2007.

SFI is the most important certification program in North America and is currently followed on more than 61 million hectares of forestland (AF&PA 2005a).

Table 14.1 Principles of the sustainable forestry initiative (AF&PA 2005b)

Principle	Description
1. Sustainable Forestry	To practice sustainable forestry to meet the needs of the present without compromising the ability of future generations to meet their own needs by practicing a land stewardship ethic that integrates reforestation and the managing, growing, nurturing, and harvesting of trees for useful products with the conservation of soil, air and water quality, biological diversity, wildlife and aquatic habitat, recreation, and aesthetics.
2. Responsible Practices	To use and to promote among other forest landowners sustainable forestry practices that are both scientifically credible and economically, environmentally, and socially responsible.
3. Reforestation and Productive Capacity	To provide for regeneration after harvest and maintain the productive capacity of the forestland base.
4. Forest Health and Productivity	To protect forests from uncharacteristic and economically or environmentally undesirable wildfire, pests, diseases, and other damaging agents and thus maintain and improve long-term forest health and productivity.
5. Long-Term Forest and Soil Productivity	To protect and maintain long-term forest and soil productivity.
6. Protection of Water Resources	To protect water bodies and riparian zones.
7. Protection of Special Sites and Biological Diversity	To manage forests and lands of special significance (biologically, geologically, historically or culturally important) in a manner that takes into account their unique qualities and to promote a diversity of wildlife habitats, forest types, and ecological or natural community types.
8. Legal Compliance	To comply with applicable federal, provincial, state, and local forestry and related environmental laws, statutes, and regulations.
9. Continual Improvement	To continually improve the practice of forest management and also to monitor, measure and report performance in achieving the commitment to sustainable forestry.

In the US more than 90% of the industry-owned forest is managed under this program (AF&PA 2005a). The current SFI standard is based upon nine principles (Table 14.1) and 13 objectives (Table 14.2) for which a set of performance measures and indicators were established (AF&PA 2005b).

SFI relates directly and indirectly to the landscape. Firstly, the landscape scale is conceptually implicit in the program since sustainability and sustainable management of forests is addressable only when considered at this scale. Processes that are essential in terms of productivity and diversity in ecological systems, namely hydrological and biological processes, operate at landscape scales and their conservation necessitates landscape scale considerations. Also, the economical component of sustainability requires a broad scale approach to be properly addressed.

The implementation of SFI is landscape dependent and the landscape scale is directly or indirectly considered throughout the program standard. This is particularly noticeable in principles and objectives dealing with conservation of biological diversity including the promotion of diversity of wildlife habitats, forest types, and

Table 14.2 Objectives for the sustainable forestry standard (AF&PA 2005b)

Objective	Description
Objectives for Land Management	
Objective 1	To broaden the implementation of sustainable forestry by ensuring long-term harvest levels based on the use of the best scientific information available.
Objective 2	To ensure long-term forest productivity and conservation of forest resources through prompt reforestation, soil conservation, afforestation, and other measures.
Objective 3	To protect water quality in streams, lakes, and other water bodies.
Objective 4	To manage the quality and distribution of wildlife habitats and contribute to the conservation of biological diversity by developing and implementing stand- and landscape-level measures that promote habitat diversity and the conservation of forest plants and animals, including aquatic fauna.
Objective 5	To manage the visual impact of harvesting and other forest operations.
Objective 6	To manage Program Participant lands that are ecologically, geologically, historically, or culturally important in a manner that recognizes their special qualities.
Objective 7	To promote the efficient use of forest resources.
Objectives for Procurement	
Objective 8	To broaden the practice of sustainable forestry through procurement programs.
Objective for Forestry Research, Science, and Technology	
Objective 9	To improve forestry research, science, and technology, upon which sound forest management decisions are based.
Objective for Training and Education	
Objective 10	To improve the practice of sustainable forest management by resource professionals, logging professionals, and contractors through appropriate training and education programs.
Objective for Legal and Regulatory Compliance	
Objective 11	Commitment to comply with applicable federal, provincial, state, or local laws and regulations.
Objective for Public and Landowner Involvement in the Practice of Sustainable Forestry	
Objective 12	To broaden the practice of sustainable forestry by encouraging the public and forestry community to participate in the commitment to sustainable forestry and publicly report progress.
Objective for Management Review and Continual Improvement	
Objective 13	To promote continual improvement in the practice of sustainable forestry and monitor, measure, and report performance in achieving the commitment to sustainable forestry.

ecological or natural community types, such as objective for management no. 4. Wildlife conservation, which includes landscape level considerations, is also part of other objectives such as objective for procurement no. 8 and objective for forestry, research, science, and technology no. 9. It is also noticeable in principles and objectives dealing with visual impacts of forest operations (objective no. 5).

Additionally, there are particular measures implemented within SFI that are likely to have a strong effect on landscapes both structurally and functionally. Examples of these measures are the establishment of streamside buffer strips, the definition of green-up intervals and the limitation of the size of clearcuts. The establishment of streamside buffer strips is an important component of SFI. Although not directly stated in the standard, these buffers are mainly implemented according to management objective no. 3 in compliance with federal, state or province regulations and best management practices (BMPs). Both performance measures of this objective support the establishment of streamside buffer strips. These buffers are also an indicator of the performance measure 2.2 ("*minimize chemical use required to achieve management objectives while protecting employees, neighbors, the public, and the forest environment*"), part of objective for management no. 2).

The definition of green-up intervals is a performance measure of the SFI objective no. 5, defined as 3 years old or 5 feet high between adjacent clearcut areas. Also size of clearcuts is addressed as a performance measure in objective 5 along with clearcut shape and location. Only size, however, is directly considered as an indicator of the performance measure. Clearcut average size should not exceed 49 ha (AF&PA 2005b). Some companies further restrict the size of clearcuts according to their own sustainable forestry policy or according to the state or province regulations where they operate.

All the measures described above based on the SFI program are relevant at the landscape scale and can profoundly affect current landscapes. Previous studies where the implementation of sustainable forestry measures was simulated indicate that the structure of the landscape is affected by the types of management changes introduced (Hagan and Boone 1997; Cissel et al. 1998). Changes in function are also to expect from the application of sustainable forestry. Both changes in structure and function caused by sustainable forestry programs need to be fully understood.

The goal of this work is to evaluate the implications of changes in forest management on landscape structure and function associated with the SFI program. The specific objective is to detect the types and nature of change in landscape structure and function caused by the application of Sustainable Forestry Initiative measures relevant at the landscape level in intensively managed forested landscapes in East Texas. In this study we addressed the following questions: (i) Is the SFI program changing the pattern of intensively managed forested landscapes in East Texas? (ii) Can changes in structure, if any, affect ecological processes at the landscape level in this region?

14.2 Is SFI Changing the Pattern of Intensively Managed Forested Landscapes in East Texas?

14.2.1 Methods

We analyzed the effect of SFI on landscape pattern comparing landscapes with different management histories. Three areas were chosen. One area (SFI) has been intensively managed according to sustainable forestry principles since 1991. Practices in this area included a reduction in harvest unit size and the establishment of streamside buffer strips and a green up interval. Another area (IM) has been managed according to traditional intensive forest management followed by the timber industry in the region. Although changed in confined parts by more recent application of SFI practices, this landscape still reflects the pattern resulting from past management. The third area (EM) has been managed for wildlife and timber based on extensive forest management. Forest management is essentially based on the selection system applied in small areas. The EM area represents the natural landscape pattern of the region. All the areas are owned and managed by Temple-Inland Forest Products Corporation, Diboll, TX.

14.2.1.1 Areas of Study

The areas of study are located in southeastern Texas, USA (Fig. 14.1) in similar ecological conditions. The SFI area is located in Sabine County and is approximately 5000 ha in size. The IM area (5200 ha) is located in Angelina County and the EM area is 4400 ha in size and located in Trinity County. We consider that differences among areas in terms of geomorphology, pedology, hydrology, and others, do not have a strong influence on differences in landscape pattern. Management at the stand level is intensive in SFI and IM including mechanical site preparation, vegetation control, use of genetically improved vegetative material, fertilization, thinning, and harvesting. Rotation is around 30 years.

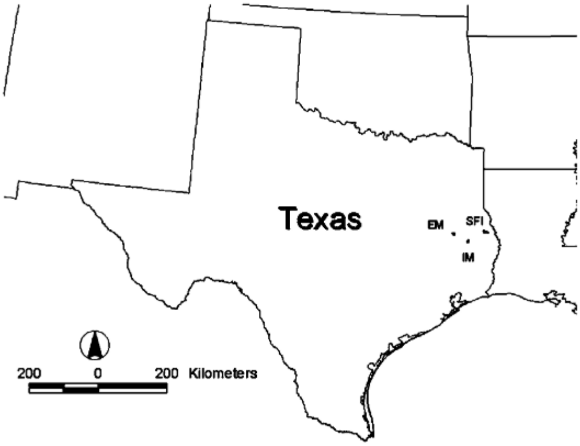

Fig. 14.1 Location of the study areas. SFI: area managed according to the SFI program; IM: area managed according to traditional forest management; EM: area managed by extensive management

14.2.1.2 Descriptive Comparison

We classified GIS coverages from 1999 of the three areas using a system comprised of seven classes, developed in order to differentiate among stands in terms of vertical (height, number of strata) and horizontal (density, basal area) structure (Table 14.3; Fig. 14.2). For that purpose we used graphical and statistical analyses (multivariate discriminant analysis and clustering methods) based on distributions of density,

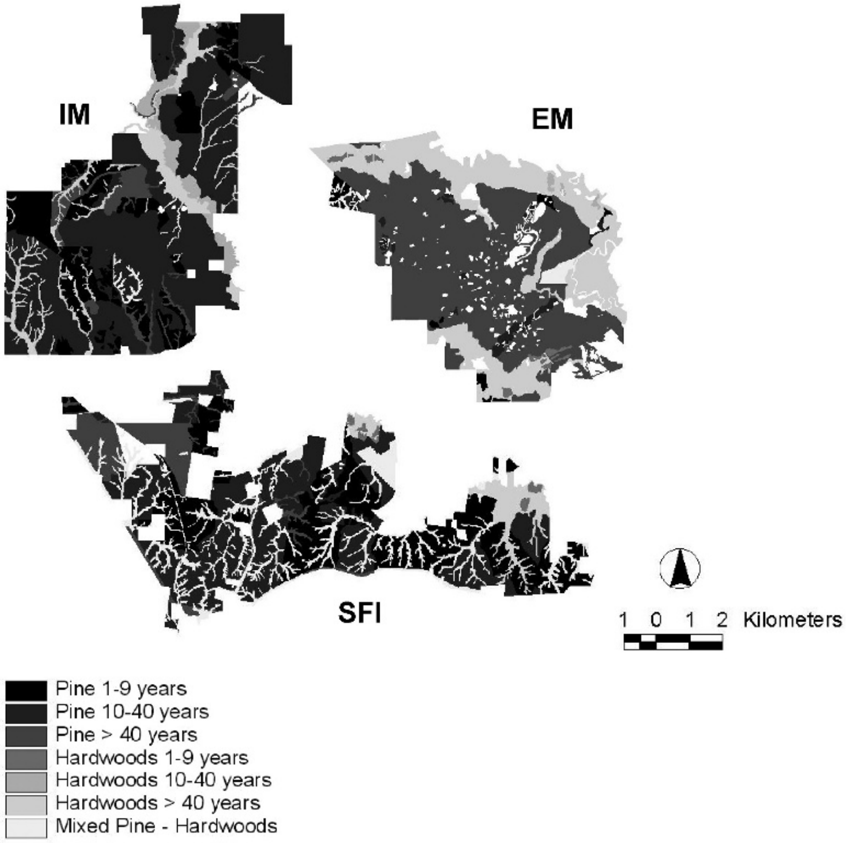

Fig. 14.2 Study areas classified according to stand structure. SFI: area managed according to the SFI program; IM: area managed according to traditional forest management; EM: area managed by extensive management

basal area, height, age and diameter at 1.3 m above ground (DBH) for both loblolly pine and hardwood stands. Raster files (10-m resolution) of the classified study areas were described in terms of landscape metrics with FRAGSTATS (McGarigal and

Table 14.3 Classes in the detailed classification system

Class number	Forest type	Age (years)
1	Pine	0–9
2	Pine	10–40
3	Pine	>40
4	Hardwood	0–9
5	Hardwood	10–40
6	Hardwood	>40
7	Pine-Hardwood	All ages

Marks 1995) at the stand, class, and landscape levels. A distance of 100 m was considered for core area and a distance of 1000 m was considered for proximity index determination.

14.2.1.3 Statistical Comparison

Multivariate analysis of variance (MANOVA) was performed to test for statistical differences in structure among landscapes. Metrics values calculated in watersheds classified according to the system described above were used in the analyses (Table 14.4). The size of the watersheds is small to allow the occurrence of a reasonable number of observations to apply statistical methods. The "Hydrologic Modeling Sample Extension" in ArcView was used in the watersheds delineation using 30 m resolution Digital Elevation Model (DEM) data (United States Geologic Survey).

Table 14.4 Small watersheds considered in the statistical comparison of the landscapes

		Area				
Landscape Name	N	Mean (ha)	St. Dev (ha)	SE (ha)	Min. (ha)	Max. (ha)
SFI	11	163.5	39.8	12.0	100.6	229.7
IM	14	162.7	52.9	14.1	91.8	248.1
EM	10	149.1	35.9	11.3	104.3	234.6

We performed MANOVA sequentially with all the metrics computed by FRAGSTATS, with the variables that graphically showed to be the best discriminants among areas of study in a previously performed hierarchical analysis, and with the variables that presented significant differences among areas of study in univariate analysis of variance (ANOVA) for the 95% and 99% levels. We established simultaneous confidence intervals (Bonferroni approach) for the 0.05 level to identify the variables and components of structure (effects) that contributed most to the observed differences in the multivariate populations.

14.2.2 Results

Both the descriptive and the statistical analysis indicated that there were differences among the landscapes compared. According to the landscape metrics calculated at the overall landscape scale (Table 14.5), SFI was the landscape presenting the highest evenness. Although young and middle age pine stands dominated both SFI and IM landscapes, in IM one single class occupied 60% of the landscape. The maximum area a single class occupied in SFI was 35% (middle age). EM was dominated by stands of the oldest classes of both pine and hardwood species (92% of the area).

SFI presented a much higher number of patches and much smaller patch size than the remaining landscapes (Table 14.5). Differences were in part due to the large average size of class 2 stands in the IM landscape. Core areas in the EM and IM landscapes represented higher proportions of the landscape and were larger in

Table 14.5 Summary of landscape metrics calculated at the landscape level

Variable	Landscape		
	SFI	IM	EM
Total Area (ha)	4943.7	5109.3	4368.6
Largest Patch Index (%)	6.5	23.8	48.3
Number of patches	207	118	77
Patch Density (#/100 ha)	4.19	2.31	1.76
Mean Patch Size (ha)	23.9	43.3	56.7
Total Edge (m)	444050	319540	108140
Edge Density (m/ha)	89.8	62.5	24.8
Landscape Shape Index	20.7	13.5	11.2
Mean Shape Index	2.45	2.67	2.06
Area-Weighted Mean Shape Index	4.4	4.1	5.4
Double Log Fractal Dimension	1.49	1.42	1.35
Mean Patch Fractal Dimension	1.13	1.15	1.12
Area-Weighted Mean Fractal Dimension	1.2	1.17	1.2
Total Core Area (ha)	1014.2	2090.3	2252.1
Number of Core Areas (#)	188	121	66
Core Area Density (#/100 ha)	3.8	2.37	1.51
Mean Core Area 1 (ha)	4.9	17.71	29.25
Mean Core Area 2 (ha)	5.39	17.28	34.12
Total Core Area Index (%)	20.51	40.91	51.55
Mean Core Area Index (%)	5.5	10.6	5.8
Mean Nearest Neighbor (m)	79.5	148	195.5
Mean Proximity Index	1594.5	4205.8	9485.1
Shannon's Diversity Index	1.48	1.21	0.99
Simpson's Diversity Index	0.74	0.59	0.54
Modified Simpson's Diversity Index	1.35	0.9	0.77
Shannon's Evenness Index	0.83	0.67	0.51
Simpson's Evenness Index	0.89	0.71	0.63
Modified Simpson's Evenness Index	0.75	0.5	0.4
Interspersion/Juxtaposition Index (%)	64.4	73.9	67.9
Contagion (%)	52.5	61.6	72.6

size than in SFI (Table 14.5). In SFI the number of core areas was much higher than in the other landscapes and the percentage of patch area in core areas was the smallest of all. In terms of edges, SFI was the landscape presenting highest absolute and relative edges at the landscape level. This was also reflected in shape metrics that indicated SFI as the landscape with more complex shapes.

On average, patches of the same class in SFI were closer to each other than in the other landscapes (Table 14.5). Contagion was much higher in the EM landscape thus reflecting the higher aggregation observed in this landscape. SFI presented the lowest contagion value.

The statistical analyses indicated that SFI had more edges, more complex shapes, and less core area than the remaining landscapes. MANOVA was initially performed with all the computed variables with the exception of Contagion, Simpson's Evenness Index, Modified Simpson's Evenness Index, and Relative Patch Richness due to the impossibility of conducting the analysis in the presence of very highly correlated variables. The null hypothesis (no difference among the groups) was rejected and the alternative hypothesis was accepted at the 0.05 level according to two of the criteria used (Wilk's and Pillai's). Significant differences were also observed having as responses diverse combinations of metrics including the variables that seemed to better discriminate among landscapes in a multiple scales pattern analysis conducted previously (NP, TE, ED, LSI, TCA, NCA, CAD, MCA1, MCA2, and MPI) and the variables that individually showed significant differences among the landscapes with univariate ANOVA at the 0.05 and 0.001 level (Table 14.6).

Throughout the analyses we observed high correlation among variables. Therefore, a smaller number of variables could be used in distinguishing effectively the

Table 14.6 Results of ANOVA for the landscape metrics considering the three areas of study simultaneously

Variable	F	p
Largest Patch Index (%)	7.40	0.002 **
Number of patches	11.12	0.000 ***
Patch Density (#/100 ha)	12.64	0.000 ***
Mean Patch Size (ha)	32.04	0.000 ***
Total Edge (m)	26.32	0.000 ***
Edge Density (m/ha)	70.44	0.000 ***
Landscape Shape Index	13.70	0.000 ***
Mean Shape Index	5.88	0.007 **
Area-Weighted Mean Shape Index	8.17	0.001 **
Double Log Fractal Dimension	11.20	0.000 ***
Mean Patch Fractal Dimension	3.36	0.047 *
Area-Weighted Mean Fractal Dimension	9.84	0.000 ***
Total Core Area (ha)	11.04	0.000 ***
Number Core Areas	3.61	0.039 *
Core Area Density (#/100 ha)	5.27	0.010 *
Mean Core Area 1 (ha)	26.15	0.000 ***
Mean Core Area 2 (ha)	5.88	0.007 **
Total Core Area Index (%)	22.00	0.000 ***
Mean Core Area Index (%)	30.90	0.000 ***
Mean Nearest Neighbor (m)	2.70	0.082 ns
Mean Proximity Index	1.99	0.153 ns
Shannon's Diversity Index	5.03	0.013 *
Simpson's Diversity Index	3.98	0.029 *
Modified Simpson's Diversity Index	3.60	0.039 *
Patch Richness	3.92	0.030 *
Patch Richness Density (#/100 ha)	1.27	0.295 ns
Relative Patch Richness (%)	3.92	0.03 *
Shannon's Evenness Index	4.85	0.014 *
Simpson's Evenness Index	4.02	0.028 *
Modified Simpson's Evenness Index	3.68	0.036 *
Interspersion/Juxtaposition Index (%)	0.17	0.845 ns
Contagion (%)	9.26	0.001 **

* - difference at the 0.05 level;
** - difference at the 0.01 level;
*** - difference at the 0.001 level.

structure of the landscapes. These could be those representing different components of heterogeneity and simultaneously proven useful in discriminating univariately among landscapes: number of patches (or density), mean patch size or contagion for arrangement, landscape shape index for shape, total edge or edge density for edges, total core area index or mean core area index (1 or 2) for core areas, and Shannon's diversity index for composition. Combinations of these variables indicated significant differences among areas of study at the 0.001 level.

Bonferroni intervals were established to compare the three landscapes pairwise for the 26 variables for which univariate ANOVA presented significant differences among areas of study for the 0.05 level (Table 14.7). SFI was different from IM in terms of edges (TE, ED), shape (LSI, AWMPFD) and core area (TCAI). Other core area metrics were very close to a significant difference between the two landscapes. It can be speculated that edges, shapes, and core areas were the major factors differentiating SFI and IM. These factors seemed also to have a great deal of interaction. SFI was different from EM in many other metrics: LPI, NP, PD, MPS, TE, ED, LSI, DFLD, AWMPFD, MCA1, TCAI, MCAI, and CONTAG.

Table 14.7 Lower and upper limits of Bonferroni simultaneous confidence intervals for comparisons among the three landscapes based upon small watersheds. Underlined values indicate significant differences for the 95% confidence level

Variable	SFI- IM		SFI-EM		IM -EM	
	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

The differences analyzed concern landscape fragments of reduced size and the analysis of the results should be cautious for this reason. No. Patches and Mean Patch Size have a strong tendency to differentiate the landscapes when the area of the sample units is large. However, here, sample areas were small thus artificially biasing patch area and number metrics. Average patch density was 10.4, 8.7, and 4.2 patches/100 ha for sample areas in SFI, IM, and EM, respectively, whereas for the total areas it was 4.2, 2.3, and 1.8 patches/100 ha.

14.2.3 Discussion

The results of this work suggest that the application of the SFI program is changing forested landscapes in East Texas. The most important changes can be described as fragmentation. Although fragmentation is often seen as a function of an organism or function taken under consideration (Loyn and McAlpine 2001) it can also be understood in a more general sense as the division of habitats into smaller pieces (Forman 1995; Turner et al. 2001). In such an approach, seral stages, communities, or ecosystems are taken as surrogates of population or physical processes. In this particular case, given the proportion of pine stands in the landscape, fragmentation is centered in this component.

Typical effects of forest fragmentation include increase in number of patches and edge length and decrease in patch size and core area (Franklin and Forman 1987; Ripple et al. 1991). Isolation among patches of interest increases also with fragmentation (Saunders et al. 1991; Andrén 1994). The sustainable landscape (SFI) presented many more and smaller patches than the non-sustainable (IM) or the non-intensively managed (EM) landscapes. It presented also the highest edge length. Isolation was not considered a major differentiating factor among the landscapes of study. Actually, average distances at the landscape level were usually smaller in SFI than in IM.

This fragmentation can be explained mainly by the inclusion in the landscape of Streamside Management Zones (SMZs), stream buffer zones wider than 30 m, and established according to the SFI program. These long, narrow elements break the large blocks of pine forest into smaller units increasing the number of patches, decreasing their size, and simultaneously increasing their edge length. Core areas consequently decrease in size and increase in number. This process corresponds to dissection (Forman 1995). The increase in proximity is also an effect of the introduction of the thin SMZs that make the average separation distance among stands of the same type smaller. Isolation is usually more evident in extreme fragmentation scenarios where area of habitats of interest is smaller (Gustafson and Parker 1992).

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. Li et al. (1993) through simulation in theoretical maps have detected increasing fragmentation with decreasing harvesting size expressed by edge density, patchiness, shape, and interior habitat parameters. When less than 40–45% of the landscape was harvested, edge density was higher if stream networks were considered as constraints. Hagan and Boone (1997), simulating the application of the Maine Forest Practices Act program noticed increasing fragmentation measured in terms of edges, core areas, and mature forest remaining. This fragmentation resulted from the reduction in clearcut size and from the establishment of separation distances and separation zones between clearcuts. Cissel et al. (1998) observed that the implementation of a management plan based on the standards, guidelines and assumptions of the Northwest Forest Plan in Oregon resulted in increasing fragmentation compared to the existing pattern. The plan included the creation of riparian reserves along streams among other measures. Patches increased very significantly in number and decreased in size and edges increased abruptly. The separation zones in the case of Hagan and Boone (1997) and the riparian reserves in the case of Cissel et al. (1998) associated with a reduction in harvest units produce the same type of pattern observed when the SFI program is implemented in East Texas. The effect of the reduction of harvest unit size seems in all cases to be less important than the establishment of buffer strips.

14.3 Can Changes in Structure Affect Ecological Processes at the Landscape Level?

14.3.1 Methods

A landscape model and several forest stand-level models were used to simultaneously simulate the dynamics of landscapes and forest stands as a function of management rules and initial conditions. Wildlife habitat quality and spatial pattern and hydrological processes (erosion and water yield) were selected as processes to evaluate based on habitat suitability models and a hydrological model. The selection of these processes resulted from the water, soil, and biodiversity conservation criteria and the indicators soil loss, water yield, and the amount, quality, and spatial pattern of habitat for vertebrate species, part of sustainable forestry programs.

Landscape dynamics were simulated using the model HARVEST 6.0 (Gustafson and Rasmussen 2002). This model allowed incorporating parameters such as harvest unit size, total area harvested, rotation length, and green-up interval, among others (Gustafson and Crow 1999). Stand-level dynamics was simulated with growth and yield models for the five forest management types applied in the area of study: (1) pine-clearcutting, (2) hardwood-clearcutting, (3) pine-selection, (4) hardwood-selection, and (5) pine-hardwood-selection. We used Compute P-Lob (Baldwin and Feduccia 1987) for planted even-aged loblolly pine stands, SouthPro (Schulte et al. 1998) for uneven-aged pine, hardwood, and mixed pine-hardwood stands, and the southern variant of the Forest Vegetation Simulator (FVS) (Donnelly et al. 2001) for even-aged hardwood stands.

Habitat suitability was modelled at the stand and landscape levels with habitat suitability index (HSI) models (Schamberger et al. 1982). HSI models provide a standardized way of quantification of habitat suitability assuming a direct linear relationship with carrying capacity (US Fish and Wildlife Service 1981). Hydrological processes were simulated with the Agricultural Policy/Environmental eXtender (APEX) model, version 1310 (Williams et al. 2000). This is a mechanistic model that combines the EPIC model (Environmental Policy Integrated Climate) with routing capabilities allowing the analysis of processes occurring simultaneously at the field and watershed levels. The model has been recently modified to describe hydrology in forested areas (Saleh et al. 2002).

The models were run stand-alone and information exchange among them occurred external to individual models. HARVEST produced landscape maps every 2 years of the simulation period using as inputs landscape structure maps prepared in a GIS according to management criteria. Stand ID, age, management type, and site index were used to link individual stands in the GIS coverage with stand structure data simulated in the growth and yield models for the respective management type and site index and with HSI scores calculated according to the HSI models. HSI variables and final scores were calculated at the stand level using data from the growth and yield models. Habitat structure was described in FRAGSTATS from HSI maps created in the GIS. APEX files used information obtained from maps provided by HARVEST and particular characteristics of the stands provided by the growth and yield models.

The changes in processes caused by management were based on the comparison to two landscape management scenarios. An SFI scenario followed on the application of SFI landscape measures, namely SMZs $\geq$30 m wide along streams, limits in harvest unit size (pine 49 ha; hardwoods 12 ha) and a three-year green up interval. A Non-SFI scenario was established in the absence of these rules.

We ran HARVEST for 400 years. For each scenario, five replicate runs were conducted using independently generated random number seeds. Partial studies on the effects of SFI on the landscape processes in intensively managed forested landscapes in East Texas are available in Azevedo et al. (2005a), Azevedo et al. (2005b), and Azevedo et al. (2006).

14.3.1.1 Study Area

The wildlife study was conducted in a 5,773-ha area, corresponding roughly to the IM area of the previous section. It lays in the Yegua Formation of coastal plain sediments of late Eocene origin. Soils were Ultisols (Rosenwall series) and Alfisols (Diboll and Alazan series). Elevation ranged from 41 to 113 m above sea level. Mean annual rainfall was 1,054 mm and mean annual temperature was 19.4 C. Most of the area was owned by Temple-Inland Forest Products Corporation, Diboll, TX, and managed for industrial forestry. For the hydrology study we considered a smaller watershed of this area, 1190 ha in size.

14.3.1.2 Wildlife Habitats

We selected eight species among vertebrates potentially occurring in the region where the study area was located (83 herps, 132 birds, 51 mammals) to represent guilds of breeding and foraging requirements. The species were classified based on vertical stratification of the pine, hardwood and pine-hardwood forest breeding and foraging habitats. We conducted a cluster analysis using the Ward's minimum variance clustering method with distances based upon Jaccard's coefficient of similarity (Lapointe and Legendre 1994). From the twelve guilds initially considered (Fig. 14.3), four were excluded for being comprised of species associated with non-existing local conditions, relying upon parameters difficult to estimate at the resolution of the data used or lacking published habitat models. One species was selected to represent the corresponding habitat requirements: American beaver (*Castor canadensis* Kuhl 1820), American woodcock (*Scolopax minor* J. F. Gmelin 1789), pine warbler (*Dendroica pinus* (Wilson, 1811)), downy woodpecker (*Picoides pubescens* (Linnaeus 1766)), barred owl (*Strix varia* Barton 1799), wild turkey (*Meleagris gallopavo silvestris* Vieillot 1817), fox squirrel (*Sciurus niger* Linnaeus 1758) and gray squirrel (*Sciurus carolinensis* Gmelin 1788). The habitats were modeled with HSI models using data provided by the growth and yield models and in few cases from assumptions based upon published data. Application of the HSI models is described in detail in Azevedo et al. (2006). At the landscape level, HSI was calculated from the GIS coverages resulting from the landscape simulations. Five habitat suitability classes were defined: "unsuitable" (HSI = 0), "low" ($0 < \text{HSI} \leq 0.25$), "medium" ($0.25 < \text{HSI} \leq 0.5$), "high" ($0.5 < \text{HSI} \leq 0.75$), and "very high" ($0.75 < \text{HSI} \leq 1$). Maps of high and very high suitability habitats were analyzed in terms of landscape metrics calculated with FRAGSTATS (McGarigal and Marks 1995).

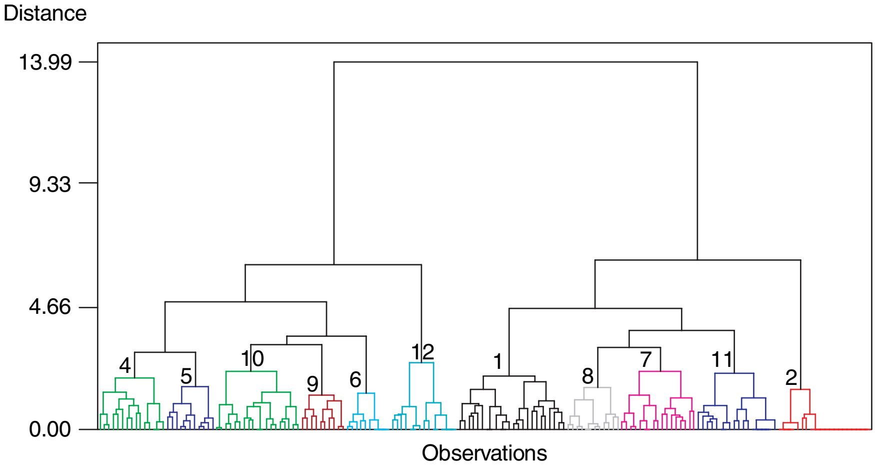

Fig. 14.3 Dendrogram for the clusters analysis with Ward's minimum variance and distances based upon Jaccard's coefficient of similarity. Numbers in the chart indicate cluster number. Cluster 3, comprised of non-forest species is not represented

14.3.1.3 Hydrology

The use of APEX relied on watershed discretization and parameterization of the model components, mainly subareas and operation schedules files. The delineation of subareas in the study area was performed with the watershed delineation module of SWAT2000, ArcView interface (Di Luzio et al. 2002) based on 30 m resolution digital elevation model (DEM) data (United States Geological Survey). Larger sub-basins were manually subdivided to reduce soil and stand variability and to minimize errors in channel length mensuration. Further discretization was made to distinguish among forest stands and buffer zones. For each scenario, routing was schematized in a diagram based on SWAT sub-basin coverages and stand maps derived from HARVEST outputs.

Subareas files were built with soil and operation schedule file codes, area, channel length and slope, upland slope, reach length and slope, when applicable, as inputs. Receiving subarea, operation schedule file, and soil file were also associated to each entering subarea. Soil series distribution in the study area was obtained from a SSURGO digital map for Angelina County (Soil Survey Geographic Data Base, USDA- Natural Resources Conservation Service). The stands were managed by operation schedules according to their composition and age. These files described stand development and management operations in the stands and synchronized APEX with the stand and landscape dynamics simulated in HARVEST.

Evaluation of the model for the study area was performed in controlled subareas for different magnitudes and combinations of parameter values for soil, crop type, density, thinning, age to maturity, partition flow through filter strips, and slope, among others. Different subarea delineations were also used to evaluate the role of discretization on the processes simulated including the effect of buffer strips on runoff and sediment loss.

Weather data were generated based on parameters for Lufkin, Texas. The model was run 30 years prior to the period of interest to allow stabilization of the system and stand growth. Three simulations for each scenario (SFI and non-SFI) were performed. The methods are described in detail in Azevedo et al. (2005b).

14.3.2 Results

All the results refer to a period of 30 years given the fact that the simulated landscapes presented a return interval of this duration.

14.3.2.1 Wildlife Habitats

There were differences between scenarios in terms of habitat suitability for the species analyzed (Table 14.8). Habitat suitability for pine warbler was slightly lower in SFI than in Non-SFI. HSI values for American woodcock and American beaver were slightly higher in the SFI scenario. Given the uniformity of simulation runs all the differences were statistically significant ($p<0.001$; repeated measures ANOVA with management as a fixed effect and runs as random subjects). There were major differences between scenarios in habitat suitability for wild turkey, fox squirrel, and gray squirrel: very low suitability in the Non-SFI scenario and relatively high suitability in the SFI scenario. HSI values for barred owl and downy woodpecker

Table 14.8 Summary statistics of habitat suitability index (HSI) values for selected species under Sustainable Forestry Initiative (SFI) and Non-SFI management scenarios. Values refer to a 30-year simulation cycle

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

*Calculated for the area within buffers only

were negligible in both scenarios. Habitat suitability was relatively stable during the simulations for all the species in both management scenarios.

Highly suitable habitat for American woodcock was abundant only in the SFI landscape. This habitat was in few patches spread over the landscape with an extremely large edge length, and few and small core areas (Table 14.9). Near 100% of the area of this class was in a single patch. This habitat class corresponded mostly to the SMZs network established in the SFI scenario (Fig. 14.4). Metrics for the high suitability pine warbler habitat, the highest observed for the species, indicated considerable fragmentation in the SFI scenario (more and smaller patches, less aggregated, more edges, less core area, and lower isolation) as compared to the Non-SFI scenario (Table 14.9; Fig. 14.4).

For fox and gray squirrel and wild turkey there was almost no quality habitat in the Non-SFI scenario. Very high suitability habitat for fox squirrel and gray squirrel comprised the majority of suitable habitat in the SFI scenario. High suitability habitat metrics express the structure of the SMZ network: few patches, one patch containing more than 90% of the class area, considerable total area occupied, low aggregation, small core area percentage, and small distances (Table 14.9). For barred owl and downy woodpecker none of the scenarios presented practically suitable habitat patches. Very few, small, and isolated patches provided the only quality habitat for barred owl. In SFI, the SMZ network provided relatively abundant but low suitability class habitat for both species.

14.3.2.2 Hydrology

The results obtained at the subarea level were generally within the expected values for forested watersheds in East Texas under similar conditions. Water and sediment yields were generally small and most of the runoff and erosion observed occurred during intense storm events.

SFI and non-SFI management scenarios originated the same amount of surface runoff and water yield at both subarea and watershed levels (Table 14.10).

Table 14.9 Selected landscape metrics for American woodcock, pine warbler and gray squirrel “high” ($0.5<\mathrm{HSI}\le 0.75$), and “very high” ($0.75<\mathrm{HSI}\le 1$) suitability habitat classes. Values are averages (three simulations; 15 observation dates)

Variable	American woodcock				Pine warbler		Gray squirrel			
	“high” ($0.5<\mathrm{HSI}\le 0.75$)		“very high” ($0.75<\mathrm{HSI}\le 1$)		“high” ($0.5<\mathrm{HSI}\le 0.75$)		“high” ($0.5<\mathrm{HSI}\le 0.75$)		“very high” ($0.75<\mathrm{HSI}\le 1$)	
	SFI	Non-SFI	SFI	Non-SFI	SFI	Non-SFI	SFI	Non-SFI	SFI	Non-SFI
Percentage of Landscape (%)	26.8	4.1	4.0	8.8	25.8	32.9	0.7	1.7	24.4	1.7
Patch Density (#/100 ha)	0.2	0.2	0.4	0.1	1.3	0.4	0.1	0.1	0.1	0.1
Edge Density (m/ha)	69.7	4.8	6.8	6.6	37.4	19.7	1.8	2.4	69.7	2.9
Largest Patch Index (%)	26.8	1.6	0.7	5.0	2.9	13.7	0.2	0.8	24.3	0.7
Landscape Shape Index	25.7	4.9	7.0	4.5	15.0	7.5	4.3	3.6	26.9	4.5
Mean Patch Area (ha)	165.4	22.9	10.4	185.7	20.8	89.3	5.4	30.2	169.6	17.8
Core Area Per. of Land. (%)	5.9	1.4	0.5	4.4	4.8	17.3	0.0	0.4	4.7	0.3
Mean Core Area (ha)	36.3	7.8	1.2	93.0	3.9	47.0	0.1	6.7	32.8	3.1
Mean Core Area Index (%)	2.3	15.0	4.8	38.9	8.2	19.9	1.1	16.5	2.3	8.4
Mean Euclidean Nearest Neighbor Distance (m)	153.0	722.8	160.5	192.4	80.6	212.2	641.9	1214.1	126.3	715.4

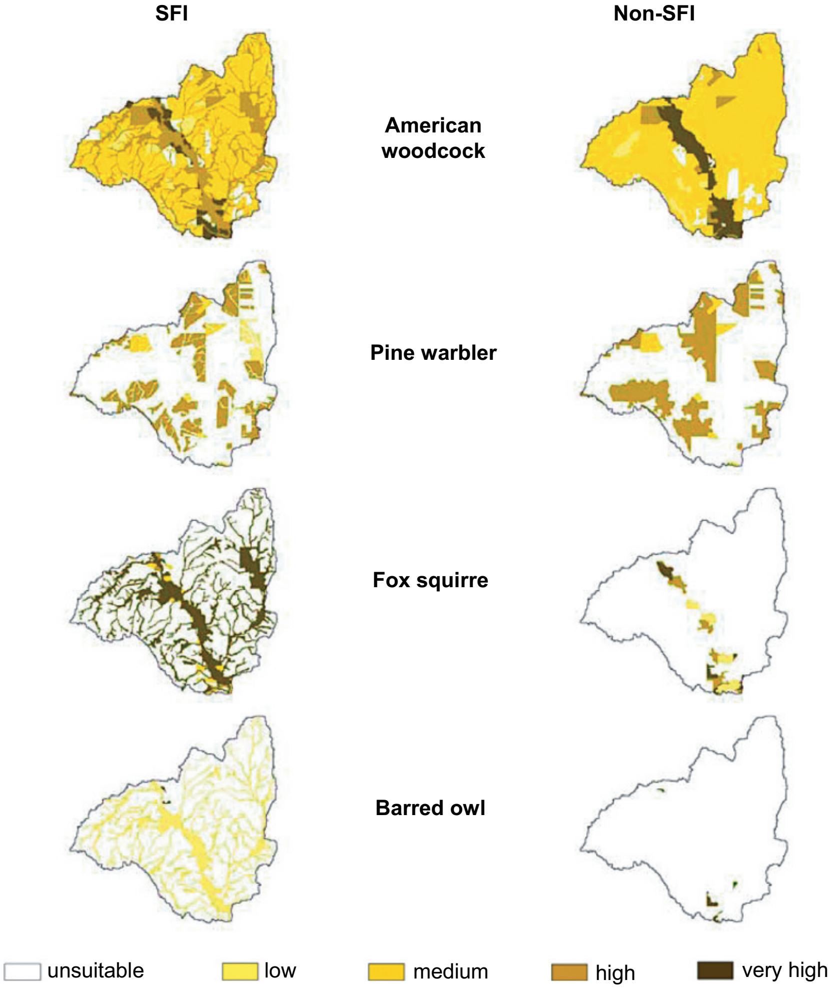

Fig. 14.4 Examples of spatial pattern of habitat suitability classes for the study area in alternative management scenarios. Images refer to a single simulation year

Differences in forest cover between scenarios were attenuated by the nearly level slopes in the study area, the lower annual mean precipitation and by the fact that results are averages for 30 years and for 3 runs.

Sediment yield at the subarea level was approximately the same in both scenarios. At the watershed level, however, the non-SFI scenario presented considerably more sediment yield than the SFI scenario. The difference in watershed sediment yield resulted from the routing processes, mainly channel degradation. Sediment deposition also occurred but in low quantity due to the fact that sediment loss is usually very low in the nearly level slopes of the area. Deposition was appreciable only during intense storm events, mainly in the SFI scenario, when sediment yield

Table 14.10 Annual precipitation, runoff and water and sediment yield in the study watershed. Results are averages from 30 years and three simulations

Scenario	Precipitation (mm)	QSS (mm)	QSW (mm)	QTS (mm)	QTW (mm)	YS (t/ha)	YW (t/ha)
SFI	1074.7	20.64	20.27	26.98	26.52	0.09	0.16
Non-SFI	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

was high. Channel degradation was common in both scenarios but higher in the non-SFI scenario (annual average values of approximately 0.3 t/ha against 0.08 t/ha in the SFI scenario). Channel degradation was responsible for the differences in watershed sediment yield between the two landscapes. The Non-SFI scenario presented fewer buffer zones and was also less fragmented than the SFI landscape. Degradation occurred mostly in periods of intense precipitation.

14.3.3 Discussion

The results above indicated that changes in forest management of the type included in the SFI program affect processes at the landscape level. Wildlife habitats of the species selected to indicate particular habitat conditions changed in quality, abundance and spatial structure when SFI landscape measures were applied. In general the SFI scenario provided higher habitat suitability. The habitat heterogeneity, expressed by higher diversity and evenness of habitats, also increased which creates the possibility of a more diverse wildlife in the SFI landscape. Spatially, changes caused by SFI can be of the kind indicated by pine warbler that presented an increase in the fragmentation of the most suitable habitat. Changes can also be of the type observed for American woodcock, wild turkey, fox and gray squirrels, where suitable habitat follows the configuration of the SMZs network established in the area according to the SFI program. The landscape structure of the habitat is not limiting for most of these species. The conditions created seem to indicate also the possibility of maintaining large populations of many species. In spite of improvements induced by the program, the SFI landscapes, however, are still insufficient in a larger perspective of maintenance of biodiversity. There are important habitats that are missing in this landscape such as mature pine and hardwood stands. These types of stands are known for the richness and abundance of species they retain and provide particular habitat for species that are exclusively associated with these environments.

Sediment yield also showed that SFI affects hydrological processes. Lower sediment yield at the landscape level was observed in the SFI scenario which was related to the establishment of SMZs along streams.

From the SFI landscape measures simulated, the SMZs seem to have the strongest effects of all. As seen before, they are key elements in landscape structure change caused by the SFI program. SMZs are also essential in the wildlife habitat quality, abundance and configuration, playing a key role in the reduction of channel erosion.

Based on the results obtained in this modeling and simulation exercise we conclude that the changes of the type occurring currently in forested landscapes in East Texas as driven by the SFI program are also changing landscape processes in this region.

14.4 Overall Conclusion

Forest management can be considered as an anthropogenic process that modifies landscape structure, which in turn influences the processes and functions of landscape such as hydrology, soil erosion, availability and quality of wildlife habitat, and species diversity. A key issue related to these complex interactions on managed landscapes is their sustainability.

In the absence of a comprehensive and operational definition of landscape sustainability (Wu and Hobbs 2002) we consider as sustainable a landscape that is able to maintain its essential structures and processes over time in a management context. Sustainability is mainly a management concept and it is particularly useful in testing the capacity of a natural system to support human induced change through resources management. According to the framework established for this work, we compared structure among landscapes managed by different management perspectives and we analyzed, based upon modeling and simulation, soil loss, water yield, and the amount, quality, and spatial pattern of habitat for vertebrate species as indicators of soil, water and biodiversity conservation, usual criteria of sustainable forestry. Based upon the results of this work we consider that SFI improves landscape sustainability. SFI creates landscapes that are better structured and contribute better to the conservation of wildlife and soil.

The SFI landscape had a more complex pattern than the other landscapes, including the non-SFI landscape, presenting more patches and more complex shapes. Evenness and diversity were also higher in this landscape.

SFI scenarios in the simulations presented higher diversity of habitats, higher suitability for most of the species considered, and a configuration that is not generally limiting for the species. The SFI scenarios in the hydrology study indicated that there is a reduction in soil loss from the system when SFI is followed. Therefore, we conclude that SFI contributes to the sustainability of forest landscapes in East Texas by changing these landscapes towards a better structure and function. Whether these changes create sustainable landscapes or not we are not able to verify.

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