Effects of the Sustainable Forestry Initiative on the Quality, Abundance, and Configuration of Wildlife Habitats

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ABSTRACT. We analyzed the effects of landscape measures within the Sustainable Forestry Initiative (SFI) program on the suitability, abundance and spatial pattern of vertebrate habitats based on modeling and simulation of landscape and stand structure in a forested watershed in East Texas. Eight vertebrate species representing guilds established according to breeding and foraging requirements were selected: American beaver (*Castor canadensis*), American woodcock (*Scolopax minor*), pine warbler (*Dendroica pinus*), downy woodpecker (*Picoides pubescens*), barred owl (*Strix varia*), wild turkey (*Meleagris gallopavo silvestris*),

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fox squirrel (*Sciurus niger*) and gray squirrel (*Sciurus carolinensis*). Habitat suitability of the landscape in general increased with the implementation of SFI measures and habitat conditions were more diverse and even. Fragmentation and establishment of narrow and elongated habitat areas in a network configuration were the main consequences of the implementation of SFI measures in terms of habitat spatial structure. These changes were usually not limiting for the species analyzed. Mature pine and hardwood stands were absent from the simulated landscapes limiting the habitat for species like downy woodpecker or barred owl. Most of the species considered in this work benefited particularly from the implementation of streamside management zones (SMZs). doi:10.1300/ J091v23n01_03 *[Article copies available for a fee from The Haworth Document Delivery Service: 1-800- HAWORTH. E-mail address: <docdelivery@haworthpress. com> Website: <http://www.HaworthPress.com> © 2006 by The Haworth Press, Inc. All rights reserved.]*

KEYWORDS. Wildlife habitat quality and configuration, landscape, sustainable forestry, Sustainable Forestry Initiative (SFI), East Texas

INTRODUCTION

Biodiversity conservation requires a combination of measures at several scales. Traditionally it has relied on few, small, and isolated reserves. However, the majority of rare and endangered species exist outside reserves and there is lack of representation of species and ecosystems in the existing reserves (Soulé and Terborgh, 1999). Increasing reserves in number or size as a solution is limited by the large areas required (Mann and Plummer, 1993; Soulé and Sanjayan, 1998), by the currently limited area available for reserves (Lindenmayer and Franklin, 2002), and by the costs of reserve acquisition (Simberloff, 1998), particularly considering the scarcity of resources available for conservation (Skole and Compton, 1993).

The major limitation to reserve-centered conservation policies derives, however, from key biological and ecological processes that exceed the scale of reserves (Lindenmayer et al., 2000). Although it is often assumed that areas between reserves can ensure these processes, there is no clear indication that these more or less intensively managed in-between areas have played that role. Managed agriculture and forest areas and human settlements occupy 95% of the terrestrial environment (Pimentel et al., 1992). Urban growth is probably the major threat to biodiversity (Main et al., 1999). Agriculture-dominated landscapes

have a low capacity to support diversity (Paoletti, 1999). In the tropics and many temperate regions managed areas outside reserves are expected to lose their capacity to support native species and ecosystems by 2050 (Soulé and Sanjayan, 1998). In the US destruction and degradation of habitats, introduction and spread of alien species, pollution, over exploitation, and diseases threaten biodiversity seriously (Wilcove et al., 1998).

Complementary to networks of reserves, management in intermediate areas needs to guarantee the processes required in the maintenance of biodiversity at larger scales. Although there are no signs of reversal on urban growth, there are prospects that agriculture and forestry can contribute to the conservation of biodiversity (Paoletti, 1995; Lotter, 2003; Pearce et al., 2003). Forestry, particularly, is under important changes worldwide through sustainable management and certification processes (Gullison, 2003). In the tropics, sustainable forestry is able to decrease loss of biodiversity (Pearce et al., 2003) and is also believed to maintain biodiversity in managed forests in other regions of the world (Wigley et al., 2000).

In the United States sustainability has become the dominant management philosophy in national forests (USDA Forest Service, 2000) and within the forest industry (Cantrell, 1998). The Sustainable Forestry Initiative (SFI) was launched in 1994 and is currently applied to 60 million hectares of forestland, > 90% of all the industry-owned forest in North America (American Forest & Paper Association, 2005a). SFI is a system of principles, objectives, performance measures and indicators combing forestry with the protection of wildlife, plants, soil, water and air quality (American Forest & Paper Association, 2005a). The current SFI standard is described in detail in American Forest & Paper Association (2005b).

Following SFI, forest products companies are implementing landscape-level measures such as establishment of buffer zones along streams, establishment of wildlife corridors, limitation in size of harvest units, and application of adjacency rules. Some of these requirements, as buffer zones along streams, were implemented prior to SFI and are part of state Best Management Practices and have been used as part of an effort to improve sustainability by SFI participants.

Among other objectives, SFI aims to "manage the quality and distribution of wildlife habitats and contribute to the conservation of biological diversity" (American Forest & Paper Association, 2002). However, can industrial forests maintain biodiversity in levels comparable to other systems? Can industrial forests managed according to SFI guide-

lines be considered as part of conservation strategies at the regional and national scales? In spite of all the optimism around sustainable forestry, the answers to questions like these cannot be given until the application of SFI measures is evaluated. Preliminary research indicates that industrial forests managed according to SFI principles can present high diversity and productivity of birds and high diversity of herpetofauna including many species of high conservation interest (Wigley et al., 2000). Other research indicates that, individually, some of the measures included in SFI have a positive effect on the maintenance of animal diversity in forested landscapes (e.g., Dickson and Huntley, 1987; Dickson et al., 1995; Lance and Phinney, 2001). Before more field data can be gathered and treated to analyze real impacts of sustainable forestry in intensively managed landscapes, other approaches can be developed in order to increase understanding of the effects of the SFI program on wildlife communities, particularly at broader scales.

It was observed previously that the implementation of the SFI program is changing landscape structure in east Texas (Azevedo, 2003). Assessment of the importance of these changes in terms of major processes, namely those related to wildlife and their habitats, requires specific treatment. The goal of this work is to study the implications of sustainable forestry on wildlife communities. More specifically, the objective of this research is to evaluate through modeling and simulation the changes caused by the application of landscape measures that have been adopted by companies in order to comply with SFI, in terms of quality, abundance and configuration of vertebrate species habitat in east Texas. We hypothesize that SFI changes composition, diversity, and spatial structure of habitats and that these changes increase diversity at the landscape scale.

METHODS

Study Area

The study area (5773 ha) was within the Chawanee Creek watershed in Angelina County, Texas, USA (Figure 1). Most of this area was owned by Temple-Inland Forest Products Corporation and managed for industrial forestry. Soils were predominantly Ultisols of the Rosenwall series and Alfisols of the Diboll series. The forest types included pine (mainly loblolly pine, *Pinus taeda* L.), 4727 ha (82% of the area), hardwoods, 796 ha (14%), and pine-hardwood mixed stands, 251 ha (4%).

FIGURE 1. Location of the study area.
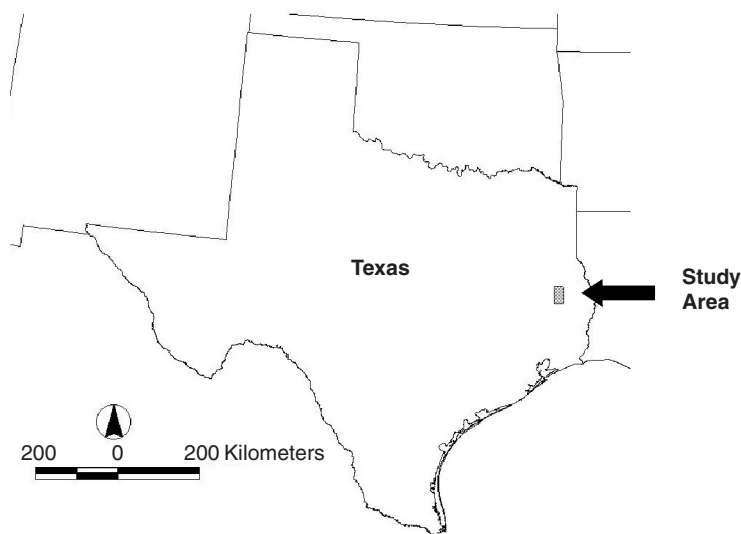
Approximately 70% of the area was managed by even-aged silviculture (clearcutting system).

Landscape, Stand Modeling and Simulation

A combination of landscape and stand models was used to simulate the dynamics of the landscape and its components in the study area. Landscape dynamics were simulated using HARVEST 6.0 (Gustafson and Rasmussen, 2002). This raster model simulates even- and uneven-aged silvicultural systems at the landscape scale incorporating parameters usually considered in forest management such as harvest unit size, total area harvested, rotation length, and green up interval, among others (Gustafson and Crow, 1999).

Five forest management types were considered in the study: (1) pine-clearcutting, (2) hardwood-clearcutting, (3) pine-selection, (4) hardwood-selection, and (5) pine-hardwood-selection. Several growth and yield models were used to simulate stand-level dynamics: 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. These models produce estimates of height, basal area, density, biomass, and volume distributions by diameter classes as well as composition in the stand under different natural and management conditions.

Two landscape management scenarios were established. An SFI scenario was based on the application of SFI landscape measures, namely SMZs $\geq$ 30 m wide along perennial and intermittent streams, limits in harvest unit size (pine 49 ha; hardwoods 12 ha) and a three-year green up interval. A Non-SFI scenario was also established in the absence of all these rules, as a reference scenario. This scenario is constructed to compare SFI to past management and does not imply current practices elsewhere in the state under the guidelines of the state Best Management Practices.

We ran HARVEST for 400 years to analyze the behavior of the system in a long period of time. For each scenario, five replicate runs were conducted using independently generated random number seeds. A detailed description of the methodology is presented in Azevedo et al. (2005).

Species Selection

The vertebrate species that potentially occur in the ecological region encompassing the study area (83 herps, 132 birds, 51 mammals) were grouped into guilds based on their breeding and foraging requirements. Breeding and foraging requirements were specified using 42 binary variables based on vertical stratification of the pine, hardwood and pine-hardwood forest habitats (Table 1) and particular aspects such as tree bole and water surfaces. One breeding and one feeding variable were used for non-forest habitats.

Cluster analysis was used to define the guilds using the Ward's minimum variance clustering method with distances based upon Jaccard's coefficient of similarity (Lapointe and Legendre, 1994). A distance matrix, D, was obtained by subtracting similarity coefficient values from 1 (Lapointe and Legendre, 1994). Based upon the analysis of dendrograms, cluster composition, and combinations of habitat characteristics, 12 guilds were initially considered (Figure 2, Table 2). Four of these guilds were excluded from this study since they were comprised of species not associated with local conditions (Guilds 3 and 12), relied upon habitat characteristics difficult to estimate given the resolution of the data used (guild 11), or lacked published habitat

TABLE 1. Breeding and foraging habitat layers and components for species classification.

Code	Name	Description
1	Terrain surface and subsurface	Below ground to 15 cm above surface
2	Understory	From 15 cm above surface to 0.5 m above surface
3	Midstory	From 0.5 m to 8 m in height
4	Tree canopy or overstory	Upwards from 8 m
5	Tree bole	Dbh $\geq$ 20 cm
6	Water	Water surfaces
7	Elsewhere	Other features within forest (snags, logs, etc)

Modified from Short (1984).

FIGURE 2. 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.
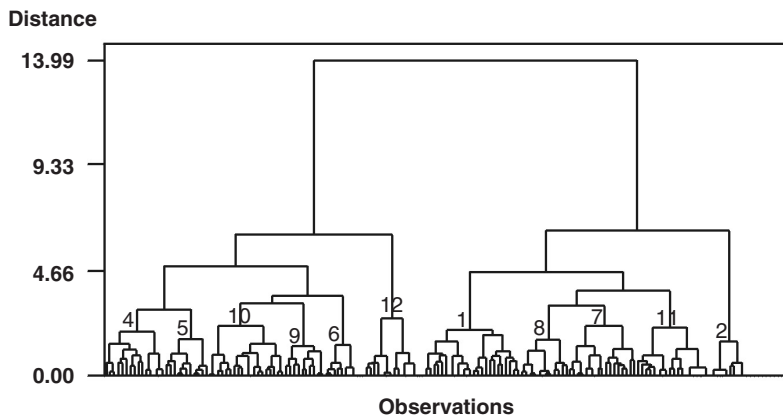
models (Guilds 6 and 11). For each of the eight guilds defined in the study, one species was selected to represent the general habitat requirements of the guild (Table 3): American beaver (*Castor canadensis* Kuhl, 1820), American woodcock (*Scolopax minor* J. F. Gmelin, 1789), pine warbler (*Dendroica pinus* Wilson, 1811), downy woodpecker (*Picoides pubescens* Linnaeus, 1766), barred owl (*Strix varia* Barton, 1799), wild turkey (*Meleagris gallopavo silvestris* Vieillot, 1817), fox

TABLE 2. Composition and description of the clusters considered.

| Cluster | Number of species | | | | Description |
	Total	Mammals	Birds	Herps	
1	24	6	10	8	Ground hardwood species
2	21	6	2	13	Exclusive ground, generalists
3	94	12	49	33	Non-forest species
4	15	8	6	1	Cavity and canopy breeding
5	11	1	10	0	Exclusive cavity birds
6	10	1	8	1	Middle/high hardwood and mixed canopy birds
7	17	1	13	3	Ground feeding, diverse breeding
8	12	6	4	2	Ground and shrub, generalist
9	10	1	8	1	Exclusive hardwood (diverse)
10	19	8	6	5	Feeding in all layers, breeding diverse
11	18	1	1	16	Water breeding, ground feeding species
12	15	0	15	0	Mid/high canopy breeding (no feeding in forest)

TABLE 3. Selected species and corresponding Habitat Suitability Index Models.

Cluster	Species	Model
1	American beaver, *Castor canadensis*	Allen (1983)
2	American woodcock, *Scolopax minor*	Cade (1985)
4	Pine warbler, *Dendroica pinus*	Schroeder (1982a)
5	Downy woodpecker, *Picoides pubescens*	Schroeder (1982b)
7	Barred owl, *Strix varia*	Allen (1987b)
8	Wild turkey, *Meleagris gallopavo silvestris*	Schroeder (1985)
9	Fox squirrel, *Sciurus niger*	Allen (1982)
10	Gray squirrel, *Sciurus carolinensis*	Allen (1987a)

squirrel (*Sciurus niger* Linnaeus, 1758) and gray squirrel (*Sciurus carolinensis* Gmelin, 1788).

Habitat Suitability Index Models

Habitat suitability at the stand and landscape levels was evaluated using Habitat Suitability Index (HSI) models (Schamberger et al., 1982), single-species models developed in the 1980s for quantifying impacts

of land use changes in wildlife habitats. In spite of their limitations as habitat models (Roloff and Kernohan, 1999), HSI models allow habitat suitability quantification in a 0 to 1 scale assuming a direct linear relationship of HSI with carrying capacity of the land unit evaluated (US Fish and Wildlife Service, 1981). These are not carrying capacity models, however, since they do not include other variables affecting abundance such as predation, weather, and competition (Schamberger and O'Neil, 1986).

HSI models for the species selected to represent the guilds defined in this work (Table 3) were based upon structural and compositional attributes of the forest stands described by model variables. These variables were calculated directly or indirectly from simulated 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 (2003). At the landscape level, HSI is calculated based upon GIS coverages resulting from the landscape simulations.

Five habitat suitability classes were defined based on HSI values: "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" ($0.75 < \text{HSI} \leq 1$). For each species and each year, maps of high and very high suitability habitats were generated and analyzed to quantify the landscape pattern using FRAGSTATS (McGarigal and Marks, 1995).

RESULTS

Stand-Level Habitat Suitability

Habitat suitability at the stand level depended on forest type, management type, and stand age (Figure 3). Suitability was often below the potential maximum values due to the effects of limiting components indicated in Table 4. American beaver was limited, minimally, by the presence of pine in pine-clearcutting and pine-selection stands and by reduced shrub cover in pine-clearcutting stands (food component). American woodcock in pine stands was limited by insufficient herbaceous and shrub cover and by low density of trees (cover component). Tree density was the only limiting factor in the remaining management types except in hardwood-clearcutting stands where vigorous vegetative growth following clearcutting and thinning operations was observed (Table 4).

The relatively low maximum value reached for pine warbler habitat

FIGURE 3. Habitat suitability index values along stand development for some species. Values based on average site index. Notice x-axes are not coincident among the plots. Management types refers to the combination of forest type and management system. (Man 1) pine-clearcutting, (Man 2) pine-selection, (Man 3) hardwood-clearcutting, (Man 4) hardwood-selection, and (Man 5) pine-hardwood-selection.
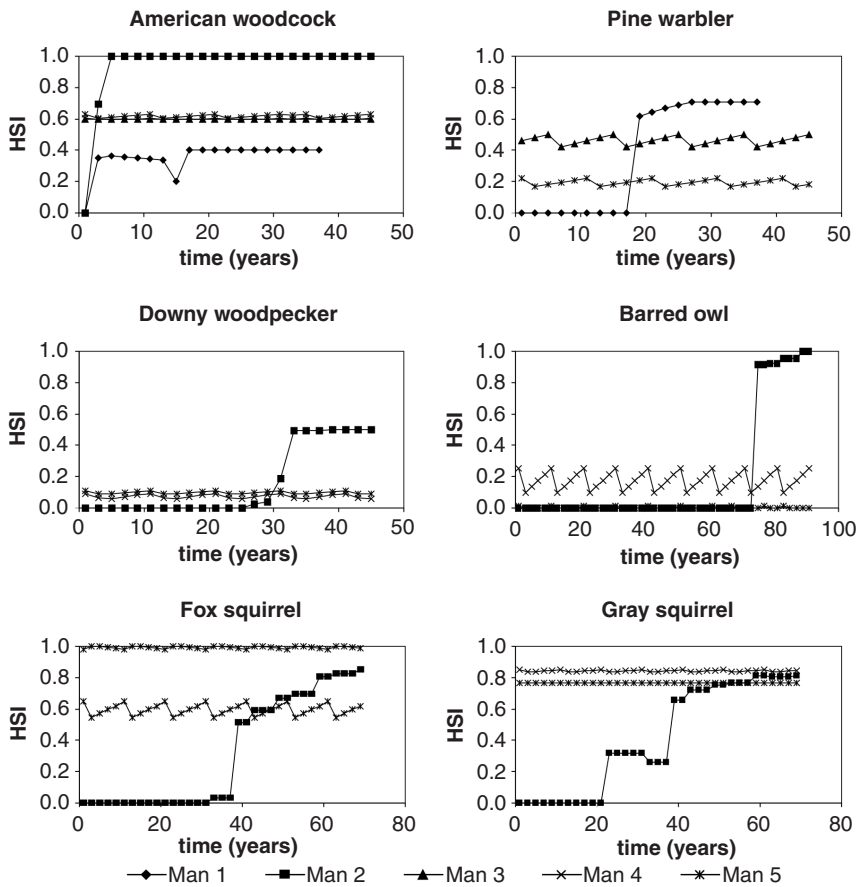
suitability in pine stands (Figure 3) was due to the "successional stage of stand" variable (Table 4). Maximum value is reached only for mature or old-growth stands. In the case of other pine management types, overstory pine cover was the major limiting factor. In mixed stands the presence of hardwoods further decreased the suitability of the stands.

TABLE 4. Limiting variables in the Habitat Suitability Models per species and management type.

| Species | Management type | | | | |
	1	2	3	4	5
American beaver	Shrub cover Composition	Not limited	Composition	Not limited	Not limited
American wood-cock	Herbaceous and shrub cover Tree density	Not limited	Tree density	Tree density	Tree density
Pine warbler	Stage	–	Pine cover	–	Pine cover Deciduous cover
Downy woodpecker	–	Basal area Snags	–	Snags	Snags
Barred owl	–	Trees ≥ 51 cm Dbh	–	Dbh	Dbh
Fox squirrel	–	Dbh	–	Not limited	Hard mast cover
Gray squirrel	–	Hard mast % Dbh	–	Not limited	Hard mast %
Eastern wild tur-key					
Cover	Evergreens	Not limited	Evergreens	Not limited	Evergreens
Summer	Herbaceous cover	Herbaceous cover	-	Herbaceous cover	Herbaceous cover
Fall/Winter/ Spring	Hard mast Soft mast	Soft mast	Hard mast Soft mast	Hard mast Soft mast	Hard mast Soft mast

Management type refers to the combination of forest type and management system; management types are: (1) pine-clearcutting, (2) pine-selection, (3) hardwood-clearcutting, (4) hardwood-selection, and (5) pine-hardwood-selection.

For year-round habitat of downy woodpecker, basal area (food component) and density of snags larger than 15 cm dbh (reproduction component) were the limiting factors in the hardwood stands managed by the clearcutting system (Table 4). Basal area was often outside the 10-20 m^2/ha optimal interval. Snags were often abundant but their occurrence was not synchronized with optimum basal area. Snags larger than 15 cm dbh were the limiting factor in the uneven-aged stands. Maximum suitability values were never reached (Figure 3).

Barred owl reproductive habitat was mainly limited by mean dbh of overstory trees (Table 4). In the hardwood-clearcutting stands, the number of trees larger than 51 cm was even more limiting until around stand age 70. In hardwood-selection stands, harvests regularly decrease average dbh. Suitability was very high for stands older than 75 years in hardwood-clearcutting stands (Figure 3).

Habitat suitability for fox squirrel in hardwood-clearcutting stands was limited by dbh of overstory trees (cover) and in pine-hardwood-selection stands was limited by cover of hard mast trees larger than 25.4 cm dbh (winter food). It was not limited in uneven-aged hardwood stands (Figure 3). Habitat suitability for gray squirrel in hardwood-clearcutting stands was partially limited by the proportion of canopy comprised of hard mast producing trees (winter food) and by dbh of overstory trees (cover). This was also the case in pine-hardwood-selection stands.

Wild turkey cover was limited in the management types with pine trees (Table 4). Summer habitat was strongly limited by the low herbaceous cover in all management types. Fall/winter/spring habitat was limited in the pine and mixed stands by lack of hard and soft mast producing trees.

Landscape-Level Habitat Suitability

The dynamics of the landscape structure presented a return interval of 30 years in the simulations (Azevedo et al., 2005). For this reason, all the results referred to a period of this duration.

The SFI and Non-SFI scenarios showed differences in habitat suitability for the species analyzed (Table 5). HSI value for pine warbler was lower in SFI than in Non-SFI. Given the similarity among runs, observed differences between management scenarios are statistically significant ($p < 0.001$; repeated measures ANOVA with management as a fixed effect and runs as random subjects). Habitat suitability for American beaver and American woodcock was slightly higher in the SFI landscape. There were substantial differences between scenarios in habitat suitability for wild turkey, fox squirrel, and gray squirrel. For these species, habitat suitability was very low in the Non-SFI scenario and relatively high in the SFI scenario. HSI values for barred owl and downy woodpecker were practically negligible in both scenarios. Habitat suitability was stable during the period simulated for all the species in both management scenarios.

Spatial Pattern

Highly suitable habitat for American woodcock was abundant only in the SFI landscape. This was distributed by very few patches spread over the landscape, with an extremely large edge length and few, small core areas (Table 6). Largest Patch Index practically equaled the Percent of Landscape indicating that near 100% of the area of this class was

TABLE 5. 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	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.

contained in a single patch (Table 6). This class corresponded mainly to the SMZs network established in the SFI scenario (Figure 4). Very high suitability habitat in the SFI scenario was comprised of several small and dispersed patches. In the Non-SFI scenario the same class occupied a larger area comprised mainly of two very large patches located in the central bottomland. Most of the landscape presented some suitability for American woodcock.

High suitability pine warbler habitat, the highest habitat class observed for the species, showed considerable fragmentation in the SFI scenario when compared to the Non-SFI scenario. In the SFI scenario it was comprised of more and smaller patches that were less aggregated, had more edges, less core area, and lower isolation (Table 6, Figure 4).

Fox and gray squirrel and wild turkey do not allow a fair comparison between scenarios since there was almost no quality habitat in Non-SFI as compared to SFI. Very high suitability habitat for fox squirrel and gray squirrel comprised the majority of suitable habitat in the SFI scenario. As in high suitability habitat for American woodcock, metrics reflected the characteristics 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 7).

HSI of wild turkey depends upon the combination of habitat components that have to be considered individually. Very high suitability

TABLE 6. Selected landscape metrics for American woodcock "high" (0.5 < HSI ≤ 0.75), and "very high" (0.75 < HSI ≤ 1) suitability habitat classes. All values are averages for three simulation runs and 15 observation dates.

| | American woodcock | | | | Pine warbler | |
| | "high" (0.5 < HSI ≤ 0.75) | | "very high" (0.75 < HSI≤1) | | "high" (0.5 < HSI ≤ 0.75) | |
Variable	SFI	Non-SFI	SFI	Non-SFI	SFI	Non-SFI
Percentage of Landscape (%)	26.8	4.1	4.0	8.8	25.8	32.9
Patch Density (#/100 ha)	0.2	0.2	0.4	0.1	1.3	0.4
Edge Density (m/ha)	69.7	4.8	6.8	6.6	37.4	19.7
Largest Patch Index (%)	26.8	1.6	0.7	5.0	2.9	13.7
Landscape Shape Index	25.7	4.9	7.0	4.5	15.0	7.5
Mean Patch Area (ha)	165.4	22.9	10.4	185.7	20.8	89.3
Mean Fractal Dimension Index	1.13	1.10	1.09	1.13	1.10	1.09
Area-Weighted Mean Fractal Dimension Index	1.39	1.07	1.10	1.15	1.13	1.13
Core Area Percentage of Landscape (%)	5.9	1.4	0.5	4.4	4.8	17.3
Mean Core Area (ha)	36.3	7.8	1.2	93.0	3.9	47.0
Mean Core Area Index (%)	2.3	15.0	4.8	38.9	8.2	19.9
Mean Proximity Index	1645.4	12.9	60.2	543.1	334.1	447.0
Mean Euclidean Nearest Neighbor Distance (m)	153.0	722.8	160.5	192.4	80.6	212.2
Interspersion and Juxtaposition Index (%)	51.9	69.0	53.7	77.3	14.6	23.7

cover habitat, very high suitability fall, winter, spring food habitat, and low suitability summer food/brood habitat in the SFI scenario (Table 8) shared the properties described above for networks of SMZs. This is of particular relevance in the case of cover habitat since it is the limiting component in both scenarios.

Suitable habitat for barred owl and downy woodpecker was extremely scarce for any of the management scenarios. Few, very small, and isolated very high suitability patches provided the only quality habitat for barred owl. In SFI, the SMZ network provided relatively abundant low suitability class habitat for both species although the HSI value for downy woodpecker was very small (Figure 3). In the case of American beaver, landscape metrics were very difficult to interpret and sometimes meaningless given the way HSI was calculated (within 0-100 and 100-200 m buffers).

FIGURE 4. Examples of spatial pattern of habitat suitability classes for the study area in alternative management scenarios. Images refer to simulation year 156.
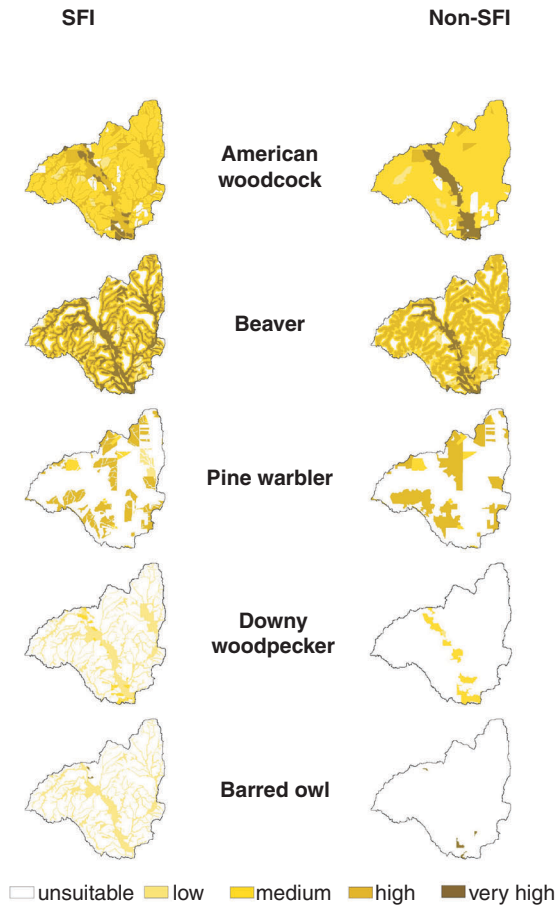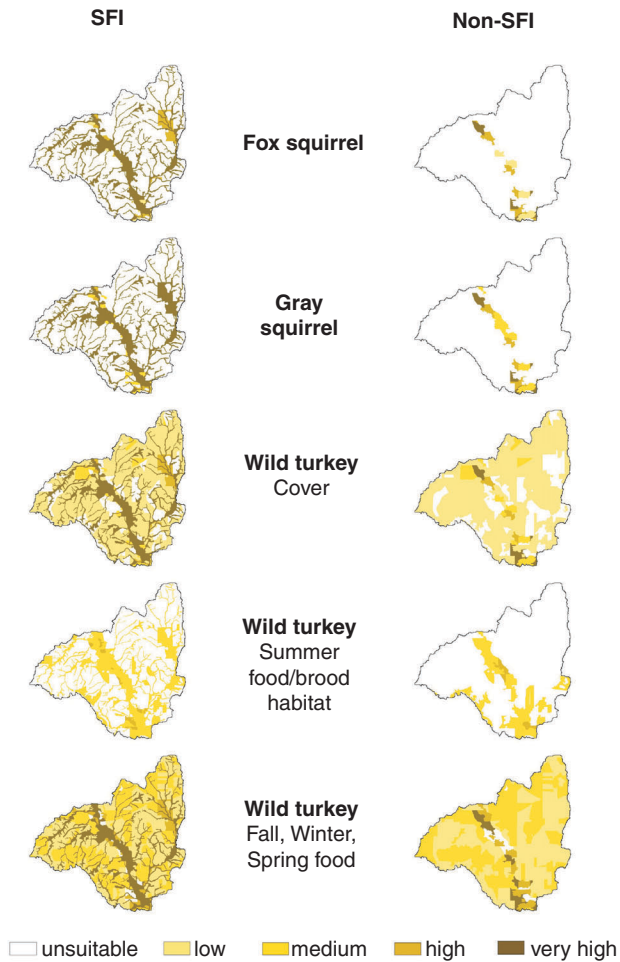
FIGURE 4 (continued)

DISCUSSION

Landscape-Level Habitat Suitability

Differences between landscapes in terms of landscape-level HSI are explained by differences in composition of forest and management types (Table 9) and by stand level habitat suitability (Figure 3). Certain

TABLE 7. Selected landscape metrics for fox and gray squirrel "high" (0.5 < HSI ≤ 0.75), and "very high" (0.75 < HSI ≤ 1) suitability habitat classes. All values are averages for three simulation runs and 15 observation dates.

	Fox squirrel				Gray squirrel			
	"high" (0.5 < HSI ≤ 0.75)		"very high" (0.75 < HSI ≤ 1)		"high" (0.5 < HSI ≤ 0.75)		"very high" (0.75 < HSI ≤ 1)	
Variable	SFI	Non-SFI	SFI	Non-SFI	SFI	Non-SFI	SFI	Non-SFI
Percentage of Landscape (%)	2.9	2.2	22.1	0.9	0.7	1.7	24.4	1.7
Patch Density (#/100 ha)	0.4	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Edge Density (m/ha)	6.2	3.3	70.5	1.8	1.8	2.4	69.7	2.9
Largest Patch Index (%)	0.7	0.9	22.0	0.5	0.2	0.8	24.3	0.7
Landscape Shape Index	7.0	4.3	28.6	3.9	4.3	3.6	26.9	4.5
Mean Patch Area (ha)	8.1	26.4	154.9	13.3	5.4	30.2	169.6	17.8
Mean Fractal Dimension Index	1.11	1.12	1.17	1.13	1.10	1.11	1.17	1.13
Area-Weighted Mean Fractal Dim. Index	1.09	1.12	1.41	1.12	1.10	1.12	1.40	1.12
Core Area Percentage of Landscape (%)	0.4	0.5	3.2	0.1	0.0	0.4	4.7	0.3
Mean Core Area (ha)	1.0	5.8	22.5	1.6	0.1	6.7	32.8	3.1
Mean Core Area Index (%)	3.5	13.8	1.8	5.6	1.1	16.5	2.3	8.4
Mean Proximity Index	56.4	17.4	1193.6	2.2	4.8	9.0	1392.3	11.5
Mean Eucl. Nearest Neighbor Distance (m)	172.6	670.0	128.1	1227.2	641.9	1214.1	126.3	715.4
Interspersion and Juxtaposition Index (%)	58.4	54.1	19.4	54.3	86.2	75.0	17.2	76.9

SFI measures could have strong influence on landscape structure. For example, the implementation of SMZs in pine stands will eventually change these areas to foster hardwood domination with effects in terms of habitat suitability at the stand but also the overall level. The SFI landscape is comprised of stands of five different management types whereas Non-SFI presents only three types (Table 9). Hardwood cover is more abundant in SFI than in Non-SFI. Approximately 1000 ha of hardwoods in SFI result from the "conversion" of pine into hardwoods within SMZ buffer strips. Evenness among management types is also higher in SFI.

Overall habitat suitability for wild turkey, fox and gray squirrels was very low in the Non-SFI scenario because hardwood stands had the

TABLE 8. Selected landscape metrics for wild turkey cover, Summer food/brood, and Fall/Winter/Spring "high" (0.5 < HSI ≤ 0.75), and "very high" (0.75 < HSI ≤ 1) suitability habitat classes. All values are averages for three simulation runs and 15 observation dates.

| | Cover | | | | Summer food/brood | | Fall/Winter/Spring | | | |
| | "high" (0.5 < HSI ≤ 0.75) | | "very high" (0.75 < HSI ≤ 1) | | "high" (0.5 < HSI ≤ 0.75) | | "high" (0.5 < HSI ≤ 0.75) | | "very high" (0.75 < HSI ≤ 1) | |
Variable	SFI	Non-SFI	SFI	Non-SFI	SFI	Non-SFI	SFI	Non-SFI	SFI	Non-SFI
Percentage of Landscape (%)	2.6	1.4	22.5	2.0	1.1	2.1	4.1	4.5	23.1	3.4
Patch Density (#/100 ha)	0.3	0.1	0.1	0.1	0.2	0.1	0.5	0.1	0.1	0.1
Edge Density (m/ha)	5.2	2.0	70.7	3.1	2.6	2.9	8.4	4.9	70.8	4.4
Largest Patch Index (%)	0.7	0.8	22.5	0.9	0.2	1.0	0.7	2.2	23.0	1.3
Landscape Shape Index	6.2	3.2	28.4	4.5	5.0	3.8	8.1	4.5	28.2	4.9
Mean Patch Area (ha)	8.7	31.5	157.7	21.0	5.8	33.7	8.3	63.8	160.3	31.2
Mean Fractal Dimension Index	1.10	1.11	1.17	1.12	1.09	1.09	1.10	1.12	1.17	1.12
Area-Weighted Mean Fractal Dim. Index	1.09	1.11	1.41	1.12	1.09	1.10	1.09	1.13	1.41	1.12
Core Area Percentage of Landscape (%)	0.4	0.3	3.3	0.4	0.0	0.4	0.4	1.5	3.6	0.9
Mean Core Area (ha)	1.2	7.6	23.4	4.4	0.2	6.4	0.9	21.6	25.2	8.4
Mean Core Area Index (%)	4.1	17.3	1.8	10.1	1.3	13.3	3.4	25.3	1.9	15.3
Mean Proximity Index	65.0	7.3	1262.1	15.7	9.2	73.8	53.5	123.5	1409.5	28.9
Mean Eucl. Nearest Neighbor Distance (m)	260.2	1487.0	126.3	672.9	467.2	1113.2	146.4	504.5	124.9	366.8
Interspersion and Juxtaposition Index (%)	69.4	77.7	61.4	78.9	63.8	52.5	70.8	93.6	72.9	91.5

highest suitability whereas pine stands had very low suitability (Figure 3 for fox and gray squirrel). These changes in forest types, however, do not affect pine warbler in the same proportion. Although there was considerably more pine stands in Non-SFI, the habitat type where stand level habitat suitability could reach the maximum, landscape-level habitat suitability increased only slightly in this scenario. This was due to

TABLE 9. Area by management type in the SFI and Non-SFI scenarios.

Management type	Forest type	Silvicultural system	SFI		Non-SFI	
			Area (ha)	Area (%)	Area (ha)	Area (%)
1	Pine	clearcutting	3964.3	68.7	4993.3	86.5
2	Hardwood	clearcutting	265.8	4.6	595.2	10.3
3	Pine	selection	164.4	2.8	183.5	3.2
4	Hardwood	selection	1260.4	21.8	–	–
5	Mixed	selection	116.9	2.0	–	–

the relatively low maximum stand-level suitability (max HSI = 0.7), the relatively short period of time (11 years) that pine stands had high suitability values, and the fact that young pine stands (< 19 years) were unsuitable.

The low landscape-level suitability values for barred owl and downy woodpecker (Table 5) reflected the rarity of suitable habitat and the low HSI value for the SMZ network in the SFI scenario for these species. High habitat suitability for barred owl in a few small areas under the Non-SFI scenario (Figure 4) resulted from the application of adjacency constraints in the hardwood areas that allow some small hardwood fragments to grow for longer periods of time. There was no high or very high suitability habitat for downy woodpeckers under either management scenario.

American beaver habitat quality was higher in the SFI than in the Non-SFI scenario. This was due to the fact that stands under hardwood-selection and pine-hardwood-selection management, which were always highly suitable (HSI = 1), were absent from the Non-SFI scenario.

Spatial Pattern

The SFI program as simulated in this work changed the spatial pattern of habitats in two ways: (1) fragmentation and (2) establishment of narrow and elongated areas in a network configuration. The first effect was observed for pine warbler and the second for American woodcock, fox and gray squirrel, and wild turkey, and for the less suitable habitat of downy woodpecker and barred owl. Implications of these changes are

unknown but can be speculated based upon the knowledge of the life history of the species analyzed.

SFI created fragmentation of pine warbler habitat mainly by dissecting large pine stands through the establishment of SMZs (Table 6, Figure 4). SMZs are, however, forested and permanent in the landscape and are also usually narrow. Although the effects of this configuration on pine warbler is unknown, the documented behavior of the species, including its ability to use pine trees within hardwood stands (Rodewald et al., 1999) indicates that this fragmentation is unlikely to have considerable effects on pine warbler populations (see discussion in Azevedo et al., 2005).

Suitable winter habitat of American woodcock was primarily associated with the network of riparian buffers. The species uses open fields, recently harvested stands, and dense hardwood stands (Keppie and Whiting, 1994; Berdeen and Krementz, 1998) but bottomlands are among the preferred habitats (Dessecker and McAuley, 2001). The fact that riparian buffers were widely spread over the study area and had a large amount of interface (edges) with other habitat types is likely to benefit the species.

Fox squirrels prefer edges (Alexander, 1994; Derge and Yahner, 2000) and can use open agricultural fields among habitat patches (Nupp and Swihart, 2000). Management practices to improve fox squirrel habitat in East Texas involve design of patches to maximize edge proportion as well as corridors for movement (Alexander, 1994). Gray squirrel is considered a more interior species than fox squirrel (Derge and Yahner, 2000; Zollner, 2000) but is common in a wide range of habitat types including urban and open systems such as cemeteries and campus when hardwoods are present (Williamson, 1983). The species is affected by habitat patch size and isolation in agriculturally fragmented landscapes (Goheen et al., 2003), where patches larger than 5 ha connected by corridors, including riparian strips, to other forest areas are required (Nupp and Swihart, 2000). SMZs in the SFI scenario provided such corridors. Fischer and Holler (1991) found narrow hardwood buffers along streams to be important components of gray squirrel habitat in Alabama. Dickson and Huntley (1987) found SMZs to be preferable habitat of both squirrel species in East Texas.

The network of SMZs and the adjacent mixed pine-hardwood stands provided simultaneously the three components of the habitat required by wild turkey including cover, the critical component in the overall HSI. Turkeys are not confined to particular habitats and move frequently among them. High edge length appeared positively related to

turkey densities in New York State (Glennon and Porter, 1999). In the South, SMZs are used by turkeys during all seasons and are key habitat to sustain viable populations in managed pine forests (Burk et al., 1990; Hurst and Dickson, 1992). Predation of turkeys in stream valleys and in forest edges can, however, be higher than in other habitats (Thogmartin and Schaeffer, 2000).

Downy woodpecker is considered a generalist (Whitaker and Montevecchi, 1999) and frequently uses open habitats, residential areas, and forest edges (Jackson and Ouellet, 2002), as well as buffer strips (Dickson et al., 1995). There were fewer and smaller patches of the most suitable habitat for downy woodpeckers in the SFI scenario than in the Non-SFI scenario. Schroeder (1982b) suggested 4 ha as the minimum size of potentially useable habitat for downy woodpecker. Although these small high-quality patches were contiguous to the large amount of low-quality habitat associated with the SMZ network it is not clear whether habitat unit size would be a concern.

There were only isolated small patches of suitable habitat for barred owl in either scenario. There was, however, a considerable amount of lower quality habitat in the SFI scenario within the SMZ network.

Given the dependence of beaver on streams and the similar suitabilities of different types of stands, the spatial distribution of beaver habitat differed little between the two scenarios. The SFI landscape, however, did favor the species by providing continuous and permanent forest cover along the streams.

SMZs

SMZs are crucial elements of the SFI scenario. Although initially implemented to control water quality, their role in wildlife conservation, particularly in short rotation forests, has been recognized. SMZs increase diversity of habitats by creating edges (Thurmond and Miller, 1994), habitat features such as den trees and snags (Wigley and Roberts, 1997), and mast- and forage-producing plants (Dickson et al., 1995). Several species that are not able to use pine habitats can be preserved only due to the presence of SMZs (Thurmond and Miller, 1994). SMZs are able to retain a large percentage of the local species that otherwise would be largely lost after harvesting (Cockle and Richardson, 2003; Vesely and McComb, 2002). At the landscape level, SMZs are important also in terms of movement of organisms within networks (Machtans et al., 1996; Burbrink et al., 1998) and spread of organisms over areas of less suitable habitats (Fischer and Holler, 1991).

A major issue of SMZs is their width. Buffers tend to maintain generalist and edge species. Some interior species are preserved as well in SMZs but others are excluded from relatively narrow SMZs (Thurmond and Miller, 1994; Thurmond et al., 1995; Meiklejohn and Hughes, 1999). In East Texas there is a positive relation between bird communities (breeding abundance and richness) and buffer width (Dickson et al., 1995). Narrow SMZs (15-25 m) are used by species associated with young pine stands and edge habitats whereas wide zones (50-95 m) were occupied by species associated with mature forest (Dickson et al., 1995). A minimum width of 30 m and a preferred width of 50 m are suggested to increase breeding birds in pine plantations. Rudolph and Dickson (1990) suggest 30 m to maintain reptile and amphibian richness in managed pine stands. The highest density of downy woodpeckers in buffer zones in recently harvested pine stands was observed in intermediate and wide zones (30-40 m and 50-95 m) (Dickson et al., 1995). Dickson and Huntley (1987) found abundant squirrels in buffers > 50 m wide in East Texas in contrast to smaller buffers. In Mississippi turkeys use all sizes of SMZs (30-45, 84-104, and 170-179 m) for traveling, roosting, feeding, loafing and summer cover (Burk et al., 1990).

The SMZs in our study were relatively narrow, averaged approximately 50 m and ranged from 30 m to more than 250 m. Although a minimum width is difficult to define and is species dependent, the SMZs width in this study appears not limiting with respect to the species considered in this study based on the habitat modeling.

Habitat Improvement

The landscape managed according to the SFI guidelines was able to offer suitable habitat for species representing a wider range of habitat requirements than the Non-SFI scenario. Some recommendation can be presented, however, in order to improve habitat components at the stand and landscape levels.

At the stand level, extended rotations and retention of individual or clustered trees or snags in harvested stands will improve barred owl, downy woodpecker, and pine warbler habitat suitability. Changing target distributions and maximum size of trees to harvest will improve habitat suitability for downy woodpeckers, barred owls, fox, and gray squirrels in uneven-aged stands. If these measures are directed to mast producer trees, habitat for turkey and squirrels will also be improved. Management of herbaceous and shrub vegetation will also improve habitat for American woodcock and turkey.

Long rotations are used to increase structural complexity in managed forests (Franklin et al., 1997) and have been defended to increase breeding bird diversity (Conner et al., 1979). Partial retention either in the form of dead or live isolated or clustered trees is an important measure for the maintenance of birds in forests (Dickson et al., 1983; Merrill et al., 1998; Lance and Phinney, 2001). Retention is a central procedure in conservation of forest diversity (e.g., Hunter, 1990; Franklin et al., 1997; Lindenmayer and Franklin, 1997).

A proper evaluation of the spatial characteristics of pine warbler's habitat is contingent on better understanding of the sensitivity of the warbler to patch size and edges, for which considerable disagreement exists in the literature (Rodewald et al., 1999; Boulinier et al., 1998; McIntyre, 1995; Noss, 1991). If pine warbler was indeed sensitive to SMZ edges and a 30-ha minimum size was required for core area, as discussed in Azevedo (2005), the landscape under the SFI scenario would provide no pine warbler suitable habitat. This situation could be alleviated by increasing the clearcut size, as argued elsewhere to reduce fragmentation (Hagan et al., 1997). However, given the high density of the SMZ network it is difficult to implement large-size clearcuts in this scenario. A possible alternative is to set aside large mature pine stands in the landscape as pine warbler breeding habitat.

Barred owls require large unfragmented mature forest areas (Mazur and James, 2000), although minimum habitat area is unknown (Allen, 1987b). In addition to the recommendations for stand level management mentioned previously, it is important to consider aggregation of hardwood stands to create reasonably large areas of suitable breeding habitat. Bottomlands are good candidates for management of barred owl habitat; the upland SMZs can also be managed for that purpose as well through hardwood-selection management.

Conservation of some of the species considered here rely upon SMZs, namely fox squirrel (Alexander, 1994), gray squirrel (Fischer and Holler, 1991), and turkey (Burk et al., 1990; Hurst and Dickson, 1992). Literature also suggests that downy woodpeckers benefit from SMZs after clearcutting (Dickson et al., 1995).

Combination of the SFI measures and additional measures for particular circumstances can help better achieve the biodiversity objectives in forest management. SMZs, retention, and long rotations in portions of a landscape appear to create the stand and landscape habitat structural features that contribute to the maintenance of habitat for species of diverse habitat requirements and hence the overall biodiversity.

CONCLUSION

SFI provides a group of measures that benefit biodiversity in managed landscapes. The species selected in this work indicated that habitat suitability of the landscape in general increased as a result of the implementation of the SFI measures. They indicated also that there was more diversity and evenness of habitat conditions in the study area and that the habitat landscape structure was usually not limiting for these species.

The landscape under SFI, however, did not support mature pine and hardwood stands that are known for the diversity they retain and particular habitat they provide for species that are exclusively associated with these environments such as the red-cockaded woodpecker (*Picoides borealis*) and the brown-headed nuthatch (*Sitta pusilla*) in pine stands and the prothonotary warbler (*Protonotaria citrea*) and Swainson's warbler (*Limnothlypis swainsonii*) in hardwoods (Conner and Dickson, 1997). Habitat for species like these can, however, be maintained through landscape and stand management. These measures can potentially be incorporated into the SFI program as essential to wildlife conservation, one of the major aims of SFI.

Most of the species considered in this study benefited directly from the implementation of SMZs in the SFI scenario and some of them found no suitable habitat in the alternative scenario. SMZs, however, increased fragmentation of the pine cover, which might limit the habitat for the species dependent on large blocks of pine habitats of older ages. The corresponding increase in edges in the landscape could potentially increase edge-related processes, such as nest predation and parasitism (Conner and Dickson, 1997). These edge-related processes, however, are landscape context dependent (Donovan et al., 1997); the low edge contrast between the SMZs covered with mature forests and the adjacent pine stands is unlikely to result in significant negative impact associated with the edge effects.

Results of this simulation study show that southern forested landscapes managed under the SFI program appear superior in supporting biodiversity, through providing greater amount of suitable habitats for the array of a set of vertebrate species representing the spectrum of habitat requirements, than landscapes managed under more traditional forest management programs. Given the larger extent of forests managed by forest products companies committed to the SFI in the South, this program can play an important role in the conservation of biodiversity at the local and broader scales.

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