Chapter 13 Application of Landscape and Habitat Suitability Models to Conservation: The Hoosier National Forest Land-management Plan

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Abstract

We demonstrate an approach to integrated land-management planning and quantify differences in vegetation and avian habitat conditions among 5 management alternatives as part of the Hoosier National Forest planning process. The alternatives differed in terms of the type, extent, magnitude, frequency, and location of management activities. We modeled ecological processes of disturbance (e.g. tree harvest, prescribed fire, wildfire, windthrow) and succession using LANDIS, a spatially explicit landscape decision-support model, and applied habitat suitability models for six species of birds to the output from that model. In this way, we linked avian habitat suitability models to spatially explicit vegetation change models that include ecological processes affecting vegetation composition, horizontal and vertical structure, and configuration. The detailed and synthetic nature of our approach provides a framework and structure that (1) is readily conveyed to multiple constituencies, (2) is based on explicitly stated assumptions and relationships, (3) provides a basis for testing, refinement, and extension to other forest commodities and amenities, and (4) provides a way to consider cumulative effects of multiple forest attributes at multiple spatial and temporal scales.

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Keywords

Decision support, dynamic landscape model, forest planning, habitat suitability models, LANDIS, multi-resource evaluation, *Scolopax minor*, *Dendroica cerulea*, *Bonasa umbellus*, *Hylocichla mustelina*, *Helmitheros vermivorus*, *Icteria virens*.

13.1 Introduction

A common goal in National Forest planning is to describe relationships of management actions, vegetation conditions, and wildlife habitat conditions for large landscapes. Inherent in most planning efforts are concepts of landscape ecology (e.g. ecological processes of disturbance and succession) as well as the implications of those processes on the composition, horizontal and vertical structure, and configuration of vegetation and wildlife habitat. Problem definition and priority setting are critical elements of planning, especially when multiple management objectives are desired, when competition or trade-offs among management objectives exists, or when management objectives are unequally weighted (Lindenmayer et al. 2008). Because forest planning often involves many integrated objectives and multiple wildlife species, some modeling approaches (e.g. optimization models, Lu and Buongiorno 1993) may be difficult if not impossible to implement (Thompson and Millspaugh 2009). When multiple, integrated, or adaptive objectives exist, the conceptual model used to characterize and simulate landscape change should provide the spatial and temporal information needed for management decisions (Lindenmayer et al. 2008). Thus, for planning purposes an ideal modeling approach would consider broad-scale landscape dynamics while retaining the fine-scale resolution needed to quantify changes in wildlife habitat (Zollner et al. 2008; Noon et al. 2009).

Our objectives are to demonstrate an approach to integrated land-management planning and to quantify differences in vegetation and avian habitat conditions among management alternatives using the Hoosier National Forest planning process as both a vehicle and application of this approach. We build upon previous planning efforts for the Hoosier National Forest lands that included the evaluation of multiple management alternatives on vegetation conditions (Gustafson and Crow 1994) and salamander habitat (Gustafson et al. 2001). As in the previous planning efforts, the management alternatives differ in terms of the type, extent, magnitude, frequency, and location of management activities. We modeled ecological processes of disturbance and succession using a spatially explicit landscape decision-support model, and applied habitat suitability models for six species of birds to the output from that model. In this way, we linked avian habitat suitability models to vegetation change models that include ecological processes affecting vegetation composition, vertical and horizontal structure, and configuration of vegetation patches.

13.1.1 Overview of the Hoosier National Forest planning process

The Hoosier National Forest (HNF) is located in southern Indiana, USA and consists of four administrative units totaling approximately 261,000 ha. Only 31 percent (approximately 81,000 ha) of the land within the administrative unit boundaries is HNF, the remainder is privately owned (Fig. 13.1). This region was subject to intensive forest harvest from 1870 to 1910, shifting the tree species composition of a maple-beech and oak-hickory forest to a primarily oak-hickory forest. This was followed by a period of settlement and conversion to agricultural land uses that persisted into the early 1930s. At present, 96 percent of HNF lands are characterized as second-growth forest, with 75 percent of the total forest area older than 50 years of age (Woodall et al. 2007). The fragmented nature of the HNF, coupled with public opposition to tree harvest over the past several decades, has strongly influenced current land-management issues (Welch et al. 2001).

The HNF Planning Team, in conjunction with the public, identified watershed health, ecosystem sustainability, and recreation management as issues to address in the planning process. The primary means for maintaining watershed health and ecosystem sustainability on the HNF is vegetation management, typically through the application (or absence) of prescribed fire or tree harvest. Because vegetation management also affects habitat for bird species, there was strong interest in monitoring changes in habitat for a diverse suite of bird species.

The HNF Planning Team considered five forest management alternatives, each of which contained different tree harvest procedures (e.g. even-aged and uneven-aged techniques), amounts and locations of tree harvest and prescribed burning treatments, and types of recreation opportunities (Table 13.1). A detailed description of the forest management alternatives is provided in Rittenhouse (2008) and US Department of Agriculture Forest Service (2006). Alternative 1, referred to as the No Action alternative in the Draft Environmental Impact Statement (US Department of Agriculture Forest Service 2006), represented continuation of the forest management practices that were implemented with the 1985 Forest Plan as amended. For all management alternatives except Alternative 2, tree harvest and prescribed fire were used to maintain biological diversity and promote oak-hickory regeneration within specified management units. Alternative 2 emphasized natural processes and limited vegetation management. After reviewing the avian habitat suitability model output from initial model runs, the HNF Planning Team created a 5,260-ha focal area within the Tell City District (southern-most administrative unit) (Fig. 13.1). The majority of even-aged management was conducted within the focal area to provide habitat for bird species such as ruffed grouse

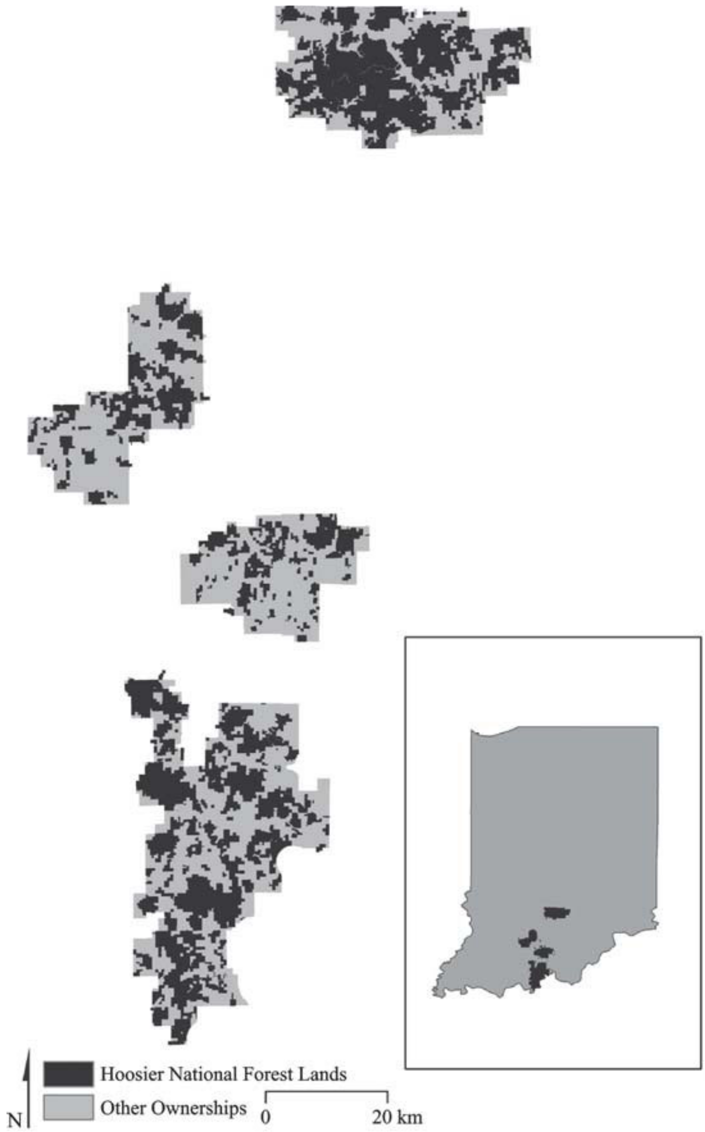


Fig. 13.1 The four Hoosier National Forest administrative units in southern Indiana. National Forest ownership is approximately 81,000 ha, or 31 percent of the total 261,000 ha within the administrative units. The majority of the remaining area within the administrative unit boundaries is privately owned.

and yellow-breasted chat that depend on early successional forest (see Table 13.2 for scientific names of bird species). Alternatives 3, 4 and 5 include the focal area.

Table 13.1 Approximate area in ha (percent) treated by management practices each decade for the 150-year planning horizon for 5 management alternatives on the Hoosier National Forest, Indiana. Alternative 5 differs from Alternative 1 only in concentrating most of the even-aged harvest in a 5,260 ha block designated for improved habitat for early successional bird species.

Alternative	Emphasis	Uneven-aged harvest	Even-aged harvest	Prescribed fire
1	Ecosystem sustainability, wilderness areas, and recreation areas	1,493 (1.8)	1,157 (1.4)	8,095 (10)
2	Natural processes and old growth	0	0	0
3	Diversity of forest age classes, increase recreational opportunities, and harvest focal area	1,643 (2.0)	2,294 (2.8)	20,235 (25)
4	Native hardwood restoration, early successional habitat, and harvest focal area	2,088 (2.6)	3,893 (4.8)	40,470 (50)
5	Alternative 1 with harvest focal area	1,493 (1.8)	1,157 (1.4)	8,095 (10)

13.2 Methods

We developed an approach to land-management planning on the Hoosier National Forest that contained desirable features from a large-scale, landscape perspective while retaining the fine-scale information useful for evaluating avian habitat suitability. The following sections describe modeling spatial and temporal trends of vegetation change and linking that change to avian habitat suitability.

13.2.1 Modeling vegetation change using LANDIS

We simulated spatial and temporal trends of vegetation change using LANDIS (version 3.6), a spatially explicit, landscape-scale, decision-support tool that models vegetation growth, succession, and response to disturbance by tree harvest, wind, and fire (He et al. 2003; He 2009). In LANDIS, a landscape is organized as a raster array of cells that represent sites in the landscape. Cell size in LANDIS is user-defined, and we used a 10m by 10m cell size (0.01 ha) because in this ecosystem it approximated the size of a canopy gap created by the death or harvest of a mature tree. Each cell contains a matrix of vegetation information such as the tree species (or species groups) present or absent in the cell and the 10-year age class of each species cohort.

We simulated four spatial processes (fire, windthrow, harvesting, seed dispersal) and four temporal processes (succession, regeneration, age-dependent mortality, sequential patterning of disturbance events) that affect the projected species composition and age structure of individual cells and, in the aggregate, of the landscape. To do this, we first calibrated the LANDIS regeneration and succession algorithms for 14 tree species or groups of similar species common to the HNF using Forest Inventory and Analysis (FIA) data for southern Indiana (see Rittenhouse 2008 for details): Eastern red cedar (J*uniperus virginiana* L.), pines (*Pinus echinata* Mill., *P. virginiana* Mill., and *P. strobus* L.), sugar maple (*Acer saccharum* Marsh.), red maple (*Acer rubrum* L), hickories (*Carya* spp.), American beech (*Fagus grandifolia* Ehrh.), ash (*Fraxinus americana* L. and *F. pennsylvanica* Marsh.), yellow poplar (*Liriodendron tulipifera* L.), black cherry (*Prunus serotina* Ehrh.), white oak (*Quercus alba* L.), chestnut oak (*Q. prinus* L.), red oaks (*Q. rubr*a L., *Q. velutina* Lam., and *Q. coccinea* Muenchh.), pin oaks (*Q. ellipsoidalis* E. J. Hill and *Q. imbricaria* Michx.), and elms (*Ulmus* spp.). We made small adjustments to the regeneration coefficients to make long-term shifts in species composition consistent with expected changes in species composition based on expert opinion from regional managers.

Next, we established initial vegetation conditions (tree age and species) for public and private lands within the HNF administrative unit boundary from FIA data, the HNF's inventory database, land-use and land-cover data, and Indiana GAP data (http://gapanalysis.nbii.gov). We estimated the expected number of trees by age class (seedling, age 1-10 years; sapling, age 11-40 years; pole, age 41-60 years; and mature, age > 60 years) for each cell in a given stand. We used FIA data to develop observed species frequency distributions by forest cover type, age class, and ecological land type, and we assigned tree species to each cell in a specific stand by random draw from the appropriate frequency distribution.

We lacked spatially explicit maps of forest cover type, age class data, and ownership boundaries for forest stands on private lands within the HNF administrative units. Therefore, we utilized the digitized land use and land cover data created by Pangea Information Technologies (2003), the Indiana GAP data (http://gapanalysis.nbii.gov), and satellite data classified by the National Agricultural Statistics Service (2008) to map locations of nonforest, coniferous forest, upland deciduous forest, mixed forest, bottomland forest types and water for private lands. We assigned an age class and forest cover type based on the frequency distribution of forest age classes and forest cover types from FIA data for southern Indiana. We also created an artificial private land ownership boundary layer with ownership sizes approximating the size distribution of forested land parcels reported by Birch (1996). This layer was used during LANDIS simulations to identify management units (e.g. stands) for private lands where stand boundary maps were unavailable. We combined our derived maps of initial conditions for private lands with corresponding maps for the HNF and used them together as initial conditions for LANDIS scenario analyses for each of the four HNF administrative units (Fig. 13.1).

We modeled tree harvests to mimic the proposed harvest actions for each Forest Plan alternative (Table 13.1) (US Department of Agriculture Forest

Service 2006) using the methodology described by Gustafson et al. (2000). The HNF designated Management Areas that divide the forest into thematic zones based on suitable management activities (e.g. riparian buffers vs. wilderness vs. timber management vs. habitat for a designated bird species). We used the Harvest module for LANDIS (Gustafson et al. 2000), which allows tree harvest activity to vary within each management area, to model differences in management practices among management areas as specified in each Forest Plan alternative.

LANDIS output included maps of tree species composition and dominance, tree age classes, fire disturbance, wind disturbance, and tree harvest disturbance in 10-year increments for each cell in the landscape. We expected the forest plan alternatives would differentially affect the spatial and temporal distribution of forest conditions based on the differences among the alternatives in the type, frequency, and extent of disturbances. To capture those differences, we summarized forest and landscape attributes for spatially defined groups of cells at different spatial scales (e.g. administrative units, management areas, or the entire HNF). Attributes included tree age class distribution, tree species composition, contiguous core forest area and edge density.

13.2.2 Linking vegetation change to avian habitat suitability

We used Landscape HSImodels version 2.0 (Dijak et al. 2007) to evaluate breeding habitat suitability or year-long habitat suitability for 6 bird species selected by the HNF Planning Team (Table 13.2). Landscape HSImodels is a Microsoft Windows-based software program that uses suitability indices (SI) to assign habitat quality across large landscapes for individual species (Larson et al. 2003; Dijak et al. 2007; Dijak and Rittenhouse 2009). Habitat suitability is described by an empirical or assumed relationship between habitat quality and resource attributes on a relative scale that ranges from 0 (unsuitable habitat) to 1 (highly suitable habitat) (US Fish and Wildlife Service 1980, 1981). We developed the suitability indices with specific objectives in mind (Rittenhouse et al. 2007). First, the SIs addressed habitat requirements for reproduction or survival and they were supported by empirical data, published literature, or expert opinion. Second, all SIs were estimated from available GIS (geographic information system) layers of vegetation (and landscape) structure and composition. Third, all required GIS layers of vegetation information were derived from LANDIS projections. Thus, we could apply the habitat suitability index (HSI) models to modeled future vegetation conditions and compare landscapes in terms of future habitat conditions.

The avian habitat suitability models use LANDIS output as well as ecological land type and land-cover type information (Table 13.2). We used ecological land types (ELT) derived from 10m Digital Elevation Model (DEM) layers by Guafon Sho (Purdue University). The ELT coding followed Van Kley et al.

Table 13.2 Description of habitat suitability index models for bird species used to evaluate proposed management alternatives on the Hoosier National Forest, Indiana.

Species	Life requisite	Habitat requisite	Model parameters and implementation	HSI equation
American woodcock (*Scolopax minor*)	Nest sites, roost sites, and food. Display sites, roost sites, and food.	Early- and mid-successional forest. Open habitat. Interspersion of life requisites.	SI_1: Tree species SI_2: Tree age by ELT SI_3: Land cover type SI_4: Land cover type SI_5: Moving window analysis of SI_2 and SI_4	$HSI = \sqrt[2]{(\max((SI_1 \times SI_2), SI_4) \times SI_5)}$
Cerulean warbler (*Dendroica cerulean*)	Nest sites and food.	Mature deciduous forest. Large forest patches.	SI_1: Tree species SI_2: Tree age by ELT SI_3: Patch size algorithm	$HSI = \sqrt[3]{SI_1 \times SI_2 \times SI_3}$
Ruffed grouse (*Bonasa umbellus*)	Food. Nest sites, food, and cover.	Hard mast. Dense forest regen. Large habitat patches. Interspersion of life requisites. Large forested area.	SI_1: Model of tree age, tree species, and land type SI_2: Tree age by ELT SI_3: Patch size algorithm SI_4: Moving window analysis of SI_1, SI_2, and SI_3 SI_5: Patch size algorithm	$HSI = \left(\sqrt{\max\left(SI_1, \sqrt{SI_2 \times SI_3}\right) \times SI_4}\right) \times SI_5$

Continued

Species	Life requisite	Habitat requisite	Model parameters and implementation	HSI equation
Wood thrush (*Hylocichla mustelina*)	Nest sites and food.	Deciduous forest.	SI_1: Tree species SI_2: Tree age by ELT	$HSI = SI_1 \times \left(\sqrt[3]{SI_2 \times SI_3 \times SI_4}\right)$
	Post-fledging habitat.	Large forest patch. Early successional forest.	SI_3: Patch size algorithm SI_4: Tree age by ELT	
		Interspersion of life requisites.	SI_5: Moving window analysis of SI_4	
Worm-eating warbler (*Helmitheros vermivorus*)	Nest sites and food.	Deciduous forest. Large forest patch. Fire avoidance.	SI_1: Tree species SI_2: Tree age by ELT SI_3: Patch size algorithm SI_4: Fire history	$HSI = \left(\sqrt[3]{SI_1 \times SI_2 \times SI_3}\right) \times SI_4$
Yellow-breasted chat (*Icteria virens*)	Nest sites and food.	Early successional forest and old fields. Large habitat patch. Edge sensitivity.	SI_1: Tree age by ELT SI_2: Patch size algorithm SI_3: Moving window analysis of SI_2	$HSI = \left(\sqrt[2]{SI_1 \times SI_2}\right) \times SI_3$

(1994) and grouped types by slope, aspect, and relative moisture. ELT classes generally correspond to north and east (cool and mesic) slopes, south and west (warm and dry) slopes, wide ridges or upland flats, narrow ridges, and mesic bottoms. We classified land-cover type using the HNF forest type codes (for public lands) and the land-use and land-cover data described above for private lands. We collapsed the HNF forest type map and the public land-cover map into 6 general land-cover types used in the HSI models: 1) forest, 2) croplands, 3) grasslands, 4) water, 5) urban areas, and 6) roads.

Rittenhouse et al. (2007) provided a thorough discussion of habitat variables used in the development of the habitat suitability models, including literature citations supporting suitability relationships of each species. The primary input data (i.e. resource attributes) for the SIs included raster maps of tree species, tree age, ecological land type, land-cover type, and fire history. Landscape HSImodels contains functions to compute patch size, edge effects, distance to resource, and composition of habitat. Thus, the suitability value of any given cell on the landscape considered attributes of that cell as well as the attributes of the surrounding cells in the landscape (Table 13.2). Landscape HSImodels computes a single Habitat Suitability Index value representing the overall habitat suitability for each species, for each cell.

We applied the species-specific habitat suitability models to raster maps from LANDIS output at four time periods for each management alternative: initial conditions, year 10, year 50, and year 150. We followed traditional habitat evaluation procedures and used the habitat unit as our metric for the amount of suitable habitat. We defined a habitat unit as the HSI value of an individual cell multiplied by the cell's area (0.01 ha). For each bird species we summarized HSI values for each 0.01 ha site across the entire HNF landscape and grouped habitat units by five HSI categories (0, 0.01-0.24, 0.25-0.49, 0.50-0.74, and 0.75-1.00). For convenience, we refer to habitat units with HSI values >0.01 as suitable habitat, and HSI values of 0.75-1.00 as high quality habitat. The HNF Planning Team assumed habitat suitability was synonymous with population viability; therefore we did not assess population viability (see Section 13.4.3 for discussion of this issue).

13.3 Results

We simulated changes in vegetation conditions and avian habitat suitability for five management alternatives. The following sections detail spatial and temporal changes in forest age class distribution, tree species composition, and avian habitat suitability. The primary emphasis for planning purposes was to summarize effects at short, intermediate, and long periods of plan implementation for the HNF. Therefore, we typically present results only for HNF ownership at simulation year 0, 10, 50, and 150 for each plan alternative.

13.3.1 Simulated changes in vegetation conditions

The five management alternatives differed in the type and frequency of disturbance due to tree harvest and prescribed fire, resulting in differences in the temporal and spatial distribution of forest by age class (Figs. 13.2, and 13.3), landscape attributes of contiguous core forest area (Fig. 13.4) and edge density (Fig. 13.5), and the temporal and spatial distribution of tree species composition (Figs. 13.6, and 13.7). The primary emphasis on planning purposes was to summarize effects at short, intermediate, and long periods of plan implementation for the HNF. Therefore, we typically present results only for HNF ownership at simulation year 0, 10, 50, and 150 for each plan alternative.

13.3.1.1 Spatial and temporal changes in forest age class distribution

The initial forest age class distribution was the same for all management alternatives. At year 0 of the simulation, less than 1 percent of the initial HNF landscape was classified in the seedling age class (1-10 years old), 18 percent was in the sapling age class (11-40 years old), 15 percent was in the pole age class (41-60 years old), and two thirds of the HNF was in the mature age class (>60 years old) (Fig. 13.2). The relative proportions of each age class shifted over time in response to disturbance by tree harvest, fire, and wind (Table 13.1, Fig. 13.2).

Three patterns stand out in the comparison of forest age class proportions over time for each alternative (Figs. 13.2, and 13.3). The first pattern, a “V” shape in the age class distribution, was partially an artifact of the way we developed the initial landscape conditions and the way LANDIS implemented age-dependent mortality, wind disturbance, and mortality due to epidemic Dutch elm disease in the first decades of the projection. The size of this effect was evident in Alternative 2, which showed a 5-8 percent increase in the seedling size class in the first decade (Fig. 13.2). The second factor contributing to the “V” shape was the implementation of harvest at the prescribed levels. The HNF is predominately old, relatively undisturbed, and undergoing transition from oak to maple. Thus, any harvest changes current and near future vegetation structure and composition. The seedling age class increased by 3-7 percent with the magnitude of the increase corresponding to the differences in amount of harvest among management alternatives. As a result of these events, in the first few decades there were rapid changes in the seedling age class that were carried forward into the older age classes in later decades. We expected this shift in age class distribution, just not as abruptly as the simulation suggests.

The second pattern occurred 90-100 years from plan implementation when age class distribution as a proportion of area equilibrated (Fig. 13.2). From years 100 to 150 of the simulation the proportion of the landscape in the 4 age classes remained stable within Alternatives 1, 3, 4, and 5 (the alternatives implementing tree harvest and prescribed fire). By year 150, the combined to-

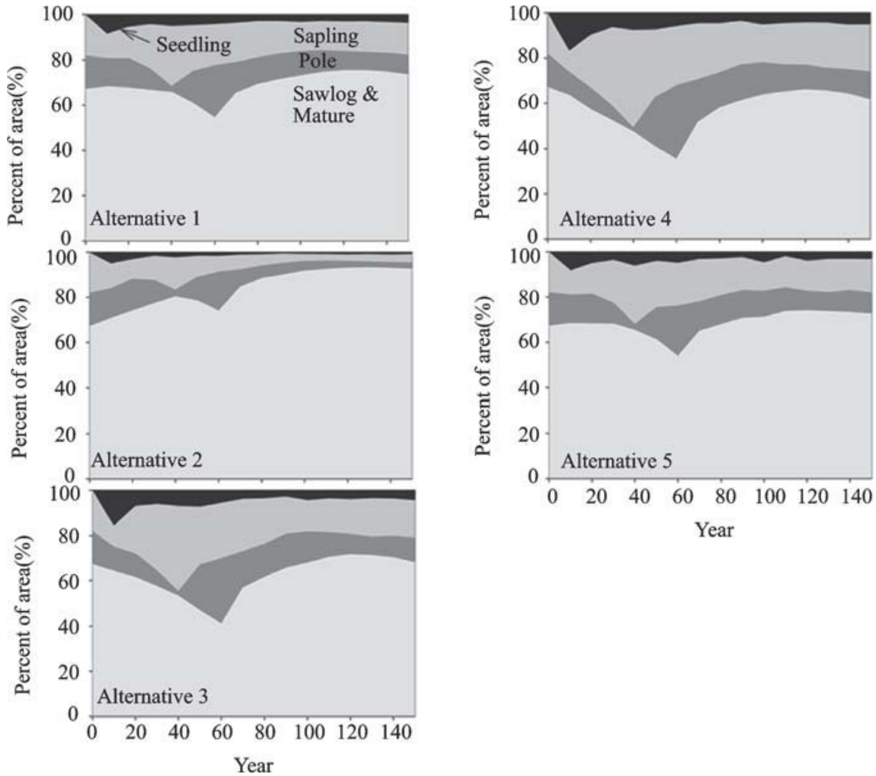


Fig. 13.2 Forest area by age class for 5 management alternatives on the Hoosier National Forest, Indiana. See Table 13.1 for details of the management practices associated with each alternative. Age classes are seedling (1-10 years old); sapling (11-40 years old); pole (41-60 years old); and mature (>60 years old).

tal of the seedling and sapling age classes as a proportion of the total area declined (relative to initial conditions at year 0) for Alternative 1 (1 percent decline), Alternative 2 (14 percent decline), and Alternative 5 (1 percent decline), whereas Alternative 3 (2 percent increase) and Alternative 4 (7 percent increase) increased the area in the seedling and sapling age classes compared to initial conditions.

The third pattern was evident in the spatial arrangement of forest age classes beginning in year 10 and continuing to year 150 of the simulation (Fig. 13.3). Even-aged harvest in Alternatives 1, 3, 4, and 5, produced even-aged patches of regeneration ranging in size from 2 ha to 16 ha. Uneven-aged harvest produced many small, similar age patches on the landscape (group selection) and stippled areas of intermixed age classes (single-tree selection). Alternative 2 resulted in a homogenous landscape dominated by the oldest age class, although scattered pockets of younger forest were maintained by a combination of fire disturbance, wind disturbance, and gap-scale replacement

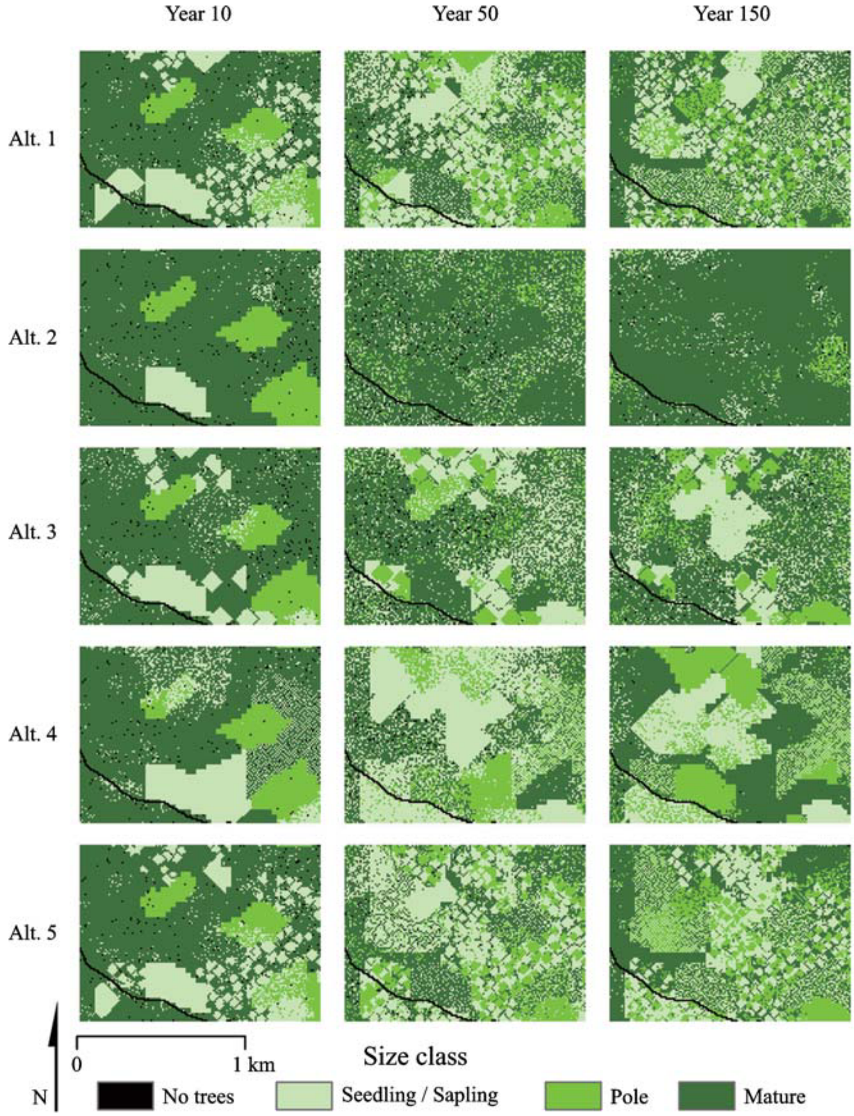


Fig. 13.3 Forest age class maps by management alternative at year 10, 50, and 150 of the plan horizon. The portion of the Hoosier National Forest displayed is approximately 150 ha. Age classes are seedling (1-10 years old); sapling (11-40 years old); pole (41-60 years old); and mature (>60 years old).

of senescent trees. Core area (Fig. 13.4) and edge density (Fig. 13.5) further document the spatial differences among alternatives in the effects of forest regeneration. When projected core and edge values equilibrated approximately 100 years into the projection, Alternative 2 created about three times as much core area and about half the edge density of the other alternatives. The other

4 alternatives were clustered in their estimated edge density and core area.

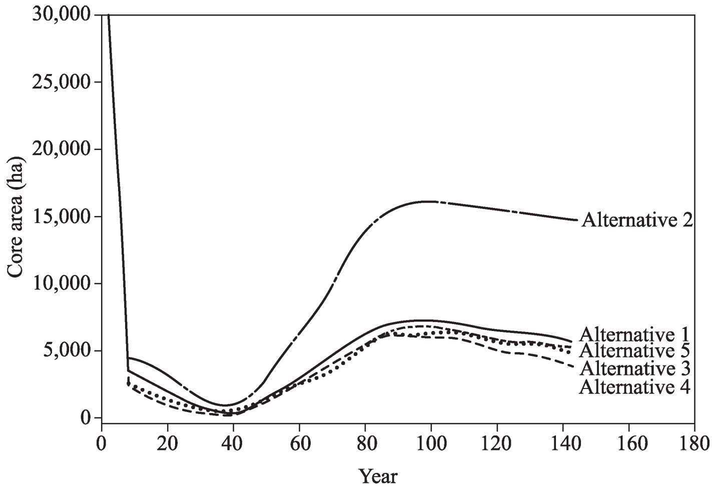


Fig. 13.4 Core area of forest in the pole and sawtimber age classes that was at least 60 m from an edge with a younger age class or nonforest on the Hoosier National Forest, Indiana. Pole and mature age classes correspond to forest ages of 41-60 years and >60 years, respectively. Computations were based on a 0.01 ha cell size, so any 0.01 ha or larger opening created by mortality or tree harvest was a breach in the core area. The minimum size opening that is ecologically relevant as a breach of core area can differ with avian habitat preferences and can be recomputed for other minimum opening sizes.

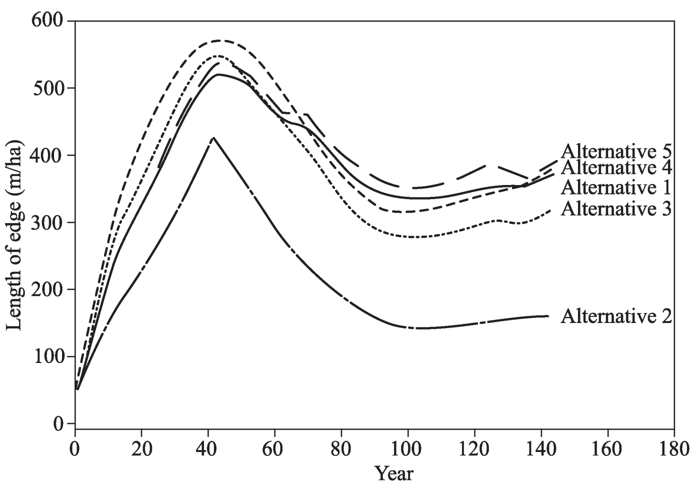


Fig. 13.5 Edge density (m per ha) between forest in the pole and older age classes (i.e. >40 years of age) with a younger forest and nonforest on the Hoosier National Forest, Indiana. Computations were based on 0.01 ha pixel size.

13.3.1.2 Spatial and temporal changes in tree species composition

The HNF planning team was particularly interested in the proportion of oaks relative to maples and other mesic species; therefore, we summarized temporal (Fig. 13.6) and spatial patterns (Fig. 13.7) in tree species composition for each alternative in terms of white oak, maple, and red oak groups. The initial tree species composition was the same for all management alternatives. At year 0, oaks were dominant (i.e., oldest tree per cell) on 42 percent of the HNF forested landscape (white and post oak comprised 19 percent; red oak group 18 percent; and chestnut oak 5 percent), followed by hickories (14 percent), and maples (12 percent). Each of the remaining species or species groups was dominant on less than 10 percent of the initial landscape.

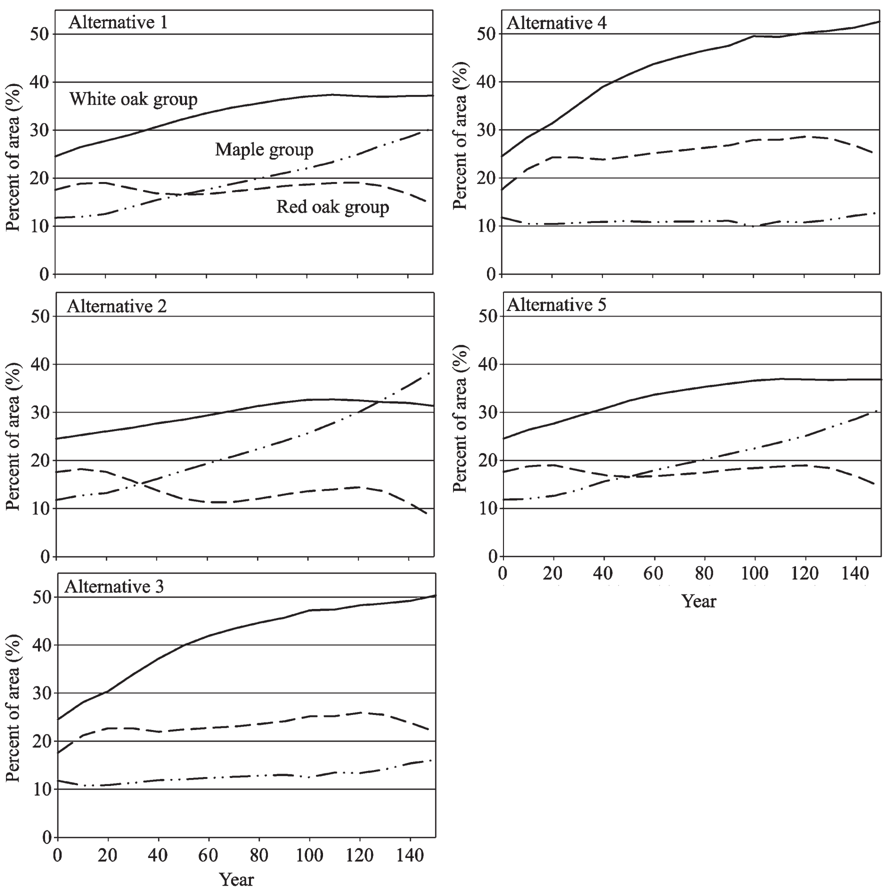


Fig. 13.6 Percent of area dominated by 3 tree species groups by decade for 5 management alternatives on the Hoosier National Forest, Indiana. Species groups were: red oaks (northern red, black and scarlet oaks), white oaks (white and chestnut oak), and maple (sugar and red maple).

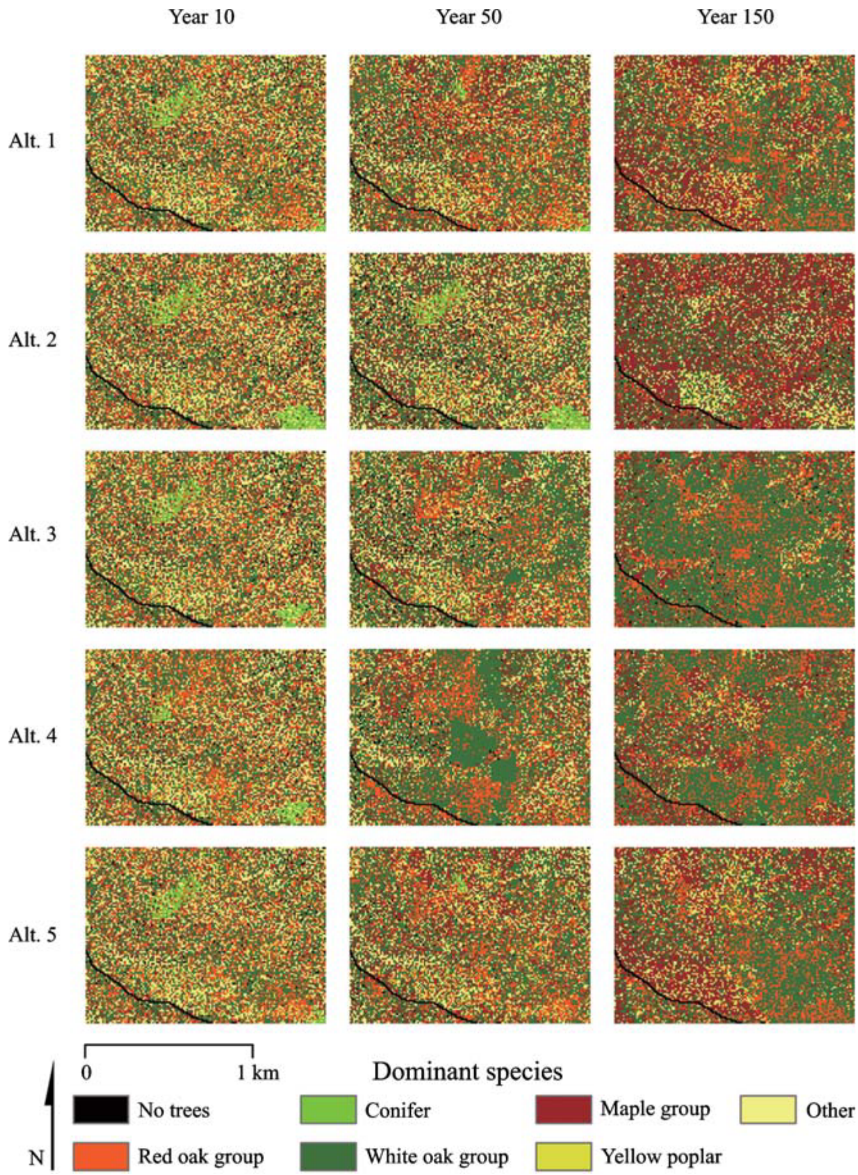


Fig. 13.7 Dominant tree species composition maps for 5 management alternatives at year 10, 50, and 150 for a 150-ha portion of the Hoosier National Forest, Indiana.

Over the 150-year simulation of vegetation change, Alternative 2 realized the greatest increase in maple dominance, from 12 to 39 percent of the forest in 150 years (Fig. 13.6). Under Alternative 4, the area of forest dominated by the maple group remained nearly constant over the 150-yr simulation while the area dominated by the red oak group increased to 25 percent and the area dominated by the white oak group increased to 52 percent (Fig. 13.6). Alternatives 3 and 4 reached the highest dominance by white oaks at 50 and 52 percent of forest area, respectively and were the only alternatives where the red oak group was dominant over a greater area than the maple group (Fig. 13.6). Alternative 5, which mirrored Alternative 1 with the exception of the added focal area to concentrate tree harvest activities, had the same species composition as Alternative 1 (Fig. 13.6).

As for forest age class, the spatial pattern in tree species composition varied by management alternative (Fig. 13.7). Even-aged and uneven-aged harvests produced patches of forest that were dominated by the red and white oak groups. By contrast, areas without harvest had higher dominance by maples.

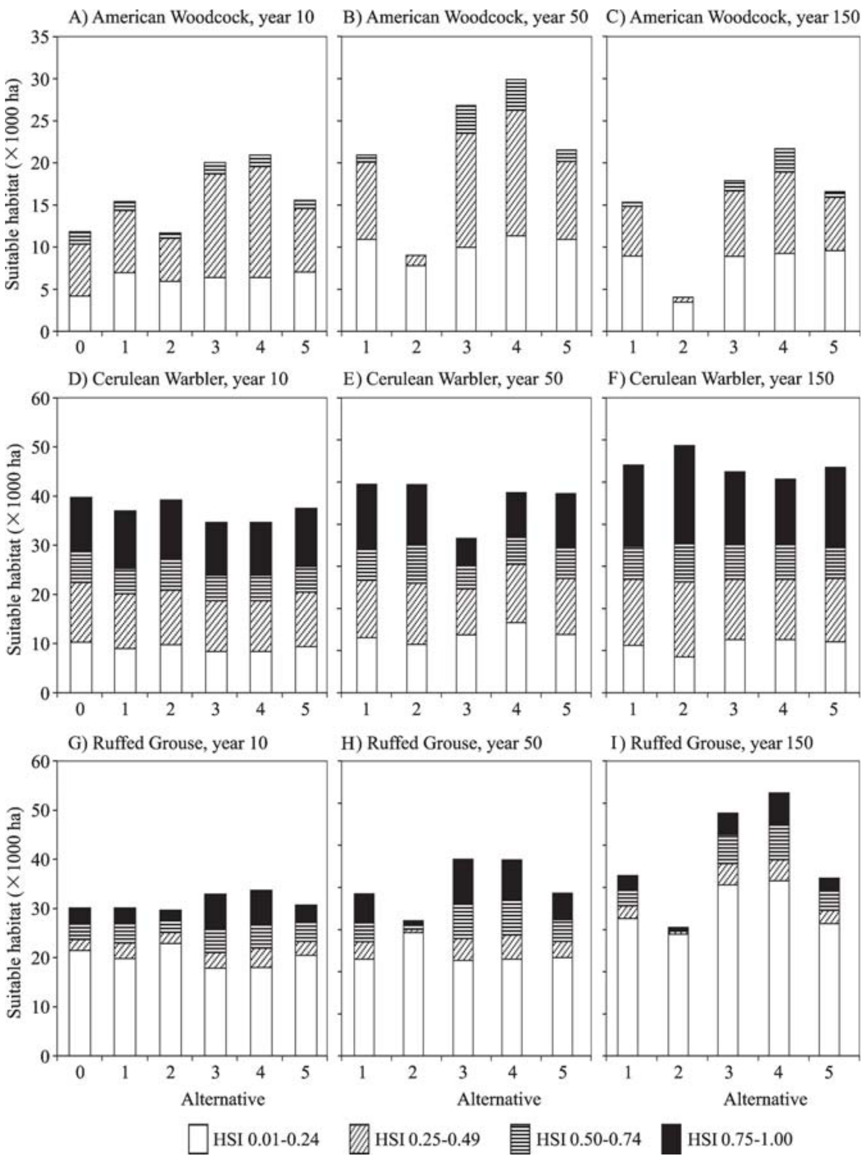
13.3.2 Changes in avian habitat suitability

13.3.2.1 American woodcock

The American woodcock is a ground-nesting, migratory species associated with early- to mid-successional, moist forested areas (Keppie and Whiting 1994). High quality American woodcock habitat for breeding occurs on mesic forest sites containing deciduous species 1-40 years old with interspersion of forest and open habitat. Alternative 4 had the highest tree harvest levels and highest prescribed fire levels among all alternatives. These levels of disturbance created early successional (regeneration) habitat used by woodcock for display and nesting, and the interspersion of young and old forest. Compared to Alternative 1, the amount of high quality woodcock habitat (HSI > 0.75) in Alternative 4 increased by 150 percent by year 10 and 10800 percent by year 150 (Fig. 13.8). Alternative 5, which added the focal area to Alternative 1, increased the amount of high quality habitat by 170 percent by year 50 and 830 percent by year 150. Under Alternative 2, the amount of high quality habitat increased by 30 percent by year 10, largely due to succession of open areas and gap-level dynamics associated with tree mortality from senescence, windthrow, or disease. However, the continued absence of tree harvest or prescribed fire agents led to the elimination of high quality habitat by year 50 (Fig. 13.8). When ranked by the total amount of suitable habitat, the rank of each alternative was constant over time (Fig. 13.8).

13.3.2.2 Cerulean warbler

The cerulean warbler is a neotropical migratory species that breeds in large tracts of mature and second-growth deciduous forests of eastern North America (Hamel 2000). High quality cerulean warbler habitat for breeding in the study region occurs in deciduous forest patches exceeding 100 years of age and 3,000 ha in size. Compared to Alternative 1 at year 10, the percent change in the amount of suitable habitat for cerulean warbler ranged from an 8 percent decrease in Alternative 3 to no difference in Alternative 5 (Fig. 13.8). The greatest separation of management alternatives occurred around year 50, with Alternative 3 producing a 53 percent decrease and Alternative 2 producing a 15 percent increase in the amount of high quality cerulean warbler habitat compared to Alternative 1 at year 50 (Fig. 13.8). It is unclear whether the percent change at year 50 was an artifact of the initial landscape conditions



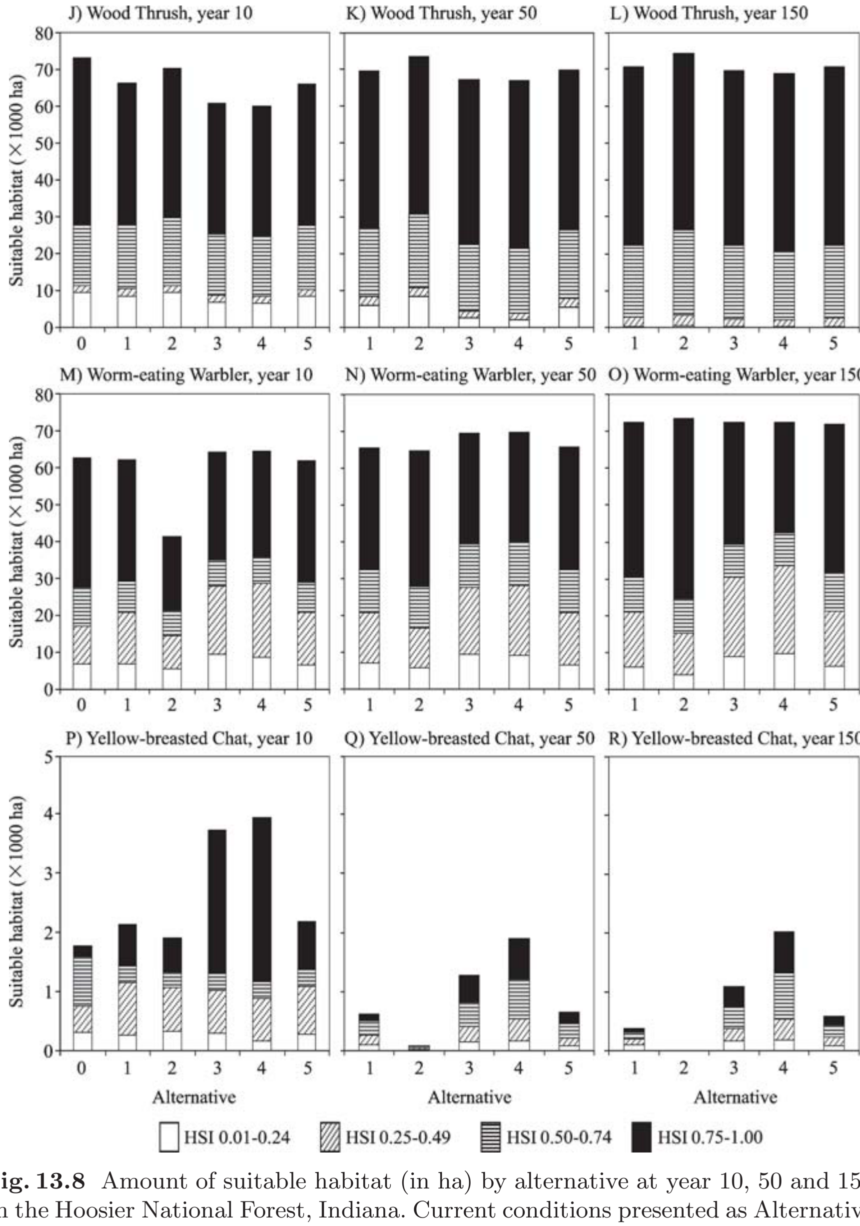


Fig. 13.8 Amount of suitable habitat (in ha) by alternative at year 10, 50 and 150 on the Hoosier National Forest, Indiana. Current conditions presented as Alternative 0 in year 10 column.

or a result of the tree harvest and prescribed fire levels. By year 150, all management alternatives had greater amounts of high quality habitat and greater total amount of suitable habitat than initial conditions. Alternative 2 produced 20 percent more high quality habitat than Alternative 1 (Fig. 13.8).

The relative rank of each alternative was not constant over time; Alternative 4 provided a greater amount of suitable habitat in year 50 than all other alternatives except Alternative 2. By year 150, though, Alternative 4 had the least amount of suitable habitat among all alternatives (Fig. 13.8).

13.3.2.3 Ruffed grouse

The ruffed grouse is a non-migratory game species associated with early successional forests in all parts of their range (Rusch et al. 2000). High quality ruffed grouse habitat occurs in forests with small patches of early successional forest surrounded by mast-producing trees. All four of the alternatives that implemented tree harvest had a greater amount of high quality ruffed grouse habitat than Alternative 2 (Fig. 13.8). Alternatives 3 and 4 consistently produced more high quality habitat than Alternatives 1 and 5 due to the higher tree harvest levels and increase in prescribed fire (Fig. 13.8). Alternative 5, which added the focal area to Alternative 1, increased the amount of high quality habitat 10 percent by year 150 (Fig. 13.8). However, the greatest increase in total amount of suitable habitat and high quality habitat was achieved through a combination of the focal area and higher tree harvest and prescribed fire levels; Alternatives 3 and 4 each increased the amount of high quality habitat by 140 percent from that under Alternative 1 by year 10 (Fig. 13.8). The large increase in high quality habitat was maintained for the plan duration such that by year 150, Alternative 3 had 60 percent more high quality habitat and Alternative 4 had 140 percent more high quality habitat than Alternative 1 at year 150 (Fig. 13.8). The relative rank of each alternative was constant over time (Fig. 13.8).

13.3.2.4 Wood thrush

The wood thrush is a neotropical migratory bird that nests in shrubs and small trees in deciduous and mixed-deciduous coniferous forests in eastern North America (Roth et al. 1996). High quality wood thrush habitat for breeding occurs in large forests with both early- and late-successional forest. The change in the amount of high quality wood thrush habitat compared to Alternative 1 was greatest for Alternative 3 (9 percent decrease) and Alternative 4 (8 percent decrease) at year 10 (Fig. 13.8). At year 50, Alternatives 3 and 4 had 10 percent more high quality habitat as Alternative 1. The change from a decrease to an increase in the amount of high quality habitat from year 0 to year 50 was an artifact of the HSI model for wood thrush and the 10-year time step of the simulation. Because the initial landscape conditions contained only dominant trees, where harvest was implemented in the first 10 years, all cells were assigned a tree age of 1-10 years. The wood thrush HSI model assigned $SI = 0$ for all cells with tree age <10 years. As a result, the alternatives that implemented the highest levels of tree harvest (Alternatives 3 and 4) had the largest decrease in the amount of high quality habitat. By year 50, cells subject to tree harvest in the previous time steps were 10-40 years old.

Of those, any cells subject to 20-40 years post-harvest were retained by the wood thrush HSI model as post-fledging habitat. Addition of the focal area in Alternative 5 produced less than 1 percent difference in the amount of high quality habitat for wood thrush compared to Alternative 1 (Fig. 13.8). The relative rank of each alternative was constant over time (Fig. 13.8).

13.3.2.5 Worm-eating warbler

The worm-eating warbler is a neotropical migratory bird that nests on the ground in large tracts of mature deciduous and mixed deciduous coniferous forests in eastern North America (Hanners and Patton 1998). High quality worm-eating warbler habitat for breeding occurs in moist ravines within large patches of unburned deciduous forest. Alternative 1 had the greatest amount of high quality habitat at year 10 (Fig. 13.8). Alternative 2 had only 61 percent as much high quality habitat as Alternative 1 at year 10 but provided 10 percent more high quality habitat than Alternative 1 at year 50 and 20 percent more high quality habitat at year 150 (Fig. 13.8). Alternatives 3 and 4, which had the highest levels of prescribed fire (25 and 50 percent, respectively), provided 10 to 20 percent less high quality habitat than Alternative 1 at each time step (Fig. 13.8). Addition of the focal area to Alternative 1 resulted in a 5 percent reduction in the amount of high quality habitat at year 150 (Fig. 13.8).

13.3.2.6 Yellow-breasted chat

The yellow-breasted chat is a disturbance-dependent shrubland bird that breeds in deciduous and coniferous forests in North America (Eckerle and Thompson 2001). High quality yellow-breasted chat habitat for breeding occurs in the interior of early successional forest patches exceeding 5 ha in size. Without tree harvest or prescribed fire, Alternative 2 contained only 82 percent as much high quality yellow-breasted chat habitat as Alternative 1 at year 10 and had no high quality habitat after year 50 (Fig. 13.8). Alternative 5 increased the amount of high quality habitat by 20 percent at year 10 of the simulation, 60 percent at year 50, and 160 percent at year 150 compared to Alternative 1 (Fig. 13.8). However, the greatest amounts of high quality habitat were produced under Alternatives 3 and 4, which had higher tree harvest and prescribed fire levels than Alternatives 1 and 5, in addition to the focal area. Alternative 4, which had the largest even-aged cut size (16 ha), the highest level of even-aged management (3 percent per decade) and the highest level of prescribed fire (50 percent per decade), produced 300 percent more high quality habitat than Alternative 1 at year 10, 480 percent more at year 50, and 1160 percent more high quality habitat at year 150 (Fig. 13.8). The relative rank of each alternative was constant over time (Fig. 13.8).

13.4 Discussion

Our approach to land-management planning on the Hoosier National Forest contains desirable features from a large-scale, landscape perspective while retaining the fine-scale information useful for evaluating avian habitat suitability. We simulated spatially explicit changes in vegetation structure, composition, and configuration due to anthropogenic and natural agents of disturbance and succession. Our comprehensive treatment of these processes advances previous Hoosier National Forest planning efforts (Gustafson and Crow 1994; Gustafson et al. 2001) by utilizing spatially explicit vegetation and avian habitat suitability models. By retaining the spatial context, we revealed important differences among alternatives in terms of the cumulative effects of management actions. First, tree harvest and prescribed fire influenced not only the species composition of vegetation communities, but also the species composition of avian communities. This result is not surprising in general, but it is unique to examine these spatially specific interactions over large landscapes and long time periods for multiple management alternatives. The scenarios indicate that in the absence of tree harvest and prescribed fire, the HNF will likely be dominated by sugar maple within 125 years, and yellow-breasted chat and ruffed grouse may face extirpation within 50 years. Second, the spatial context of tree harvest affected habitat suitability for early successional bird species. By concentrating even-aged timber harvest within a focal area, a given level of tree harvest provided more suitable habitat for yellow-breasted chat and ruffed grouse than applying the same tree harvest level across the entire HNF, without appreciably affecting habitat suitability for the late-successional bird species. Thus, linking vegetation simulation and avian habitat models provided a straightforward, intuitive, and scientific basis to support subsequent management decisions.

Our approach provided a comprehensive yet readily communicable perspective of landscape change. One of the goals of the HNF planning team was to engage the public and instill ownership of the HNF plan. The vegetation and avian habitat suitability maps were important tools for visualizing changes in landscape configuration, such as the spatial patterns that emerged over time from the different tree harvest techniques, despite similar composition with respect to tree age classes (Figs. 13.2, and 13.3). The maps also facilitated discussion of the HNF management goals and the methodology for achieving those goals, including the type and location of tree harvest activities. For example, public responses to proposed management actions on the Hoosier National Forest typically identified tree harvest as a controversial activity. The type and intensity of tree harvest affected forest species composition (Fig. 13.6) and ultimately affected avian habitat suitability through impacts on forest structure and mast production by the red oak and white oak groups. Thus, when selecting among management alternatives it is important to clearly understand the simultaneous tradeoffs, the potential conflicts, and the potential synergies among avian habitat quality for multiple species, levels of tree harvest, and by extension the availability of products, services and amenities that improve people's lives.

13.4.1 Tradeoffs among management alternatives

We tracked tree age class, tree species, core area, edge density, and avian habitat suitability information for five different management alternatives over a 150-yr planning horizon. No single management alternative maximized vegetation and habitat conditions for all features and species of interest. Rather, tradeoffs existed among all management alternatives. The sharpest tradeoffs occurred among Alternative 2, which contained no tree harvest or prescribed fire, and the remaining alternatives in terms of early vs. late-successional forest conditions and species composition. The range of alternatives considered was consistent with contemporary public land management polices, but narrow compared to the extent and severity of anthropogenic disturbances that affected this landscape over the previous 150 years. Modeling generalized management scenarios that incorporate higher levels of disturbance via harvest or prescribed burning is an approach that can be used to gain insights into how higher levels of disturbance are likely to affect vegetation structure, vegetation species composition, and avian habitat suitability without modeling new alternatives across the entire HNF (Shifley et al. 2006).

The LANDIS projections of dominant forest vegetation (Figs. 13.6, and 13.7) illustrate four important points with respect to management decisions. First, white oak will increase in area of dominance under all alternatives. White oaks are generally longer lived and marginally more shade tolerant than species in the red oak group. Over the next century, white oaks currently in the forest canopy are expected to survive in greater proportion than the red oaks. Second, the proportions of red oak species and maples are affected by the intensity of forest disturbance via harvest and fire. Red oaks are favored more than white oaks and much more than maples in the face of intense and/or repeated disturbances such as harvest or fire. This dynamic is visible in the pattern of tree species composition change over time (Figs. 13.6, and 13.7). The relative proportion of red oak to maple increases over time in response to increasing levels of disturbance. Third, in the absence of anthropogenic disturbance, the HNF will be dominated by late-successional vegetation conditions. Finally, the alternatives differed greatly in terms of the area subject to even-aged versus uneven-aged harvest techniques. Importantly, the relatively large increase in early successional vegetation due to even-aged management under Alternative 4 did not correspond to a large reduction in the amount of suitable habitat for late-successional bird species. Several recent studies support our simulation results that sustainable levels of harvest based on single tree selection, group selection or clearcutting improve habitat conditions for early successional bird species with minimal impacts on late-successional birds (Annand and Thompson 1997; Robinson and Robinson 1999; Gram et al. 2003), provided the spatial distribution of cuts maintains core areas of mature forest (Wallendorf et al. 2007).

Alternatives 3, 4, and 5 modeled the 5,260-ha focal area designed to consolidate the location of even-aged regeneration harvests for the benefit of bird species that depend on early successional forest habitat. The effect of the focal area was most apparent when comparing Alternative 1 with Alternative 5, which had the same tree harvest and prescribed fire levels, but Alternative 5 contained the focal area. Alternative 5 increased the effective size of early successional forest patches within the focal area and provided a greater amount of suitable habitat for ruffed grouse and yellow-breasted chat than Alternative 1. The focal area also increased interspersion of early successional forest patches with mature, mast-producing forest, and this improved the habitat suitability for ruffed grouse. Besides those avian benefits, the focal area reduced the amount of tree harvest occurring elsewhere on the forest. This would generally benefit the aesthetic qualities of vegetation outside the focal area, but may simultaneously reduce habitat suitability for ruffed grouse and yellow-breasted chat outside the focal area.

13.4.2 Interactions between public and private lands at landscape scales

Our approach to land-management planning was designed to take advantage of LANDIS's ability to simulate changes in forest vegetation over time under different management scenarios, and to produce GIS layers of outputs (e.g. tree age, tree species, wind damage, and fire history) over time. We used those GIS layers as inputs for the avian HSI models. This approach worked well within the predominantly forested landscape of the HNF; however, it had less value when applied to the non-forested parts of the HNF and surrounding private lands. Time since disturbance and type of disturbance (e.g. grazing, haying, and prescribed fire) are important factors in determining what bird species will be present within grasslands (Walk and Warner 2000). The 10-yr time step we used limited our ability to model succession within grassland vegetation and associated changes in habitat suitability. However, newer versions of the LANDIS software permit modeling and analyzing vegetation change using annual time steps (He et al. 2005).

An important consideration of our approach was the treatment of private lands adjacent to the HNF. Private lands cannot be relied upon to meet policy requirements for species viability on National Forests, but they may play a vital role in the conservation and management of habitat for many avian species particularly when public lands are embedded within a predominantly private land matrix. Private lands provide adjacent habitat that can complement or detract from habitat quality on public lands.

We used different tree harvest scenarios on private lands (e.g. high grading and selective harvest) other than on the HNF. We made four simplifying assumptions about private land management. First, we assumed private land-management trends were static over time; we did not increase or decrease the area of private lands subject to tree harvest per decade. However, tree harvest constraints on public lands may increase tree harvest on private lands (Haynes 2002). Second, we assumed the amount and location of public and private lands would remain constant over the analysis period. Third, we assumed that land use (forest, agriculture, developed) would also remain constant, even though conversion to residential development is likely to increase in some regions of the United States (Brown et al. 2005; Pocewicz et al. 2008). Fourth, we assumed private land parcel size would be stable over time. However, the average size of private forest land parcels is decreasing over time (Mehmood and Zhang 2001). If these trends extend to private lands adjacent to the HNF, then habitat suitability for some bird species could decline across the entire landscape over time despite management efforts on the HNF per se. Coordination of site-specific management efforts among private and public ownerships is certainly desirable and may be necessary to achieve regional avian habitat and conservation goals (Thompson and DeGraaf 2001).

13.4.3 Habitat suitability as a proxy for viability

Throughout the forest planning process the HNF planning team assumed that changes in habitat suitability were synonymous with numerical changes in avian populations. Rittenhouse et al. (2010) validated the wood thrush and yellow-breasted chat HSI models using 10-year territory density and nest success data from the Missouri Ozark Forest Ecosystem Project (Shifley and Kabrick 2002). They found support for HSI models as predictors of demographic response to vegetation change, but the strength of support varied by demographic response (e.g. territory density, nest success) and species. Other modeling approaches link population viability modeling to LANDIS using a habitat model as an intermediate step between vegetation simulation and viability analysis (Akcakaya et al. 2004; Larson et al. 2004). These modeling approaches may be considered an advancement over HSI models because of the link to population viability. Yet, at a minimum, population viability analysis requires estimates of adult survival and fecundity. Unfortunately, demographic data are lacking for many avian species despite being the critical link needed to translate population goals into habitat objectives. Further, when multiple species are included in the planning process it is convenient to have one metric for comparison among species. Thus while HSI models may not represent a demographic response for all species, they remain a common and convenient basis for evaluating wildlife habitat for many species.

13.5 Recommendations for future planning efforts

The detailed and synthetic nature of our approach provides a framework and structure that (1) is readily conveyed to multiple constituencies, (2) is based on explicitly stated assumptions and relationships, (3) provides a basis for testing, refinement, and extension to other forest commodities and amenities, and (4) provides a way to consider cumulative effects of multiple forest attributes at multiple spatial and temporal scales. We offer the following recommendations and observations to help guide the future application of landscape and wildlife habitat models to conservation planning:

1) Define explict, detailed management objectives. They are the focal points for model development, verification and validation, application, and comparison of outcomes.
2) Carefully consider tradeoffs between geographic extent, resolution of the modeling approach, and study objectives. While coarse resolutions will reduce processing time of large landscapes, they may lack detail necessary to assess impacts of forest management on avian species of concern. Select a resolution that is small enough to simulate disturbance, succession, and avian habitat at a scale relevant to the objectives. We chose to model ecological processes and habitat suitability at a resolution of 0.01 ha to account for disturbances as small as a tree fall gap. This resulted in hundreds of hours of computer processing to estimate habit suitability. However, the burden associated with modeling of avian habitat suitability for multiple species may be alleviated by additional computing capacity or modifications to the algorithms.
3) Model outputs, and even the modeling process, can be valuable tools for fostering communication and discussion with stakeholders. Understanding the relative differences among management alternatives and uncertainty associated with the modeling process is critical for making informed management decisions. Presentation of future vegetation conditions and avian habitat suitability as interactive maps provides scientific information in a format amenable to comprehension by the diverse stakeholders involved in the planning process.
4) Develop methods for evaluating and comparing multidimensional outcomes of management alternatives. We produced a variety of tabular and graphical output to allow comparison of management alternatives. The planning team recommended an alternative based on a review of these materials and stakeholder input. Alternatively, mathematical models could be developed to guide the selection of a preferred management alternative based on quantifiable objectives, provided such objectives can be articulated. Planning teams often default to choosing from a few alternatives by consensus because of the difficulty of quantifying objectives and developing optimization approaches when many resources and bird species are being considered.

5) We believe planning, model development, and application will be most effective when considered in an adaptive management framework. Ongoing monitoring of forest response during implementation of the chosen Forest Plan can provide valuable feedback on model performance and other assumptions made in the planning process, especially when models have not been previously validated. Forest plan implementation executed in specific project areas ranging from a few hundred to a few thousand hectares in extent can utilize many of the same modeling tools, although at finer resolutions and/or with greater site-specificity. The associated forest inventory and monitoring can provide a means to test and improve forecasting capabilities specific to a geographic region.

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