Journal of Environmental Management 92 (2011) 1618–1627

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Evaluating the effects of alternative forest management plans under various physiographic settings using historical records as a reference

Yangjian Zhang[a,*], Hong S. He[b,1], Stephen R. Shifley[c,2], Jian Yang[b,3], Brian J. Palik[d,4]

[a] Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[b] School of Natural Resources, University of Missouri, Columbia, MO 65211, USA
[c] Northern Research Station, USDA Forest Service, Columbia, MO 65211-7260, USA
[d] Northern Research Station, USDA Forest Service, Grand Rapids, MN 55744, USA

A R T I C L E I N F O

Article history:
Received 12 January 2010
Received in revised form
17 December 2010
Accepted 20 January 2011
Available online 16 February 2011

Keywords:
GLO data
LANDIS
Management plan
Physiographic settings

A B S T R A C T

Using historical General Land Office record as a reference, this study employed a landscape-scale disturbance and succession model to estimate the future cumulative effects of six alternative management plans on the tree species composition for various physiographic settings for the Mark Twain National Forest in Missouri. The results indicate that over a 200-year horizon, the relative abundance of black oak and pine species groups will decrease and the relative abundance of the white oak species group will increase, regardless of management strategy. General Land Office witness tree records provide a measure of tree species composition in the period from 1800 to 1850, prior to the large-scale influx of European settlers. Compared to the tree species composition described in the General Land Office records, the six contemporary management alternatives considered all would lead to a lower abundance of pine species, a higher abundance of red/black oak species, and a slightly higher abundance of white oak species after 200 years.

Impacts of management on tree species composition varied with physiographic settings. The projected relative abundance of pine differed significantly across the five physiographic classes over the first 40 years of the simulation. In the medium term (simulation years 41–100) the projected relative pine abundance differed significantly among only four physiographic classes. In the long term (simulation years 100–200) the projected relative pine abundance differed for only one physiographic class. In contrast, differences among physiographic classes in the relative abundance of black oaks and white oaks increased over time. In general, the expected long-term differences in relative tree species abundance among six proposed alternative management plans are small compared to shifts in tree species composition that have occurred from 1850 to the present.

1. Introduction

Knowledge of forest management outcomes is important in evaluating their effectiveness, and on U.S. National Forests it is required by the National Forest Management Act (Morrison, 1994). Management outcomes are the cumulative effects of complex interactions among natural disturbances such as fire and wind, anthropogenic disturbances (e.g. harvest), physical environments (e.g. land types) (Cardille et al., 2001; Cumming, 2001), and current stand conditions. Traditional field trials or direct observations have only a limited capacity to evaluate long term, broad-scale cumulative effects of management. Moreover, tools that forest managers possess for assessing the consequences of forest management are mostly nonspatial (Bettinger and Chung, 2004; Turner et al., 2002). Forest landscape simulation models provide an effective addition to field observation and landscape-scale field trials in evaluating the effects of various management actions. Landscape models can provide spatially explicit output at broad spatial and long temporal scales and can assist in understanding the complex interactions between management and environmental factors. They embody explicit assumptions and produce quantitative estimates. They

* Corresponding author.
E-mail addresses: zhangyangjian@yahoo.com (Y. Zhang), heh@missouri.edu (H.S. He), sshifley@fs.fed.us (S.R. Shifley), jym6b@missouri.edu (J. Yang), bpalik@fs.fed.us (B.J. Palik).
[1] Tel.: +1 573 882 7717; fax: +1 573 882 1977.
[2] Tel.: +1 573 875 5341x232.
[3] Tel.: +1 573 884 3574; fax: +1 573 882 1977.
[4] Tel.: +1 218 326 7116.

0301-4797/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jenvman.2011.01.021

allow quantitative estimates of future landscape responses to forest management and thus are useful for illustrating and comparing the potential effects of different management plans (Gram et al., 2001; Gustafson et al., 2007; He, 2008; Radeloff et al., 2006; Shifley et al., 2006; Zollner et al., 2005, 2008). In the best circumstances forest landscape simulation models are a vehicle for accumulating experience about how forest landscapes respond to management and other disturbances and useful for exploring expected outcomes of new management alternatives.

Previous studies using forest landscape models have typically focused on effects of management plans. Studies of management effects that take into account the physiographic settings such as slope or aspect are less common (Gustafson et al., 2004). Physiographic settings strongly influence vegetation patterns and dynamics, which in turn influence decisions about suitable forest management plans (Cardille et al., 2001; Gustafson et al., 2004; Zhang et al., 1999).

Maintaining, enhancing, or restoring site-appropriate natural vegetation is one of the management objectives in contemporary National Forest Plans (e.g. USDA Forest Service, 2010). Evaluating the effectiveness of forest management in restoring site-appropriate natural vegetation is challenging due to the lack of credible reference conditions, especially at broad spatial and temporal scales. Dendroecological and paleoecological studies can be useful sources from which to derive historical conditions (Wimberly et al., 2001), but evidence from these types of studies are limited in that they provide little information on forest structure and species composition. General Land Office (GLO) data collected prior to extensive European settlement (late 1800 to early 1850 in the Midwest) provide a rare opportunity for reconstructing historical vegetation in parts of the U.S. (He et al., 2007). Midwest forest conditions prior to widespread immigration by European settlers represent a period when anthropogenic disturbances were comparatively minor, although Native Americans and early European immigrants nevertheless greatly influenced historical fire regimes (Gustafson et al., 2007; Guyette and Larson, 2000; Guyette et al., 2002; Moore et al., 1999). Historical estimates of tree species composition reconstructed from GLO data have been shown to be consistent with those reported in archaeological and historical documents in the Missouri Ozarks (Batek et al., 1999). The assumption that vegetation conditions prior to European settlement represent typical conditions for lightly disturbed native vegetation adapted to local physiographic conditions is commonly employed (Gustafson et al., 2007; Moore et al., 1999; Swanson et al., 1994).

The objective of this study was to model the long-term cumulative effects of alternative management plans on forest species composition for various physiographic settings. Specifically, we assessed how alternative management plans are expected to affect tree species composition for each of five physiographic classes, and we compared the outcomes of trees species composition by slope and aspect with records of tree species composition from a period prior to widespread immigration by European settlers. Results from this study can provide insight into the cumulative effects of management plans that differ in the location and intensity of harvest and other disturbances. The work also sheds light on the utility of landscape-scale disturbance and succession models for analysis of effects of National Forest plan alternatives through time and by physiographic classes.

2. Methods

2.1. Study area

The Mark Twain National Forest mainly lies in Southeastern Missouri (Fig. 1). It encompasses 0.6 million hectares in the heavily forested Missouri Ozarks and is one of the largest expanses of public forest land in the Midwest (Missouri Department of Conservation, 2010). The fire history of the region has been well documented, as have forest vegetation conditions in the early 1800s prior to European settlement (Batek et al., 1999; Guyette et al., 2002). Current forest composition is radically different from the pre-settlement era due to shifting patterns of harvesting, agriculture, and wildfire associated with European settlement (Zhang et al., 2009). Heavy logging between 1890 and 1920 (Shifley and Brookshire, 2000) and fire suppression since 1940 (Guyette et al., 2002) have decreased the abundance of shortleaf pine (*Pinus echinata* Mill.) and favored the development of mixed oak forests (Batek et al., 1999). Current forests are dominated by black oak (*Quercus velutina* Lam.), scarlet oak (*Quercus coccinea* Muenchh.), white oak (*Quercus alba* L.), post oak (*Quercus stelatta* Wangenh.), hickory (*Carya* spp.), and shortleaf pine. Seventy five percent of current forest stands are older than 50 years (Fig. 2). Management challenges include an abundance of aging black and scarlet oaks that are prone to drought-induced oak decline with high rates of mortality (Johnson et al., 2009). The Mark Twain National Forest (MTNF) plan (USDA Forest Service, 2005) considers five alternative forest management plans (MP). The five alternative MPs share the same forest-wide goals and follow agency policies, but they differ in allocating varying area to each management practice to emphasize different issues and concerns (Tables 1 and 2, Fig. 3). Implementation of each MP alternative is similar to dynamic zoning strategies for timber harvesting which change the spatial allocation of forest management practices (Gustafson and Crow, 1994) (Fig. 4). The difference from dynamic zoning lies in that the MPs were spatially static over the study period. The spatial allocation of each MP is mainly determined by the MP objective and local conditions such as species composition and physiographic setting. The combined result is five unique MPs (MP1 to MP5) that differ in where (Fig. 3) and how (Table 1) management is implemented and in the cumulative harvest disturbance for each (Table 2). The management practices differ in emphasis: MP1 emphasizes passive restoration with lower levels of active management than other MPs; MP2 emphasizes restoration of native terrestrial communities and maintenance of native forest ecosystem composition and structure; MP3 emphasizes a balance between restoration of natural communities and production of forest commodities; MP4 emphasizes production of forest commodities,

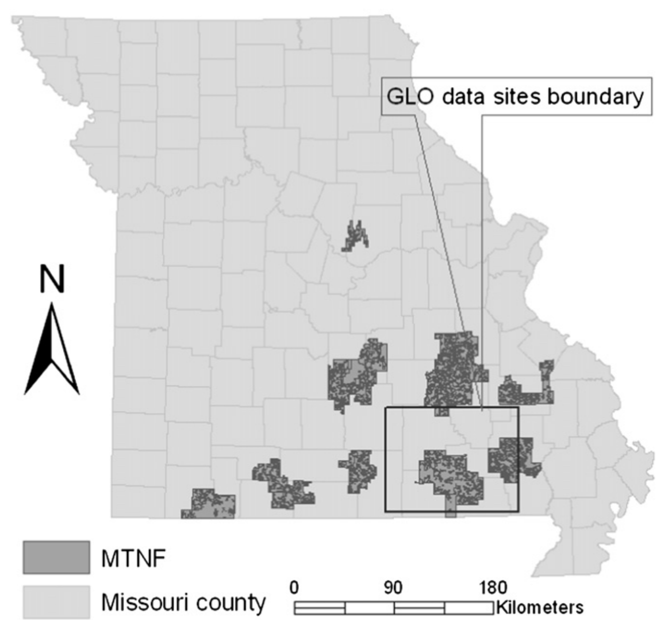

Fig. 1. Study area.

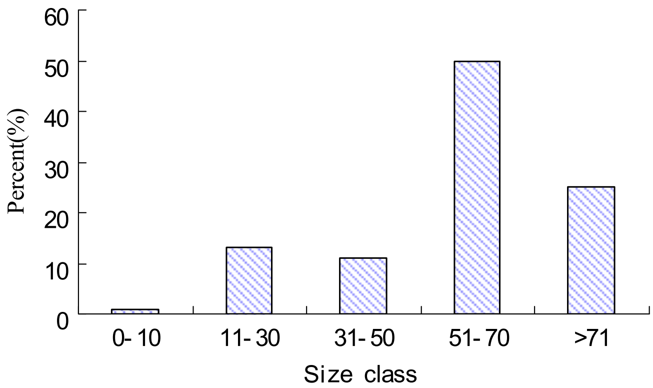

Fig. 2. Forest stand size structure in Mark Twain National Forest.

and MP5 emphasizes wildlife habitat restoration. For the purposes of this study we implemented a sixth alternative (MP6) as a control or reference condition where no harvest was implemented. Among the alternatives other than the control (MP6), MP1 had the smallest area of commercial thinning and regeneration cutting. MP4 had the largest area of regeneration cutting, and MP5 had the largest area of commercial thinning (Table 2). Natural regeneration is the primary mode of reforestation following harvest or other stand initiating disturbances.

2.2. The LANDIS model parameterization

The LANDIS (Forest Landscape Disturbance and Succession Model) model is a spatially explicit model that integrates forest stand and landscape dynamics (He et al., 2005). It can be used to forecast spatial and temporal dynamics of forest conditions across large forest landscapes. In addition to the core stochastic models that forecast forest succession and fire disturbance, LANDIS has several other modules that can incorporate the effects of landscape processes such as wind-throw, harvesting and biological disturbance (He and Mladenoff, 1999). The total landscape extent that LANDIS can simulate at one time is typically from 10^3 to 10^6 ha depending on computing capacity and required spatial resolution, with coarser resolution permitting greater spatial extent in most cases.

To encompass the entire Mark Twain National Forest area in one simulation run, we parameterized LANDIS (version 4.0) at a 120 m resolution (i.e., each cell or site representing 1.44 ha). Besides succession, fire and harvest modules in LANDIS 4.0 (He et al., 2005) were implemented in this study. Initial tree species composition and tree age on the modeled landscape were derived from stand-level inventory data maintained by the MTNF. Four tree species groups were utilized in the LANDIS model; groups were based on species abundance and gross similarities of species' ecological traits. Groups include (1) the white oak group (white oak; post oak.; Chinkapin oak, *Quercus muehlenbergii* Engelm.); (2) the black oak group (black oak; scarlet oak; northern red oak *Quercus rubra* L.); (3) the pine group (shortleaf pine; eastern red cedar *Juniperus virginiana* L.); (4) the maple group (red maple, *Acer rubrum* L.; sugar maple, *Acer saccharum* Marsh.), and (5) other species. The first four species groups comprise nearly 80% of the basal area of mature forests in the study region. Hickories comprise the majority of the remaining basal area and they occur ubiquitously across the landscape at low frequency. They were not modeled explicitly in this study.

The physiographic condition for each 1.44 ha site was classified as (1) north and east slope, (2) south and west slope, (3) ridge, (4) upland drainage, (5) mesic/bottomland, or (6) water. Among the six physiographic classes, north and east slopes accounted for 30% of the landscape, south and west slope for 28%, ridges for 20%, mesic/bottomland sites for 16.5%, and upland drainage sites for 4%, respectively. These physiographic classes were used in LANDIS to model differential rates of tree species establishment by physiographic class (Table 3). The tree species establishment coefficients used in LANDIS range from zero to one, where zero represents the lowest probability for species establishment and one represents the highest probability.

In addition to forest succession, harvest and fire were simulated as disturbances in this study. The harvest module was parameterized as six scenarios according to the six management plans described above (Tables 1 and 2). Management area maps, stand maps, and stand condition data were acquired from the Mark Twain National Forest (USDA Forest Service, 2005). The current wildfire return interval in the Missouri Ozarks ranges from 300 to 415 years with current fire suppression practices in Missouri with longer fire-free intervals on northeast slopes, upland drainages, and mesic sites than on southwest slopes and ridges (Guyette and Larson, 2000; Guyette et al., 2002; Westin, 1992; Yang et al., 2007). In this study the wildfire return interval was set as 415 years on northeast slopes and upland drainage area, 300 years on southwest slopes and ridges, and 450 years on mesic sites.

2.3. LANDIS simulation

Each simulation was run for 200 years to allow succession and disturbance factors for each scenario to diverge from the common initial vegetation conditions used for all scenarios and reach

Table 1
Management prescription descriptions of each management area (Ma).

Mgmt. area	Management area name	Harvest method	Forest opening (ha)
1.1	Natural community restoration, Roaded Natural Recreation Opportunity Spectrum (ROS)	Even-aged	16–200
1.2	Natural community restoration, semi-primitive motorized ROS	Even-aged	16–200, Harvest <20% of an Ma during each decade
2.1	General forest, roaded natural	No timber harvest is specified for this Ma	
5.1	Designated wilderness	No timber harvest is specified for this Ma	
6.1	Semi-primitive non-motorized ROS	Even-aged	<6, Harvest <10% of an Ma during each decade
6.2	Semi-primitive motorized ROS	Even-aged	<6, Harvest <20% of an Ma during each decade
6.3	Candidate wild, scenic, recreation rivers	No timber harvest is specified for this Ma	
7.1	Developed recreation areas	No timber harvest is specified for this Ma	
8.1	Designated special areas other than wilderness	No timber harvest is specified for this Ma	

Table 2
Harvested area in a 10-year frame under each management plan (MP).

Harvest type	Management plan (MP)					
	MP1	MP2	MP3	MP4	MP5	MP6
Short description	Passive restoration	Restoration and maintenance of native communities	Balanced restoration and commodities	Commodity production	Wildlife habitat restoration	No harvest
Commercial thinning (ha)	1377	54,736	56,640	58,322	177,328	0
Regeneration cut (ha)	21,615	44,373	45,628	47,219	45,344	0
Prescribed burning area	249,523	288,938	272,461	249,523	81,797	0
Regeneration	Natural regeneration	Natural regeneration	Natural regeneration	Natural regeneration		

equilibrium (Wallin et al., 1994). Each simulation was replicated fifteen times to capture the variation among repeated runs that is introduced by the stochastic elements of the model.

The initial landscape conditions input to LANDIS had only one or two (of four possible) tree species groups per 1.44 ha site (or per pixel). Over time, the total number of sites with a given species group (whether for pine, white oaks, black oaks, or maples in this study) generally increased since each site can accommodate multiple species. This effect is partially an artifact of model initialization and is common to most LANDIS analyses for the region (Shifley et al., 2006). The GLO data was the survey results based on sampling points. The percent cover index on the entire landscape, which is the most widely utilized index in summarizing LANDIS simulation results, is thus not viable for the GLO data. In addition, there was some inconsistence between species groups simulated by LANDIS in this study and the GLO record. For example, the GLO data is unable to produce the equivalent results of the fifth group (other species) as simulated in LANDIS. To circumvent the artifact result problem of the LANDIS simulation and to make simulation results compatible with GLO data we summarized and reported *relative* species abundance by the four species groups (i.e., pines, white oaks, black oaks, or maples) as the total number of sites containing that species group divided by the total number of sites containing any of the species groups. Pines, white oak and black oak are the main species groups concerned in this study. The maple group was so small and constant in relative abundance that

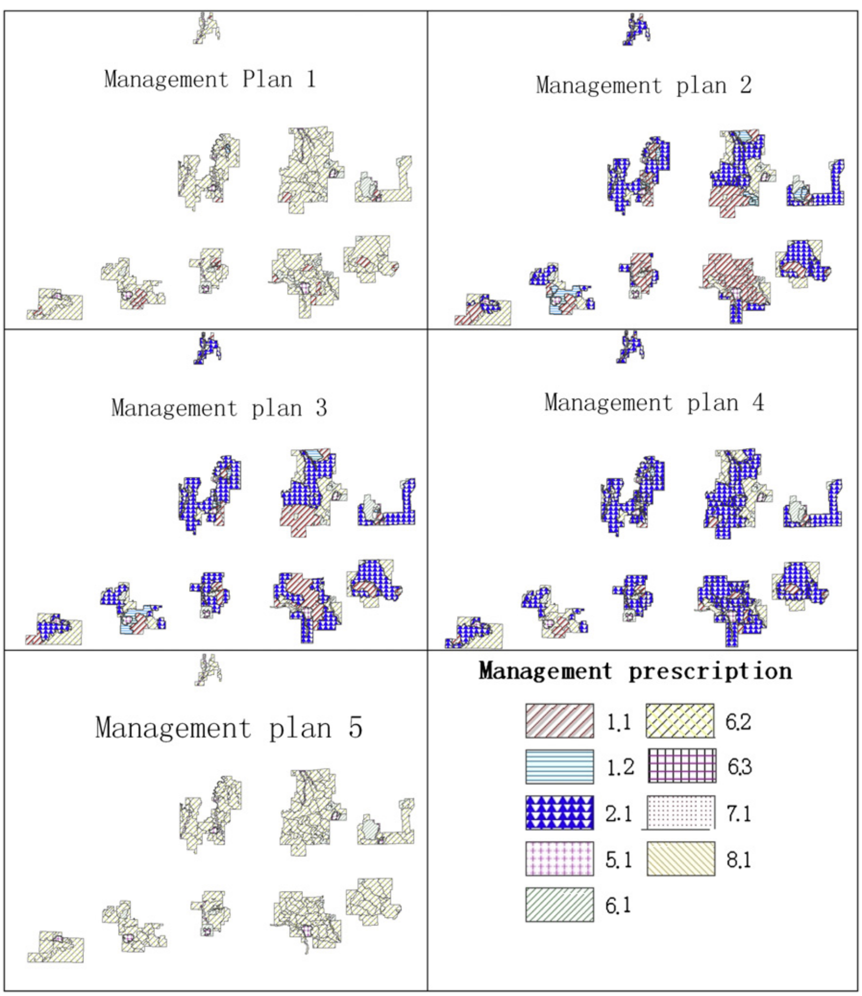

Fig. 3. Dynamic zonation of management areas for management plan (see also Tables 1 and 2).

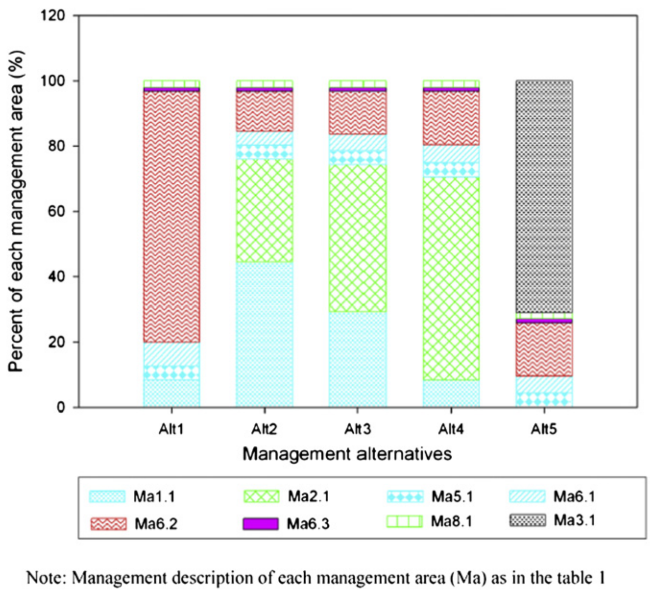

Fig. 4. Percentage of each management area assigned in each management alternative. Management 1.2 and 7.1 were not included in the implementation. See Tables 1 and 2 for additional definition of management prescriptions (MPs) and management areas (Mas).

analyses are focused almost exclusively on differences among the pine, black oak, and white oak groups.

2.4. Reconstruction of historical vegetation

The accessible GLO data were present as a continuous block which encompassed 1,050,000 ha, nearly twice the extent of the Mark Twain National Forest (Fig. 1). Three main species groups comparable with LANDIS simulation output (white oak, black oak, and pine) were compiled from the GLO data. The GLO database provides an estimate of relative species abundance for each physiographic setting (i.e. each land type) for the period 1800–1850. This allowed the GLO data to serve as a reference of tree species abundance prior to European settlement in a format comparable to LANDIS output.

2.5. Data analysis

As part of the analysis in this study, the relative abundance of the three most common species groups recorded in the GLO records (white oak, black oak, and pine) were compared with the relative species abundances forecast by LANDIS under the six MPs. The comparisons were done in a two-step process for the short (10–40 years), medium (41–100 years), and long (101–200 years) simulation periods and for each of the five physiographic settings separately. First, for each time period we assessed whether each MP led to significantly different relative species abundance on each physiographic setting. This was accomplished using one way ANOVA with SAS (2008). No-significant difference would mean that the six MPs had similar species composition within a given physiographic setting. If there were significant differences, we pursued the second step in which we computed the difference between the relative tree species abundance forecast by LANDIS simulations and the relative species abundance calculated from GLO data. Smaller absolute differences in species composition values indicated greater similarity in species composition between the data sources.

Table 3
Species establishment coefficients by land type used in the LANDIS scenario analyses.

	North and east slope	South and west slope	Ridge	Upland drainage	Mesic/ bottomland
Maple group	0.015	0.0058	0.0335	0.025	0.017
Pine group	0.4	0.5	0.5	0.4	0.2
White oak group	0.7	0.7	0.7	0.7	0.7
Black oak group	0.8	0.85	0.84	0.75	0.9

3. Results

3.1. Historical species composition

For the GLO data collected prior to extensive European settlement, the individual species groups varied in abundance by physiographic setting. The pine group was dominant on northeast and southwest slopes and ridgetops. The pine group was relatively more abundant in dry areas (i.e. slopes, upland drainages, and ridges) than on mesic sites. Historic pine abundance was greater than other species groups on northeast slopes (on 43% of sites), on southwest slopes (35%), and on ridges (41%) (Fig. 5). Historically the white oak group was more abundant than other species groups on upland drainages (on 42% of sites) and bottomland sites (41%). The relative abundance of the black oak group was similar on each physiographic setting; on average it occurred on 24% of sites on the entire landscape.

3.2. Effects of management plan and physiographic settings on relative species abundance

Among the six MPs, the no-harvest management alternative (MP6) had the greatest similarity to the GLO results during the middle term (41–100 years) of the modeled scenario, and MP3 and MP4 had the least similarity to the GLO results over that term (Fig. 6). Over the entire time horizon under all MPs (a) the pine group maintained a relatively constant abundance well below the corresponding abundance observed for the GLO data (b) the white oak group increased in relative abundance and exceeded the abundance observed for the GLO data, and (c) the black oak group decreased in relative abundance but still exceeded the corresponding abundance observed for the GLO data.

In the short term (10–40 years), MP6 (no harvest) led to the greatest similarity to the GLO reference data in relative abundance for the pine group on northeast slopes, ridges, upland drainages, and mesic sites, as well as for the entire landscape.

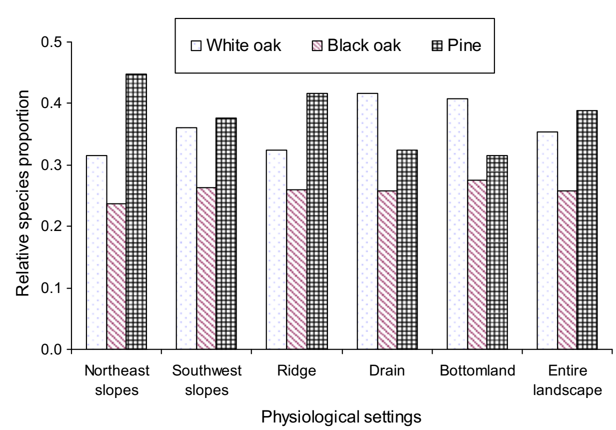

Fig. 5. Species composition on each land type as derived from historical General Land Office data. The sum of species proportions for each physiographic setting is 1.0.

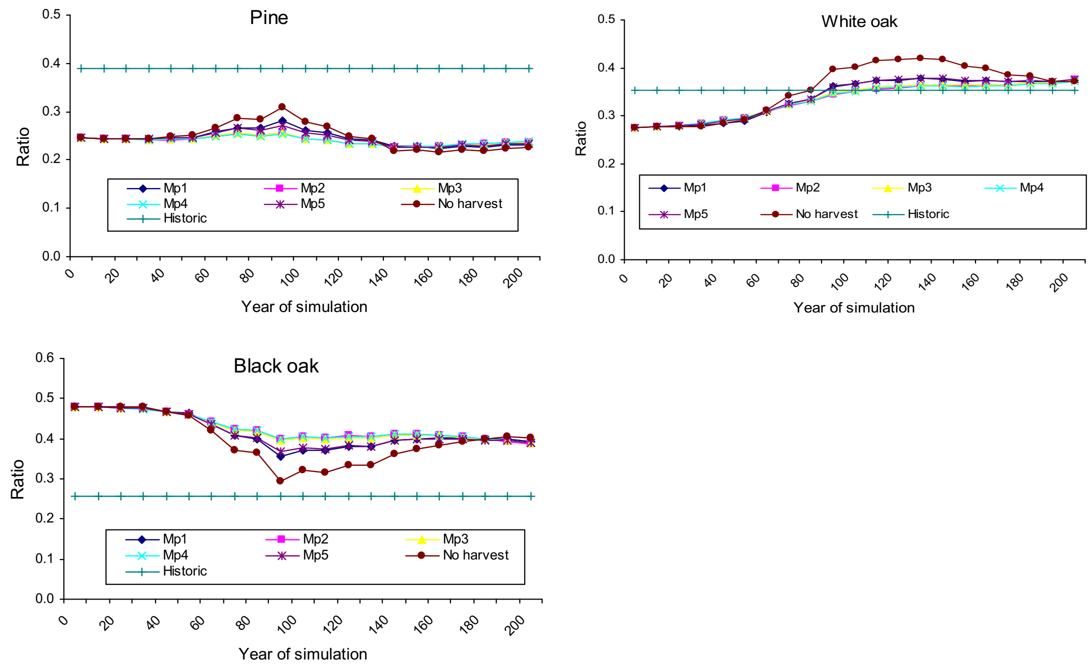

Fig. 6. Trend of percent cover of each species group under each management plan (MP). The alternative management plans are described in Tables 1 and 2 and Fig. 2.

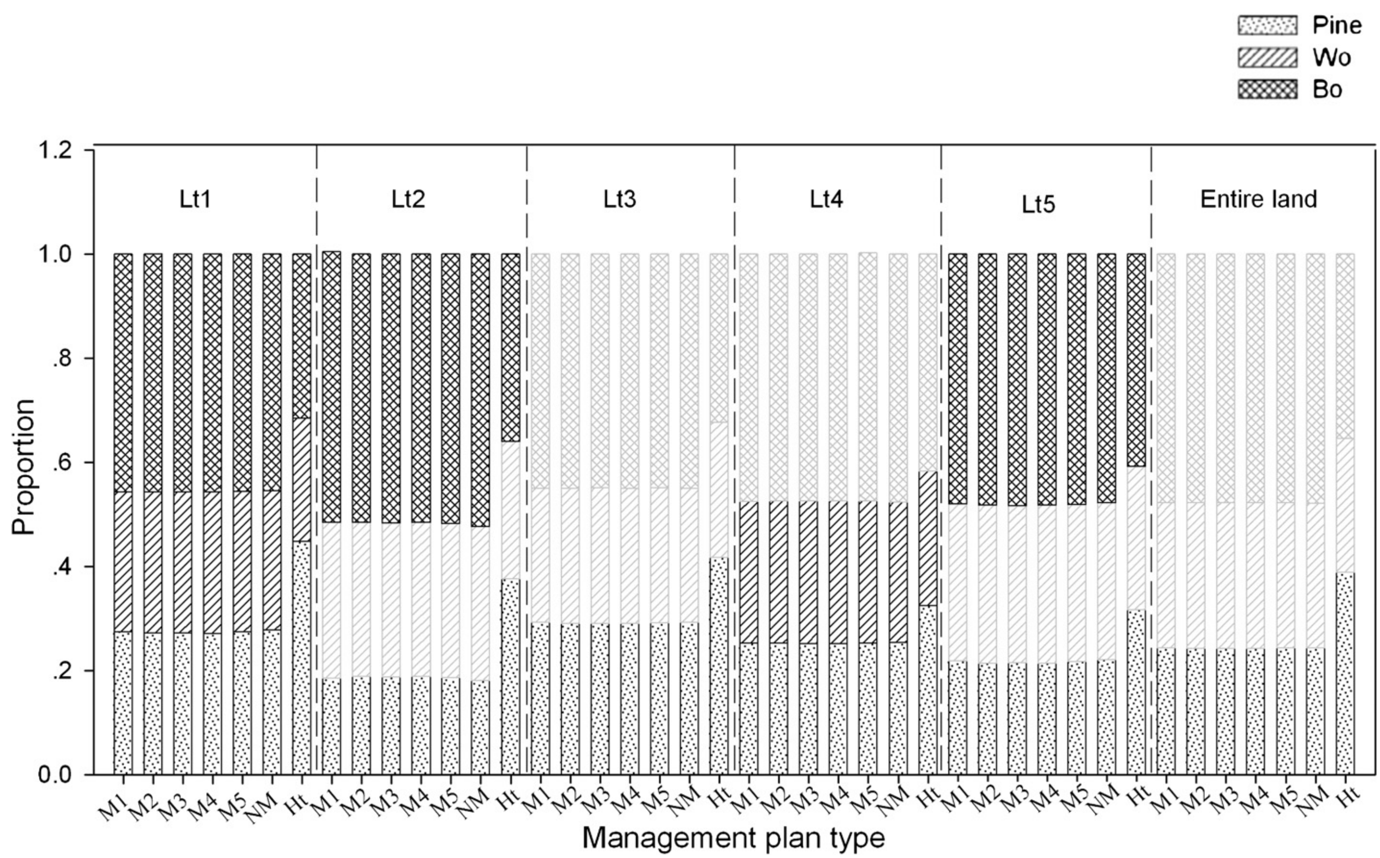

Fig. 7. Impact of alternative management plans and land types on species composition in the short term (0–40 years). Statistically significant differences among management plans at 0.01 level are in deep black color and non-significances are marked in gray. Labels M1 to M5 indicate management plans 1 to 5 on each land type; NM indicates the No Harvest and Ht indicates GLO survey results.

MP4 had the greatest similarity to the pine group for the GLO reference on southwest slopes (Fig. 7). MP6 (no harvest) had the greatest similarity to the GLO reference for the white oak group on northeast slopes and upland drainages. For the black oak group, MP6 (no harvest) had the greatest similarity to the GLO reference on northeast slopes and mesic sites, whereas MP4 resulted in the greatest similarity to the GLO reference data on southwest slopes.

In the medium term (41–100 years), MP6 (no harvest) resulted in the greatest similarity of the relative species abundance to the GLO reference for the pine group on northeast slopes, ridges, upland drainages, mesic sites and the entire landscape (Fig. 8). For the white oak group, MP2 had the greatest similarity to the GLO reference data on southwest slopes. The similarity of the black oak group to the GLO reference was greatest under MP6 (no harvest) on northeast slopes, ridges, mesic sites, and the entire landscape, while it was greatest on upland drainages under the MP5.

In the long term (101–200 years), the greatest similarity to the GLO reference was exhibited for the pine group on southwest slopes under MP4 (Fig. 9). The similarity of the white oak group to the GLO reference was greatest under MP4 on each individual physiographic setting and for the entire landscape. For the black oak group the greatest similarity to the GLO reference was exhibited under MP6 (no harvest) on northeast and southwest slopes, ridges, mesic sites, and the entire landscape while upland drainages had the greatest similarity to the GLO reference data under MP4.

4. Discussion

Prior to extensive settlement by European immigrants, fire was the dominant disturbance factor influencing species composition in the study region. Historically, mean fire-free intervals in the region were a few decades or less. With contemporary levels of fire suppression the mean fire-free intervals are now three centuries or more and simulated as such in the model. The pine group was a dominant species group sustained by frequent fires (Guyette and Larson, 2000) due to the relatively high fire tolerance of mature shorleaf pine trees. Frequent surface fires lowered the density of hardwoods and created growing space for pine seedlings to germinate (Cunningham and Hauser, 1989). The change in fire regimes and the widespread exploitive pine harvesting that occurred more than a century ago are factors that have indelibly altered the current species composition from that observed in the GLO data.

Over the entire MTNF landscape, differing harvest intensities can alter species composition dynamics to some extent. With the current forest age structure dominated by stands of 50 years and older, low levels of disturbance will favor a shift toward the longer lived pines and especially white oaks. Trees in the white oak and the pine species groups are longer lived than those in the black oak group. Greater levels of harvest disturbance will favor the black oak group which sprouts aggressively and grows faster than its associates. Larger shifts in species composition will likely require more intensive management (e.g. widespread pine site preparation, pine seeding, or planting) over large areas to have a more discernable impact.

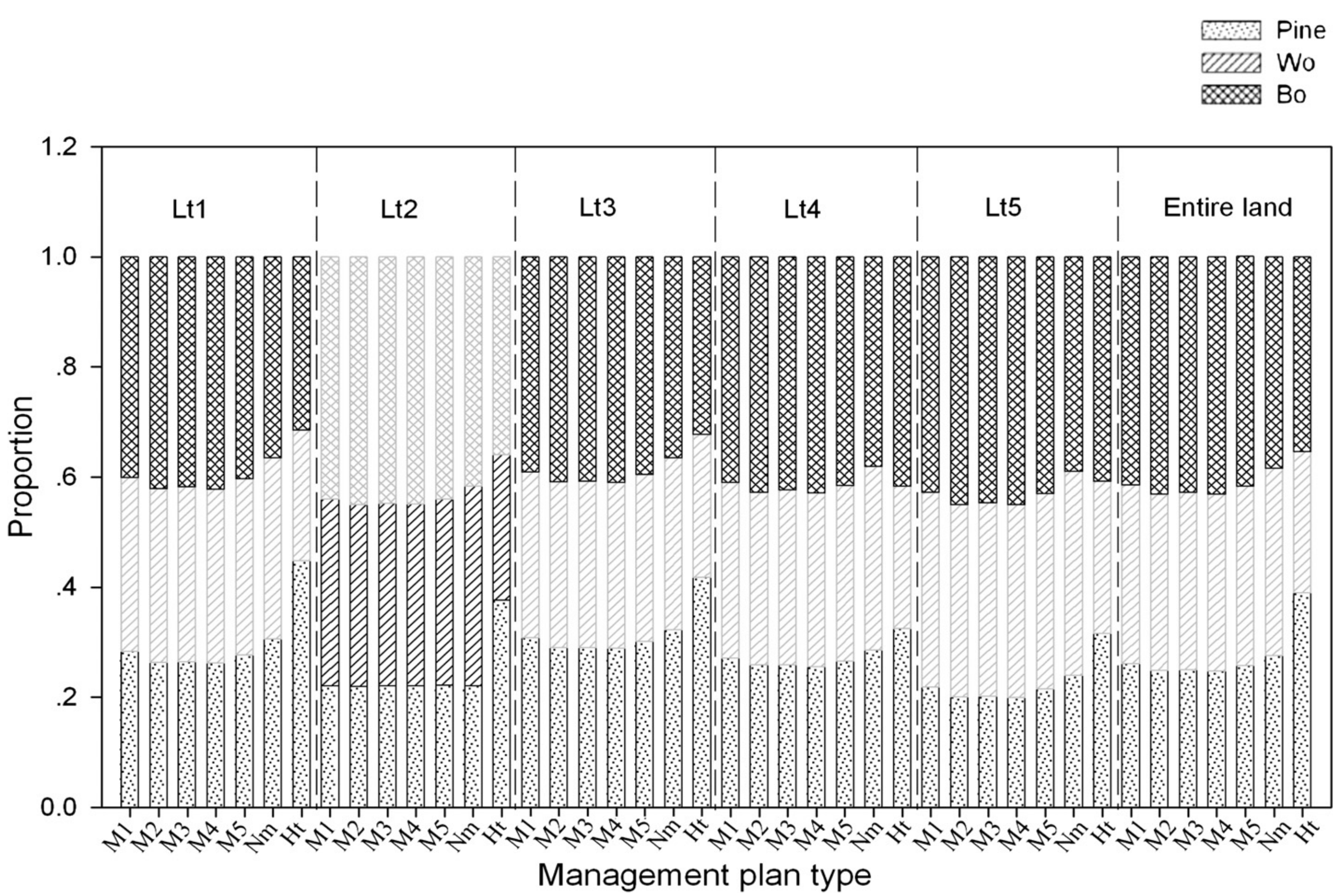

Fig. 8. Impact of alternative management plans and land types on species composition in the medium term (41–100). Statistically significant differences among management plans at 0.01 level are in deep black color and non-significances are marked in gray. Labels M1 to M5 indicate management plans 1 to 5 on each land type; NM indicates the No Harvest and Ht indicates GLO survey results.

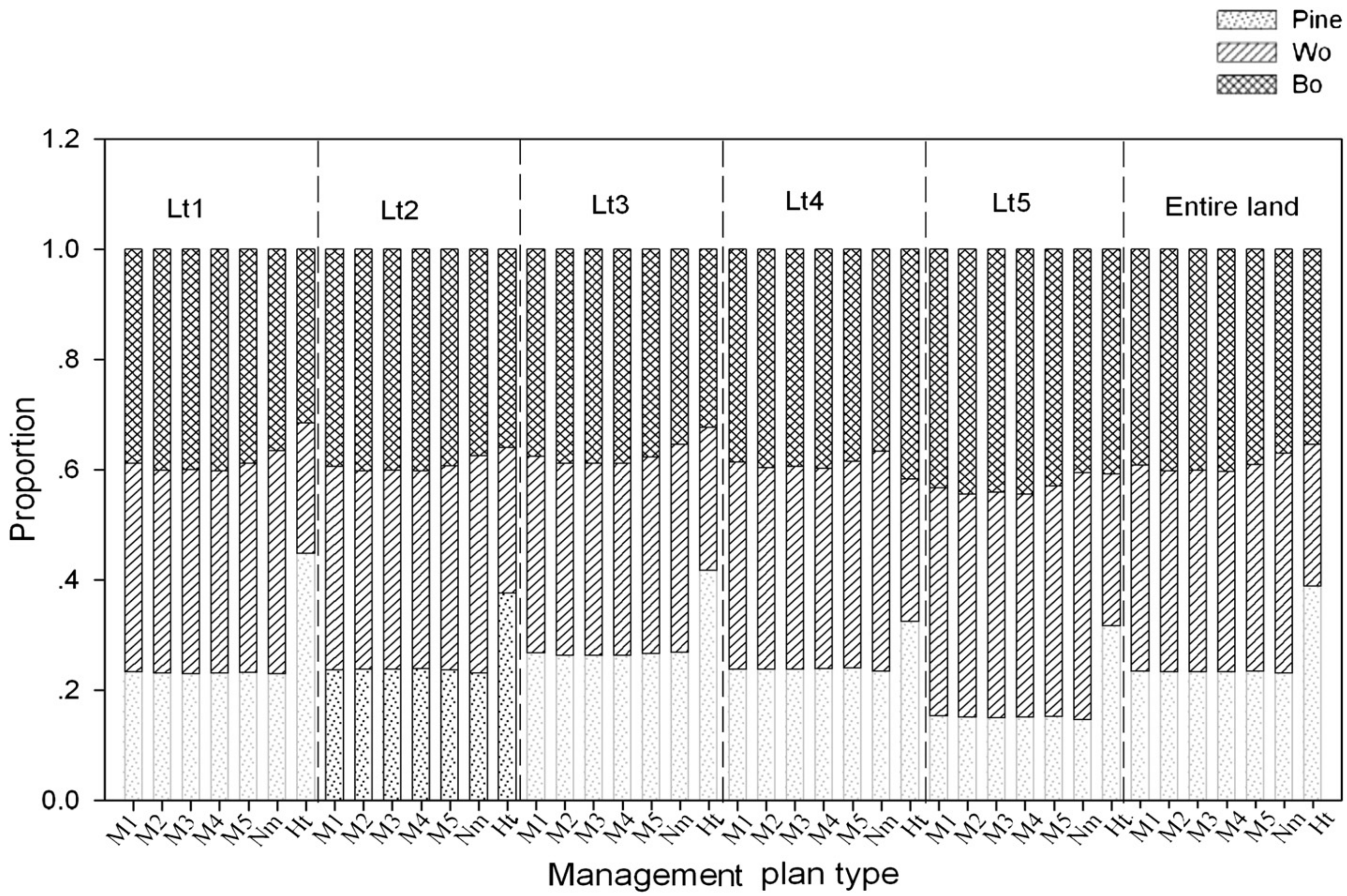

Fig. 9. Impact of alternative management plans and land types on species composition in the long term (101–200). Statistically significant differences among management plans at 0.01 level are in deep black color and non-significances are marked in gray. Labels M1 to M5 indicate management plans 1 to 5 on each land type; NM indicates the No Harvest and Ht indicates GLO survey results.

Fire is another variable that can influence future forest species composition, and it certainly did so in the past. This analysis assumed continuation of wildfire suppression with mean fire-free intervals in excess of 300 years. Prescribed fire applied frequently and consistently on a large scale, has the potential to alter the trajectory of tree species composition over time. This variable was not explored in this analysis, but LANDIS does provide the modeling capability to explore alternative fire regimes. Lacking is detailed information on the differential effects of fire frequency and intensity on tree mortality by tree size or age. When that information becomes available, the effects of prescribed fire can be analyzed using a process similar to that used to examine harvest effects.

The management effects vary with temporal periods considered. Management Plans 1 through 5 involve various amounts of harvesting, while Management Plan 6 (no harvest) served as a baseline for comparison of management effects. Landscape-scale simulations suggest that differing harvest practices, in combination with normal forest growth, mortality and succession are likely to create some shifts in forest-wide tree species composition in the long term, but harvesting practices alone are unlikely to restore pine or black oak species composition to levels observed in the GLO data, if that is desired. The contemporary species composition which has been many decades in the making will be slow to change for this large forest landscape. With the management practices and intensities proposed, our simulation experiments indicate it will be six or more decades before substantial shifts in species composition are likely to be observed at the landscape scale. It is a lengthy process to effect changes in forest species composition that differ from the trajectory of natural succession. Harvest levels in management plans 1 through 5 remove a certain amount of pine which in essence works against restoring pine to levels observed in the GLO reference data. Large-scale management activity focused on natural and artificial pine regeneration may be necessary if pine species composition is to be substantially increased. Management plan 4 effectively reduces the relative abundance of white oak compared to other management plans and drives white oak abundance toward levels observed by site for the GLO reference data.

Simulated management effects varied with physiographic settings. In the short term (0–40 years, Fig. 7) all harvest management practices brought pine and black oak to a status closer to the historical GLO reference conditions than non-harvest on southwest slopes. During the mid-term (41–100 years, Fig. 8) on southwest slopes the three studied species groups moved toward species composition observed in the GLO data. The varying effects among physiographic settings are related to the species establishment and fire return intervals on each physiographic setting. Pine has a higher species establishment probability on southwest slopes, and the contemporary fire return interval is shorter on southwest slopes than other physiographic classes, which creates favorable conditions for pine establishment.

Interactions of management and physiographic classes vary by species groups and temporal periods considered. A statistically significant management differentiation for pine was exhibited on most physiographic settings in the short and medium terms (up to

100 years of simulation). In contrast, significant differentiation of management effects for oaks occurred on more physiographic settings in the long term (101–200 years) than in the short and medium terms. The opposite response pattern along temporal periods revealed that management effects on pine emerge earlier in the simulation than on oaks. It takes longer for oaks to respond to management effects. This phenomenon is related to the regeneration properties of pine which requires more open space and light to regenerate effectively than do the oaks.

Prior to the extensive anthropogenic forest disturbance associated with European settlement, distributions of tree species groups on various physiographic settings in the Missouri Ozarks reflected biophysical relationships among species, sites, and natural disturbances. Although GLO data are biased partially by surveyors' preference and exclusion of certain species and age groups (Mladenoff et al., 2002), these data are the only source from which reasonably accurate tree species distributions prior to European settlement can be inferred (Black et al., 2006). Serving as a reference, the GLO data are one "yardstick" that can be used to compare differences among proposed management alternatives and to provide a broader context (e.g. encompassing more of the range of natural variation) than would be achieved by simply comparing the modeled management alternatives among themselves. If, for example, we had only compared the six MP scenarios among one another, the relative differences would appear much larger than they do in the context of the GLO species composition which is vastly different than what is expected from any of the proposed management alternatives. The no-harvest management alternative (MP6) serves a similar role as a control or baseline, but even it lacks the range of natural variation in species composition that is embodied in the GLO data.

This simulation study examines the MTNF as a whole. One strength of the LANDIS methodology is its capacity to provide higher spatial resolution that can support finer resolution evaluations with greater spatial detail. Although this analysis includes only lands within MTNF ownership, from a larger perspective the surrounding private forests will contribute to changes in landscape-scale species composition over time.

This study summarized the LANDIS simulation result as a relative abundance, rather than the conventional percent cover. The relative species group abundance index at year zero indicated that pine and white oak are relatively less abundant and black oak is more abundant than in the historical forest conditions indicated by GLO relative index.

5. Conclusions

Analysis of the six management alternatives over two centuries (including a baseline or "control" treatment of no harvesting) revealed changes in species composition that are strongly dictated by the species composition and age structure of the current forest. The current forest species composition has been shaped by decades of harvest and fire suppression practices and will take decades of intensive management to modify, if that is desired. The analysis methods used in this study have helped quantify the effect of physiographic classes on future species composition under alternative management scenarios. The methods appear to be applicable for other LANDIS scenario analyses on large landscapes.

References

Batek, M.J., Rebertus, A.J., Schroeder, W.A., Haithcoat, T.L., Compas, E., Guyette, R.P., 1999. Reconstruction of early nineteenth-century vegetation and fire regimes in the Missouri Ozarks. Journal of Biogeography 26, 397–412.

Bettinger, P., Chung, W., 2004. The key literature of, and trends in, forest-level management planning in North America, 1995–2001. International Forest Review 6, 40–50.

Black, B.A., Ruffner, C.M., Abrams, M.D., 2006. Native American influences on the forest composition of the Allegheny Plateau, northwest Pennsylvania. Canadian Journal of Forest Research 36, 1266–1275.

Cardille, J.A., Ventura, S.J., Turner, M.G., 2001. Environmental and social factors influencing wildfires in the upper Midwest, United States. Ecological Applications 11, 111–127.

Cumming, S.G., 2001. Forest type and wildfire in the Alberta boreal mixed wood: what do fires burn? Ecological Applications 11, 97–110.

Cunningham, R.J., Hauser, C., 1989. The decline of the Ozark forest between 1880 and 1920. In: Waldrop, T.A. (Ed.), Proceedings of Pine-hardwood Mixtures: A Symposium on the Management and Ecology of the Type; 1989 April 18–19; Atlanta, GA. Gen. Tech. Rep.SE-58. U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station, Asheville, NC, pp. 34–37.

Gram, W.K., Sork, V.L., Marquis, R.J., Benken, R.B., Clawson, R.L., Faaborg, J., Fantz, D.K., Corff, J.L., Lill, J., Porneluzi, P.A., 2001. Evaluating the effects of ecosystems management: a case study in a Missouri Ozark forest. Ecological Applications 11, 1667–1679.

Gustafson, E.J., Crow, T.R., 1994. Modeling the effects of forest harvesting on landscape structure and the spatial distribution of cowbird brood parasitism. Landscape Ecology 9, 237–248.

Gustafson, E.J., Lytle, D.E., Swaty, R., Loehle, C., 2007. Simulating the cumulative effects of multiple forest management strategies on landscape measures of forest sustainability. Landscape Ecology 22, 141–156.

Gustafson, E.J., Zollner, P.A., He, H.S., Sturtevant, B.R., Mladenoff, D.J., 2004. Influence of forest management alternatives and land type on susceptibility to fire in Northern Wisconsin, USA. Landscape Ecology 19, 327–341.

Guyette, R., Larson, D., 2000. A history of anthropogenic and natural disturbances in the area of the Missouri Ozark forest ecosystem project. In: Shifley, S.R., Brookshire, B.L. (Eds.), USDA General Technical Report.

Guyette, R.P., Muzika, R.M., Dey, D.E., 2002. Dynamics of an anthropogenic fire regime. Ecosystems 5, 472–486.

He, H.S., 2008. Forest landscape models, definition, characterization, and classification. Forest Ecology and Management 254, 484–498.

He, H.S., Dey, D.C., Fan, X., Hooten, M.B., Kabrick, J.M., Wikle, C.K., Fan, Z., 2007. Mapping pre-European settlement vegetation using a hierarchical Bayesian model and GIS. Plant Ecology 191, 85–94.

He, H.S., Li, W., Sturtevant, B.R., Yang, J., Shang, Z.B., Gustafson, E.J., Mladenoff, D.J., 2005. LANDIS, a spatially explicit model of forest landscape disturbance, management, and succession—LANDIS 4.0 user's guide. USDA Forest Service North Central Research Station general technical report; NC-263.

He, H.S., Mladenoff, D.J., 1999. Spatially explicit and stochastic simulation of forest landscape fire disturbance and succession. Ecology 80, 81–99.

Johnson, P.S., Shifley, S.R., Rogers, R., 2009. The Ecology and Silviculture of Oaks. CABI Publishing, Wallingford, Oxon, United Kingdom.

Missouri Department of Conservation, 2010. http://mdc.mo.gov/forest/landE/forests/owner.htm (accessed 02.07.2010.).

Mladenoff, D.J., Dahir, S.E., Nordheim, E.V., Schulte, L.A., Guntenspergen, G.G., 2002. Narrowing historical uncertainty: probabilistic classification of ambiguously identified tree species in historical forest survey data. Ecosystems 5, 539–553.

Moore, M.M., Covington, W.W., Fule, P.Z., 1999. Reference conditions and ecological restoration: a southwestern ponderosa pine perspective. Ecological Applications 9, 1266–1277.

Morrison, J., 1994. Integrating ecosystem management and the forest planning process. PNW-GTR-318. In: Jensen, M.E., Bourgeron, P.S. (Eds.), Ecosystem Management: Principles and Application, vol. II. USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon, USA, pp. 281–290.

Radeloff, V.C., Mladenoff, D.J., Gustafson, E.J., Scheller, R.M., Zollner, P.A., He, H.S., Akcakaya, H.R., 2006. Modeling forest harvesting effects on landscape pattern in the Northwest Wisconsin pine barrens. Forest Ecology and Management 236, 113–126.

SAS, 2008. SAS User's Guide. SAS Institute Inc., Cary, NC, USA.

Shifley, S.R., Brookshire, B.L., 2000. Missouri Ozark Forest Ecosystem Project: site History, Soils, Landforms, Woody and Herbaceous Vegetation, Down Wood, and Inventory Methods for the Landscape Experiment. U.S. Department of Agriculture, Forest Service, North Central Research Station, St. Paul, MN, p. 314.

Shifley, S.R., Thompson III, F.R., Dijak, W.D., Larson, M.A., Millspaugh, J.J., 2006. Simulated effects of forest management alternatives on landscape structure and habitat suitability in the Midwestern United States. Forest Ecology and Management 229, 361–377.

Swanson, F.J., Jones, J.A., Wallin, D.O., Cissel, J.H., 1994. Natural variability-implications for ecosystem management. In: Jensen, M.E., Bourgeron, P.S. (Eds.), Ecosystem Management: Principles and Applications. Eastside Forest Health Assessment, vol. 2. US Forest Service, Portland, OR, USA General technical report PNW-GTR-318, Pacific Northwest Research Station.

Turner, B.J., Chikumbo, O., Davey, S.M., 2002. optimization modeling of sustainable forest management at the regional level: an Australian example. Ecological Modeling 153, 157–179.

USDA Forest Service, 2005. 2005 Land and Resource Management Plan-2005 Forest Plan. Mark Twain National Forest, Rolla, MO.

USDA Forest Service, 2010. National Forest Management Act (NMFA): Eastern Region Forest Plans. http://www.fs.fed.us/r9/projects/ (accessed 30.11.10.).

Wallin, D.O., Swanson, F.J., Marks, B., 1994. Landscape pattern response to changes in pattern generation rules: land-use legacies in forestry. Ecological Applications 4, 569–580.

Westin, S., 1992. Wildfires in Missouri. Missouri Department of Conservation.

Wimberly, M.C., Spices, T.A., Long, C.J., Whitlock, C., 2001. Simulating historical variability in the amount of old forests in the Oregon coast range. Conservation Biology 14, 167–180.
Yang, J., He, H.S., Shifley, S.R., Gustafson, E.J., 2007. Spatial patterns of modern period human-caused fire occurrence in the Missouri Ozark highlands. Forest Science 53, 1–15.
Zhang, Q., Pregitzer, K.S., Reed, D.D., 1999. Catastrophic disturbance in the presettlement forests of the upper peninsula of Michigan. Canadian Journal of Forest Research 29, 106–114.
Zhang, Y., He, H.S., Dijak, W.D., Yang, J., Shifley, S.R., Palik, B.J., 2009. Integration of satellite imagery and forest inventory in mapping dominant and associated species at a regional scale. Environmental Management 44, 312–323.
Zollner, P.A., Gustafson, E.J., He, H.S., Radeloff, V.C., Mladenoff, D.J., 2005. Modeling the influence of dynamic zoning of forest harvesting on ecological succession in a northern hardwoods forest. Environmental Management 35, 410–425.
Zollner, P.A., Roberts, L.J., Gustafson, E.J., He, H.S., Radeloff, V.C., 2008. Influence of forest planning alternatives on landscape pattern and ecosystem processes in northern Wisconsin, USA. Forest Ecology and Management 254, 429–444.