Environmental Management (2009) 44:312–323
DOI 10.1007/s00267-009-9307-7

Integration of Satellite Imagery and Forest Inventory in Mapping Dominant and Associated Species at a Regional Scale

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Received: 15 April 2008 / Accepted: 5 April 2009 / Published online: 2 June 2009

Abstract To achieve the overall objective of restoring natural environment and sustainable resource usability, each forest management practice effect needs to be predicted using a simulation model. Previous simulation efforts were typically confined to public land. Comprehensive forest management practices entail incorporating interactions between public and private land. To make inclusion of private land into management planning feasible at the regional scale, this study uses a new method of combining Forest Inventory and Analysis (FIA) data with remotely sensed forest group data to retrieve detailed species composition and age information for the Missouri Ozark Highlands. Remote sensed forest group and land form data inferred from topography were integrated to produce distinct combinations (ecotypes). Forest types and size classes were assigned to ecotypes based on their proportions in the FIA data. Then tree species and tree age determined from FIA subplots stratified by forest type and size class were assigned to pixels for the entire study area. The resulting species composition map can improve simulation model performance in that it has spatially explicit and continuous information of dominant and associated species, and tree ages that are unavailable from either satellite imagery or forest inventory data. In addition, the resulting species map revealed that public land and private land in Ozark Highlands differ in species composition and stand size. Shortleaf pine is a co-dominant species in public land, whereas it becomes a minor species in private land. Public forest is older than private forest. Both public and private forests have deviated from historical forest condition in terms of species composition. Based on possible reasons causing the deviation discussed in this study, corresponding management avenues that can assist in restoring natural environment were recommended.

Keywords Ecoregion · Forest Inventory and Analysis · Land ownership · Landsat Thematic Mapper · Species composition · Stand size

Introduction

One key aspect of sustainable development is to restore natural environment to the condition prior to large-scale anthropogenic disturbance. In achieving this goal, effective management planning often requires the ability to predict the outcomes of management practices. Due to the spatial and temporal scales involved, long-term, large-scale cumulative effects of management generally cannot be evaluated using field trials or direct observation. Rather, landscape model simulations or simulation experiments are often used instead to compare management alternatives. Previous analyses of cumulative effects of management have been typically limited to the public lands where management plans are crafted for large areas where inventory data are available to describe current forest conditions (e.g., Gram and others 2001, Shifley and others 2006, Radeloff and others 2006). In comparison, the

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cumulative effects of management decisions on landscapes dominated by numerous private landowners with adjacent holdings have been relatively less studied. The cumulative effects of management decisions by private owners are of intense interest because they control 57% of all U.S. forest land and 83% of eastern U.S. forest land which is defined as a land area of larger than 0.5 ha, with a tree canopy cover higher than 10% (U.S. Forest Service 2001). The interactions between public and private forests can be significant since many spatial processes such as fire spread, fire ignition, seed dispersal, and wildlife movement do not recognize ownership boundaries. Recent surveys have provided new information about the collective management intentions of the population of private landowners (Butler and Leatherberry 2004). Even though we generally do not know how any given individual private tract will be managed, we can use what is known about the population of private landowners to explore the cumulative effects of management decisions for landscapes consisting of multiple private ownerships.

The interaction of public land and private land management decisions are of particular interest in the Missouri Ozark Highlands where public and private lands are highly intermingled. The largest public land ownership is the Mark Twain National Forest (MTNF) which has nine management districts among over 10000 individually owned private land patches in the Missouri Ozark Highlands. Wildfire escaping from public land to private land or vice versa is one representative interaction example between private and public land. Wildfires can easily develop into large catastrophic fires on private lands because they are mostly covered by a mixture of forest and grassland and grassland has the feature of carrying fire much faster than forest (Grabner and others 2001). Simulating interaction between public and private lands under each management plan using landscape models entails spatially explicit input of forest species and tree age. A spatially explicit species composition map with single species detail, including major and associated species, has never been generated for the entire Missouri Ozark Highlands.

Public lands often have detailed forest survey data available for individual stands or tracts that describe forest cover type and stand size or size class. This is one of the primary reasons that landscape models have been applied successfully on public lands. In contrast, private forest generally lacks consistent information describing the forest type and forest age class or size class. Typically, the data available include only coarse-scale remotely sensed data describing broad forest cover type groups and widely dispersed Forest Inventory and Analysis (FIA) plot data. Remotely sensed satellite data, for example the National Landcover Dataset (Homer and others 2004; Vogelmann and others 2001), have the capacity to differentiate between land cover types such as deciduous, evergreen or mixed forest and can separate coniferous forest into several coarse forest age and basal area classes (Cohen and others 1995). Landsat Thematic at spatial resolution 30 m can capture 70–95% of dominant species information if they are available for several time slots (Wolter and others 1995). However, the wide usability of TM data is constrained by its inability to provide forest understory information (Ghitter and others 1995, Woodcock and others 1994). For forest with less structural and age range, satellite image is incapable of deriving accurate age or size classes (Mladenoff and Host 1994). Newly developed active remote sensing technology like Light Detection And Range (LiDAR), or Airborne Laser scanners have been shown to be able to capture forest structure information such as age and basal area (Lima and others 2003, Yu and others 2004). However, the limited cover area and expensive cost excludes them from being applied to the regional scale.

Currently, FIA data is the most widely used ground-based forest inventory data. Plot-level FIA data include dozens of survey items describing current forest conditions and factors that that can influence forest dynamics: current stand type, stand size, dominant species and associated species, basal area, stand size, slope and aspect (Hahn and Hansen 1985; FIA 2007). However, FIA data have several limitations for use in describing current forest vegetation patterns across a landscape. For example, FIA data are collected for discrete, dispersed plots, while vegetation patterns are continuously distributed across a landscape. Moreover, sampled FIA plot density is low, approximately one sample plot per 2500 hectares of land area. Spatially explicit information for areas between sample plots needs to be interpolated or estimated using other means. Some prior attempts have been made to extend ground-based measurements using correlations with remotely-sensed data (Treuhaft and others 2004). Land cover data inferred from satellite image has been integrated with FIA by employing stratified analysis to improve estimation of forest area (McRoberts and others 2002). However, to produce a spatially explicit species composition map that has information about dominant and sub-dominant species and can be used as an input layer of current conditions for a forest landscape model entails a full integration of remote sensed land cover data and ground inventoried field data.

This study applies a new method to create spatially explicit species composition and tree age maps for both public and private land in the Missouri Ozark Highlands by integrating classified remotely sensed imagery and FIA data. The derived spatially explicit maps of dominant trees species, associated tree species, and dominant tree age can be used, among other things to illustrate the deviation of current forest from conditions prior to European settlement. A thorough understanding of current differences in species composition and forest size or age class among public and private lands can assist in assessing options and priorities for a wide range of management activities including vegetation restoration, managing prescribed fires or wildfire, and managing wildlife habitat.

The specific objectives of this study are the following:

1. Produce a raster format forest species composition map with spatially explicit dominant and associated species information.
2. Produce a raster format forest species age map with spatially explicit dominant and associated species information.
3. Compare forest species composition and age differences between public and private lands.
4. Identify departure of current forest species composition from historical conditions measured at the time of the first land survey (early 1800s).

Study Area

The study region is 24,887 km^2 and includes the entire southern Missouri Ozark containing the Mark Twain National Forest (MTNF). Within the study area, the MTNF occupies 6070 km^2 and the length of its shared boundary with private land is 23,316 km. The land cover data Missouri spatial data information service (http://msdis.missouri.edu/) illustrated that private land in the study area is composed of 46% forest, 36% grassland, 11% crop and 4% barren area (Fig. 1). White oak (Quercus alba L.), post oak (Quercus stellata Wangenh.), and black oak (Quercus velutina Lam.) are the dominant tree species in the Missouri Ozark Highlands. Topographic variation is high, with elevations averaging 290 m and ranging from 40 to 540 m. The study area includes all or parts of five different FIA units in Missouri 1: Eastern Ozarks; 2: Southwestern Ozarks; 3: Northwestern Ozarks; 5: Riverborder; 4: Prairie: five counties in the southern tip. The mountainous topography of the St. Francois Mountains located mostly in unit 2, averages 500 meters in elevation and extends westward from units 1 to 2. The Missouri river flows eastward across unit 5, which results in low elevation plains in unit 5.

Prior to European settlement in the 1870s, burning by Native Americans and natural fire were the predominant disturbance in the Missouri Ozarks and oak-pine forests, pine-oak woodlands, and oak savannas were dominant vegetation types (Batek and others 1999; Nelson 1997). They were adapted to frequent fire through developing such biological features as germination on burned-over

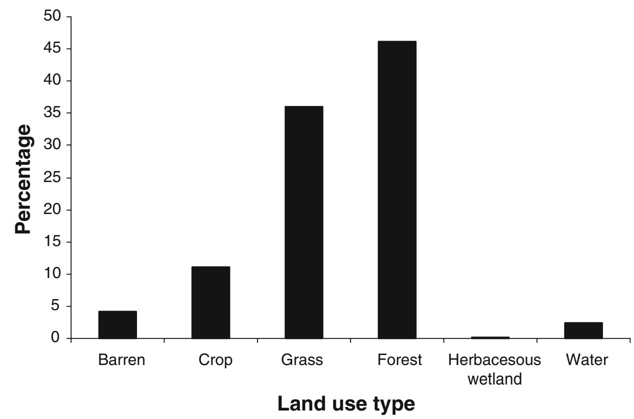

Fig. 1 Land use type on private land of the Missouri Ozark Highlands

mineral soil, sprouting ability, thick bark, and resistance to rotting after scarring (Van Lear and Watt 1993). In contrast, red maple, black cherry, and black gum are not adapted to wildfire due to their fire-intolerant features such as thick bark and shade tolerance (Abrams 1992). The frequent historical wildfire with occurrence interval of 3–18 years led to the sparser historical forest, which is beneficial to species favoring open space (Guyette and Spetich 2003). After the 1870s, European settlement disrupted the natural ecosystem through suppressing fire, timber logging, transformation to and from agricultural land or open grazing. Under the current fire suppression scenario, total basal area has increased from 10 m^2/ha of historical forests to 23 m^2/ha of current forest (Larsen and others 1999), along with tree density increasing from historical 140 trees/ha to current 1600 trees/ha (Anderson and others 2003).

Methods

Historical species composition has already been reconstructed for the Missouri Ozarks in the previous research through combining early nineteenth-century Public Land Survey notes and dendrochronological studies (Batek and others 1999). This study utilized the already reconstructed historical species composition as an indicator of historical forest status in the Missouri Ozarks. Current forest conditions on public and private lands were addressed separately due to different data availability. The entire procedure of generating species composition and resulted maps in this study were all raster formatted. The spatial data can typically be represented as a raster format composed of pixel or a vector format composed of point, line and polygon. However, the probability assignment process in which the species map is generated in this study and the input data of a spatially explicit landscape model needs to be in raster format.

Species Mapping on Public Land

We directly used forest stand inventory data on public land through converting vector formatted stand data to raster format, since comprehensive forest inventory data is available for the entire MTNF lands in the form of forest stand (polygons) inventories (Fig. 2). Average size of each stand polygon is seven hectares and boundaries of each forest stand polygon are delineated based on ecological land types (Miller 1981) which tends to reduce species heterogeneity within each stand polygon.

Species Mapping on Private Land

On private land, the stand data is not available. We estimated current forest composition, structure and age class on private lands through combining easily accessible FIA and classified satellite imagery. The resulted species map on public and private lands were combined to produce a continuous species map for the entire Missouri Ozarks.

Ecotype Delineation Based on Forest Type and Land Form

The FIA data was downloaded from http://ncrs2.fs.fed.us/4801/fiadb/.

The entire study area was divided into five units using FIA unit boundaries because (1) FIA unit boundaries approximate ecoregions defined by Bailey (1998), and (2) the Missouri Ozark Highlands encompass too large an area to analyze as a single unit (Fig. 3). Eight land cover types at 30 m resolution (1: barren, 2: crop, 3: grass, 4: deciduous, 5: evergreen, 6: mixed forest, 7: herbaceous wetland, 8: water) were retrieved from the 1990s Missouri land use land cover data of Missouri spatial data information service (http://msdis.missouri.edu/). Only deciduous, evergreen and mixed forest land types were included in this study; the five non forest land types were excluded since FIA data does not inventory grassland. To verify the capability of TM images in capturing forest land type information, evergreen and deciduous forests inferred from forest stand data in public land were used to cross validate the evergreen and deciduous forests classified from remote sensed data.

Five landforms were classified from a 30 m digital elevation model using Topographic Position Index (Jenness 2006, Dijak and Rittenhouse 2009). Landform classifications are: (1) North and east slope; (2) South and west slope; (3) Ridge; (4) Upland drainage; (5) Bottomland. Three Landsat forest types were combined with the five landforms in geographic information system (GIS) to generate 15 classes of ecotypes for each of the five FIA ecoregions in the study area (Fig. 2). In this context we defined an ecotype as the unique combination of each forest type by landform. Due to relatively homogenous soils, physiography, and forest type characteristics, species heterogeneity within each ecotype is reduced and species composition (including dominant and secondary species) and stand size are specific to ecotype (Bailey 1998, He and others 1998). Each cell has a corresponding ecotype ID (Table 1). For example, ecotype 214 represents deciduous forest (4) on the North and east slope (1) in unit 2.

Estimating Species Composition and Age for Each Ecotype Through Probability-Based Assignment

Dominant species and associated species by stand size class were compiled from spatially explicit FIA plot data. FIA data has readily available stand age information and they are calculated from average age of trees in the

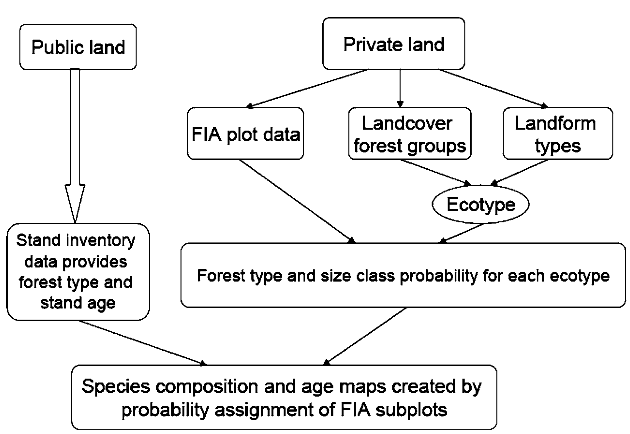

Fig. 2 Method framework

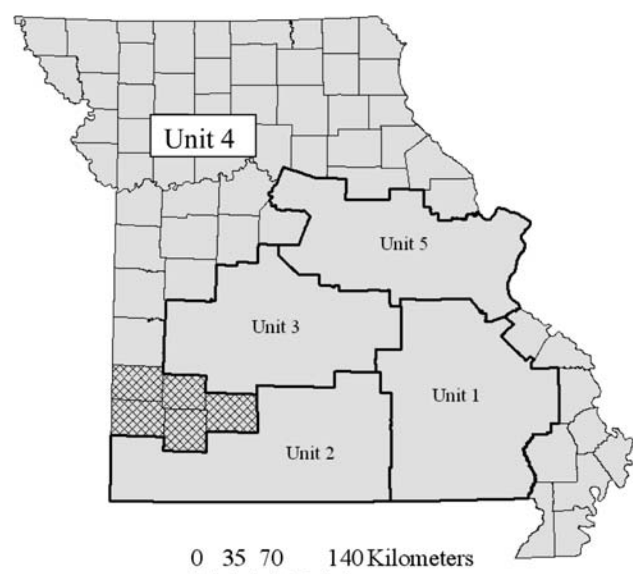

Fig. 3 The spatial pattern of units 1, 2, 3, 5 and the five counties in the unit 4

Table 1 Percentage occurrence of each forest type for each ecotype of unit 1

Ecotype									
114	Species[a]	501	503	504	510	515	801		
	Percent	0.0678	0.6487	0.1679	0.031	0.071	0.014		
115	Species	162	181						
	Percent	0.5625	0.4375						
116	Species	402	404						
	Percent	0.279	0.7209						
124	Species	501	503	504	510	515	520	706	801
	Percent	0.0798	0.6208	0.2198	0.019	0.029	0.012	0.01	0.01
125	Species	162	181						
	Percent	0.6667	0.3333						
126	Species	404							
	Percent	1							
134	Species	501	503	504	515	520			
	Percent	0.2139	0.5781	0.0982	0.075	0.035			
135	Species	162	181						
	Percent	0.5556	0.4444						
136	Species	402	404						
	Percent	0.1212	0.8788						
144	Species	501	503	504	520				
	Percent	0.0678	0.5763	0.2033	0.153				
146	Species	404							
	Percent	1							
154	Species	503	706						
	Percent	0.619	0.381						

The first number of ecotype code represents unit; second represents landform type; third represents forest type. Percentage occurrences on units 2, 3 and 4 have the same format with that of unit 1 and they are not listed here (evergreen forest has no presence on upland drain of the unit 1. Evergreen and mixed forests have no presence on bottomland of the unit 1. Their combinations are not listed in the table)

[a] Forest type code for Tables 1 and 2

162 (Shortleaf pine), 181 (Eastern redcedar), 402 (East redcedar/hardwood)

404 (Shortleaf pine/oak), 501 (Post oak/blackjack oak), 503 (White oak, red oak, hickory), 504 (White oak), 510 (Scarlet oak), 515 (Chestnut oak/black oak/scarlet oak)

520 (Mixed upland hardwoods), 706 (Sugar berry/hackberry/elm/green ash)

801 (Sugar maple/beech/yellow birch)

predominant size class. One stand has only one stand age value and there is no age variation within the stand. To capture the heterogeneity of tree ages within a stand and provide for a more realistic initial stocking of pixels by populating them with multiple species of varying ages, this study derived tree age from tree diameter, rather than using stand age as in FIA data. Different types of models (linear, polynomial, etc) were evaluated on each species group in relating DBH to age. The data used to generate these equations came from combined site index trees for the FIA data in Missouri and site index trees from Missouri Ozark Forest Ecosystem Project. The best fit equation was selected from the trial array in converting DBH to age (Table 2). FIA stand size was grouped into five size classes: 0–10: seedling (1); 11–30: sapling (2); 31–50: Pole (3); 51–70: Small mature (4); >71: Large mature (5). The forest type and stand size class for each FIA plot was summarized by ecotype and the proportions of forest types

Table 2 Model parameters for converting tree DBH to tree age

Species	Sample size	r^2	*p* value
Hickory	432	0.3295	0.0001
Maple	96	0.1506	0.001
Other	841	0.2839	0.0001
Red cedar	492	0.2774	0.0001
Red oak	3726	0.3056	0.0001
Shortleaf pine	783	0.3402	0.0001
White oak	3129	0.345	0.0001

and size class for each ecotype were calculated for units 1, 2, 3 and 5. For example, forest type 501 accounts for 6.78% of ecotype 114 and its average stand size class is 4 in ecotype 114 (Table 1). Ecotype maps were converted to ASCII raster and the following assignments were accomplished through C programming. Forest type and stand size class were assigned to each ecotype on the landscape based on their relative proportions computed from the FIA data for the study region. For example, as FIA calculated 6.78% of forest type 501 on ecotype 114, 6.78% of land from ecotype 114 was randomly selected and they were assigned a forest type of 501.

Individual species or species groups and ages were then assigned to each pixel from the subplot pool for the ecotype's forest type and stand size class. The number of subplots used in populating the units is 3806 for the unit 1; 1614 for the unit 2; 1331 for the unit 3; and 1774 for the unit 4. The five southern counties dominated by grassland in unit 4 are nearly surrounded by units 2 and 3 (Fig. 3). In light of the particular spatial location and the relatively small number of forested cells in these five counties, the species and size class proportions were calculated from probabilities of neighboring FIA unit 2 which had the most similar topography.

The resulting forest species composition and age proportion were assigned probabilistically to the private land based on the proportion calculated from FIA data. To verify that the resulting species composition and age maps had proportions equal to the theoretical proportions calculated from the FIA data, we compared the proportion of occurrence by species and age class in the derived maps with the original proportions calculated from FIA data. The assignment process for each unit utilized the same algorithm. It is unnecessary to validate the assignment process for all the five units. We conducted the verification process in unit 1 since it is more representative of the assignment process with its much higher forest coverage than other units. The occurrence proportion and original proportion were compared in SPSS using a paired-sample T test.

Table 3 Comparison between the observed percentage (calculated from FIA data) and predicted percentage (percentage in the resulted map) of each forest type on unit 1

Ecotype									
114	Forest type[a]	501	503	504	510	515	801		
	Theoretical per.[a]	7	65	17	3	7	1		
	Occurrence per.	7	65	17	3	7	1		
124	Forest type	501	503	504	510	515	520	706	801
	Theoretical per.	8	62	22	2	3	1	1	1
	Occurrence per.	8	62	22	2	3	1	1	1
134	Forest type	501	503	504	515	520			
	Theoretical per.	21	58	10	8	4			
	Occurrence per.	22	55	10	10	4			
144	Forest type	501	503	504	520				
	Theoretical per.	7	58	20	15				
	Occurrence per.	7	58	20	15				
154	Forest type	503	706						
	Theoretical per.	62	38						
	Occurrence per.	63	37						

Comparison results on units 2, 3 and 4 have the same format with that of unit 1 and they are not listed here

[a] Forest type code is the same with that in Table 1; All the numbers were rounded to integers

Results

Method Verification

The species and age map proportions for each ecotype were not significantly different from the proportions calculated from the FIA data for each ecotype ($p = 0.96$). This validates our algorithm and the assumption that resulting species composition map has proportions for each species or species group that are similar to the original forest inventory data (Table 3).

Overall Forest Type Composition and Size Structure in the Missouri Ozarks

The comparison between remotely sensed forest types and those determined from public stand data revealed that remotely sensed land cover can capture 98.6% of deciduous forest type derived from stand data. While for evergreen forest the accuracy decreased to 67%. Considering the sparse presence of evergreen forest in Missouri Ozark area and they exist primarily as a sub-dominant species, remotely sensed data will have decreased accuracy in identifying these sub-dominant species.

The resulting species composition map has a spatially explicit representation of dominant and associated species, and ages that are unavailable from either satellite imagery or forest inventory data. It combines the known spatially explicit pattern of physiographic regions with the known (spatially inexplicit) proportions of forest cover by species and age class though the observed probabilities of occurrence for a large population of FIA plots where physiographic class, species composition, and size class are know simultaneously.

The top 14 species or species groups in the Missouri Ozarks are shown in Fig. 4. Combined, they account for 99% of the forested land in the Missouri Ozarks. The map shows that public land has higher percent forest cover within the MTNF proclamation boundaries than most private lands; southeastern Missouri Ozarks has a higher percent forest cover than other regions of the Missouri

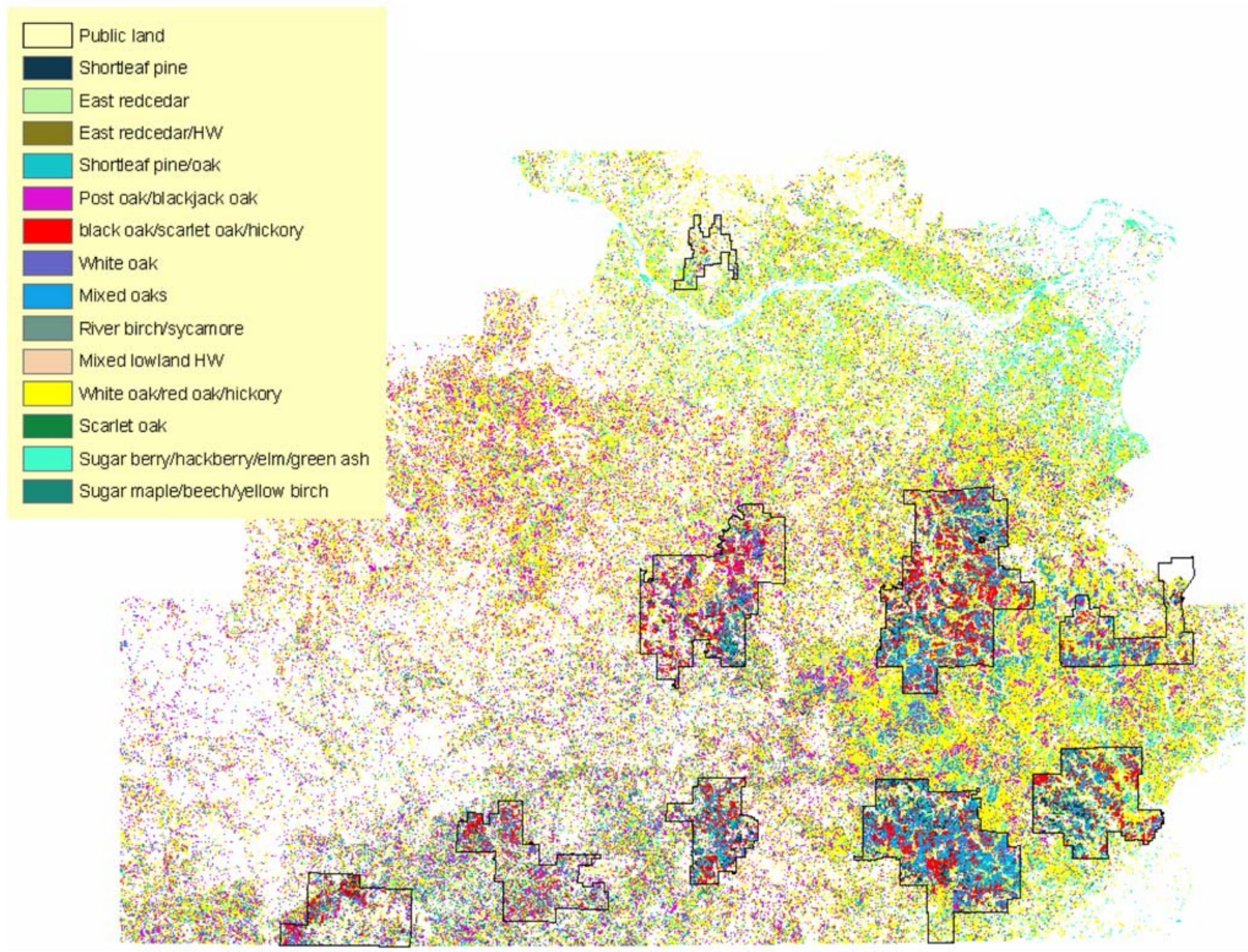

Fig. 4 Species composition map

Ozarks; and public land has distinctly different species composition from private land. Eighty percent of the forest stands in the Missouri Ozarks are in pole or small mature stage (Fig. 5). Sapling stands and large mature stands account for 11% and 8% of the forest in the Missouri Ozarks, respectively (Table 4).

Comparison Between Historical and Current Forest Composition

European settlement in the early nineteenth century brought fundamental changes in species composition and structure through harvesting, wildfire, and eventually fire suppression. The historical vegetation reconstruction for the 1800s indicated that shortleaf pine was the dominant species and occupied 23% of the total 2770 km^2 of upper Current River watershed of southern Missouri (Table 5). Mixed shortleaf pine and oaks (white oak, black oak and post oak) covered another 31% of the watershed. Pure white oak and post oak accounted for 7% and 4% of the watershed, respectively. White oak and post oak also were also associated with other species such as black oak, hickory, and red oak and in mixed forest group. Mixed white oak with other species and mixed post oak with other species occupied 11% and 6.9% of the watershed, respectively. Black oak, red oak and hickory were rarely found as dominant species during the original land survey; they were mostly associated with white oak or post oak. Generally, pure shortleaf pine dominated dry land such as upper watershed positions, and post oak dominated barren areas such as savannas or open woodlands (Batek and others 1999).

Compared with historical forest, current forest in the study region includes much less shortleaf pine (Table 5). Pure shortleaf pine and shortleaf pine mixed with other species accounts for about 1% and 2% of current forest cover, respectively, in contrast to 23% and 31% of the historical forest in the Missouri Ozarks. Mixed white

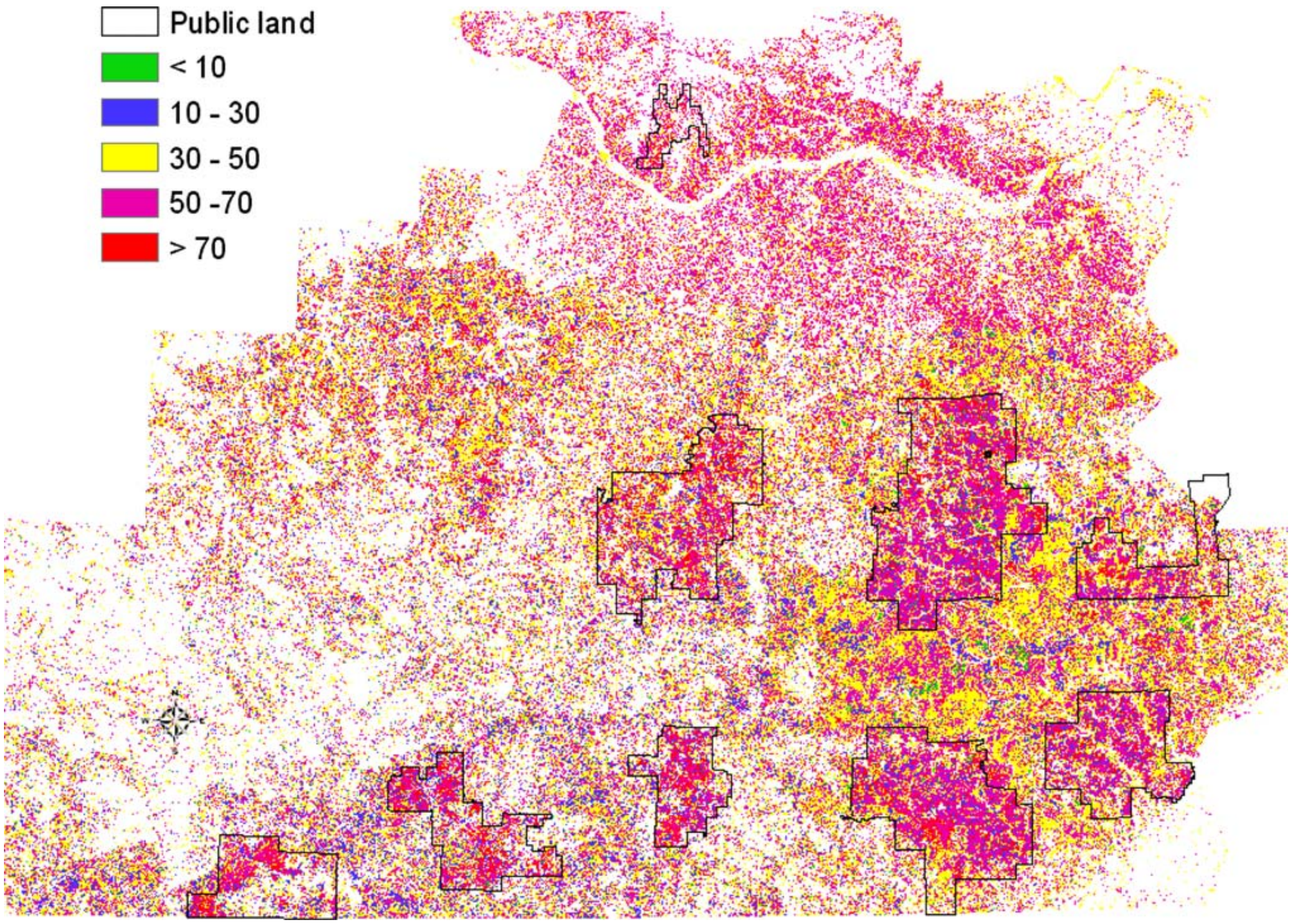

Fig. 5 Stand size map

Table 4 Forest stand size structure for the entire Missouri Ozarks and comparison of forest stand size between private and public forest

Size class	The entire Missouri Ozarks	Private forest (%)	Public forest (%)	Difference between private and public forest
0–10	1.4	1	1	0
11–30	10.8	11	13	−2
31–50	41.2	45	11	34
51–70	38.5	37	50	−13
>71	8.1	6	25	−19

oak/red oak/hickory is now the dominant forest cover type and accounts for 46% of the current forest, in contrast to about 1% of the historical forest (Table 5). Among the top six single species or species groups occurring on 85% of forested land in the Missouri Ozarks, five belong to the oak group. The only exception is mixed sugar berry/hackberry/elm/green ash that currently occupies about 10% of the forested land (Table 5). White oak used to exist in a mixed status with other oaks or with species in the history. The relative abundance of pure oak was lower at present than in the history. Today, post oak is frequently found with blackjack oak and blackjack oak, red oak and hickory generally exist in association with other oaks.

Comparison Between Private and Public Forests

Mixed oak/hickory is the dominant forest type in both private and public lands (Table 6). Sugar berry/hackberry/elm/green ash forest type that accounts for 11% of the private forest is not found in public forest. Post oak/blackjack oak is an important forest type in both private and public lands, but it occurs in greater proportion on private land than public land. White oak dominated stands have higher dominance in private land than in public land. Pure shortleaf pine and shortleaf pine mixed with oak are distributed much more extensively in public land than in private land. For other minor forest types, river

Table 5 Comparison of forest type between current and historical forest (Batek and others 1999)

Forest type	Current forest (%)	Historical forest (%)	Difference
Shortleaf pine	1	23	−22
Sugar maple/beech/yellow birch	1		1
Eastern redcedar	2		2
Shortleaf pine/oak	2	29	−27
Chestnut oak/black oak/scarlet oak	2		2
River birch/sycamore	2		2
Mixed upland hardwoods	2	1	1
Mixed oaks	3	11	−8
Black oak/scarlet oak/hickory	4		4
White oak	10	7	3
Sugarberry/hackberry/elm/green ash	10		10
Post oak/blackjack oak	14	3	11
White oak, red oak, hickory	46	1	45
Total[a]	100	75	24

[a] Some forest types or groups reconstructed for historical forest have no matches with current forest and they are not included in the comparison; therefore, the total percentage of historical forest is less than 100%

Table 6 Comparisons of forest type composition between public and private forest

Forest type	Private land percent (%)	Public land percent (%)	Difference (%)
East redcedar/hardwood	<1	2	−2
Shortleaf pine/oak	<1	16	−16
Shortleaf pine	1	9	−9
Eastern redcedar	2	2	0
River birch/sycamore	2	0	2
Mixed upland hardwood	3	0	3
White oak	11	6	4
Post oak/blackjack oak	15	6	9
Mixed oak/hickory	55	58	−3
Sugar berry/hackberry/elm/green ash	11	0	11
Scarlet oak	<1	0	<1

birch/sycamore and eastern redcedar have higher dominance and eastern redcedar/hardwood has lower dominance in private land than in public land.

Public forest generally has larger stand size than private forest; large mature and small mature forest accounts for 25% and 50 % of public forest, respectively, compared to 6% and 37%, respectively, for private forest. Pole stands account for 46% of private forest while public forest has only 11% of forest in the pole size class. Seedling and sapling stands have comparable percentage in public and private lands (Table 4).

Discussion

The shortage of spatially explicit species composition information at the regional scale has constrained application of landscape models on simulating effects of environmental restoration measures across multi-owned land in the Missouri Ozark Highlands. The information contained in the resulting species composition map produced in this study can be classified into three types: (1) single species (e.g., shortleaf pine, eastern redcedar, white oak, scarlet oak), (2) forest composed of similar species (e.g., eastern redcedar/hardwood, post oak/blackjack oak, black oak/scarlet oak/hickory, mixed oak, white oak/red oak/hickory, sugarberry/hackberry/elm/green ash, sugar maple/beech/yellow birch, river birch/sycamore), and (3) mixed forest (e.g., shortleaf pine/oak and mixed upland hardwoods). In terms of applicability as input to landscape models that need spatially explicit species composition information, the type (1) is ideal because one species has one set of ecological parameters related to ecological processes such as fire behavior or seed dispersal. The type (2) composed of species with similar or compatible ecological properties) can be assigned one set of ecological parameters like for single species. The type (3) consists of species that have distinctly different ecological properties and excludes the possibility of assigning them the same set of ecological parameters and its application as input of landscape model. However, the low presence (e.g., 4%) of mixed forest will not significantly degrade the applicability of species composition map produced by this study as model input. Besides species composition, forest size class detailing at the levels of seedling, sapling, pole, small mature and old large mature, are adequate to differentiate most ecological processes related to age. The exhaustive species and age product facilitate the incorporation of all species (including dominant and associated species) into landscape simulation and can improve landscape model performance in simulating such landscape processes as fire spread, forest succession or seedling dispersal. For example, black oak is an associated but widely distributed species in the Missouri Ozarks. Traditional simulation methods that used remote sensed species data would miss tracking its involvement in ecosystem processes such as competition and seed dispersal.

This new method integrates the currently available remote sensed and ground surveyed data. Dominant and associated species and forest age were produced with spatial detail so that their related effects or functions in the entire ecosystem can be represented well. Percentage of each species on each ecotype is calculated from ground surveyed data and it is deterministic. Within each ecotype, species composition is assigned based on species occurrence probability. The probability assignment process will not decrease the usability of the resulting species map in a simulation model, because common landscape models focus on simulating natural or human disturbance at the patch level, not the individual pixel level (Mladenoff and He 1999). Instead, the probabilistic assignment process of generating species composition as model input can assist in balancing the tradeoffs between individual tree growth models that can optimize detail by giving up landscape extent and landscape models that can simulate a large spatial extent at the expense of detail (Hummel and Cunningham 2006).

Advantage of this method over the traditional spatial interpolation avenues lies in that this method can result in a spatially explicit vegetation map with dominant and associate species information that is irretrievable either from pure satellite data or FIA data. In addition, forest patch structure can be revealed from the resulted map as well. Information relevant to dominant species patch structure and spatial distribution in the landscape is preserved by satellite classification. The probabilistically assigned stand age and associated species can provide spatial patch structure information. Commonly used statistical inference methods such as ISOLINE, kriging, or co-kriging use the vegetation information of the sampled points to interpolate vegetation for places not covered by sampled points. These interpolation methods have significant limitations when being used to interpolate between FIA plots because they assume that interpolated data are numerical and are spatially continuous (He and others 2007). That is often not the case with forest cover type, age class, size class, species composition or stand density since many factors such as soil, elevation, and competition among species often cause the spatial discontinuity of a species distribution (Bolliger and Mladenoff 2005).

The proposed method is not without limitations. First, the spatial autocorrelation typically accounted for in other spatial interpolation technique such Kriging or co-kriging can not be taken into account in our method since sampling resolution of FIA data is too coarse to estimate autocorrelation at small spatial distances. Second, the resulted map is not spatially exact. So validation of the resulted species map will be problematic. The only validation in this study is to validate the probabilistically assigned map follows a similar distribution as the proportion calculated from FIA data. Future certainty analysis of the species map under this method may be able to compare the frequency distributions of forest type and sizeclass for multiple years of FIA data. In addition, sub-plot data were used in this study in deriving species occurrence probability on each ecotype. It might cause some errors when statistical interval ranges were needed to be added to the result. Although sub-plot data can provide more spatially explicit information, plot data should be employed in the future when statistical error bars are needed. Third, the FIA data used in this study was based on swapped coordinates since the accurate coordinates of each plot is not released to the general public in meeting the agreement of protecting privacy of each land owner. The intentionally shuffled public plot coordinates would lead to some errors such as grouping plots into wrong ecotypes. However, the perturbed plot location would not affect the applicability of this method since only 10% of the plot location has been swapped in FIA data and the swapping happens only between plots with similar forest and land features (McRoberts and others 2005). Furthermore, previous research has established that effect of this swapping was negligible for analysis conducted a regional scale (Coulston and others 2004; McRoberts and others 2005). Fourth, the historical data covers only one part of the study area and its result may be biased partially when used in being compared with the current species composition in the entire Missouri Ozark area.

This study only generated a map representing forest distribution, while grassland was not incorporated. Grassland is a landuse type that anthropogenic effort tries to maintain its current status in state of Missouri. The land use type derived from remote sensed image can be used directly in retrieving the grassland information, it is unnecessary to incorporate grassland into forest mapping in this study. Forest Landscape model simulation typically addresses forest succession (He 2008) while grassland dynamics is not included. Sometimes grassland plays a crucial role in shaping ecosystem dynamics through interactions with adjacent forest ecosystem like carrying a frequent and fast wildfire. To realize its role, grass can be simulated in landscape model as a pseudo tree species with a much shorter longevity and re-sprouting every simulation time step. Grassland is also treated as a land type. The establishment probability on this particular land use type is zero for every tree species since this land type needs to stay steady.

Species composition and stand size are distinct between historical and present forest, as well as between contemporary private forest and public forest. Relatively, private forest deviates further away from historical condition than public forest. Some pure forest types such as post oak and some mixed forest type such as shortleaf pine-hickories existed in the history, while their counterparts can not be found in the current forest. Anthropogenic activities are the main factors causing these deviations. These disturbances happened in various time stages and their effect on current Missouri Ozark forest varied. Timber harvesting reached its peak around the 1870s because of railroad construction (Bass 1981). The number of farm owners decreased 72% from 1925 to 1974 and some abandoned agricultural lands recovered to their original forest conditions (Walters 1992). Open range for livestock such as hogs and cattle reached its peak between 1890 and 1950. Grazing and widespread burning of rangelands are still affecting Ozark forests. Fire suppression effort since 1940 and heavy logging have decreased the abundance of shortleaf pine to 20–25% of its original occurrence through accumulation of debris, inhibiting shortleaf pine regeneration in the Missouri Ozarks (Shifley and Brookshire 2000, Guyette and Larson 2000). Current stand structure originates mostly from tree establishment and recruitment since the 1920s and 1930s when fire prevention was effectively implemented and fire abruptly decreased. At present, impacts of agricultural activity, timber harvesting and open grazing have all passed their peak period and their effects are limited. Shortages of regular wildfire compared to the frequent burning of historical fire regimes is a common phenomena though prescribed fire is being gradually introduced into some public forests. Reintroduction of regular fire should be an important forest management practice in restoring presettlement vegetation. Other management practices such as clearing accumulated ground fuels can assist in providing bare ground for shortleaf pine seeds to sprout. Current dense forest does not favor the establishment and recruitment of pine which has low tolerance of shade. Restoring stand's stocking to ecologically acceptable level for pine forest is one key silvicultural avenue (Larsen and others 1999). In restoring the natural status of forest, current forest health issues facing Ozark Highlands forest is worthy of attention. Since the 1970s, climatic events (severe drought), herbivorous insects, and virulent pathogens (root disease) have been causing oak decline in Ozark Highland area (Jenkins and Pallardy 1995).

Conclusions

The spatially explicit species composition map generated in this study can improve landscape model performance in that associated species information, unavailable from either remote sensed or FIA data, has been derived. Anthropogenic disturbances have caused deviation of present forest in both public and private lands from historical condition. Relatively, public forest is in a closer condition to historical one than private forest. More attention should be paid to private land in achieving the goal of restoring forest along the ecological and sustainable utilization track.

Acknowledgments Funding support is from US Forest Service North Central Research Station. We thank three anonymous reviewers for helpful reviews on the manuscript.

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