SIMULATING THE EFFECTS OF RIPARIAN ZONE DELINEATION AND MANAGEMENT PRACTICES ON LANDSCAPE PATTERN AND TIMBER PRODUCTION

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by

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The undersigned, appointed by the Dean of the Graduate School, have examined the thesis entitled:

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MANAGEMENT PRACTICES ON LANDSCAPE PATTERN AND TIMBER
PRODUCTION

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ABSTRACT

Best management practices (BMPs) are essential to giving the forest manager guidelines to follow that result in the least amount of negative impact on the forest landscape and corresponding riparian areas. One particular type of BMP is the application of buffers to riparian areas. Establishment of riparian buffers is the practice of maintaining the timber within a certain distance of a riparian area so as to protect the tributaries from various adverse effects. Often the width of a riparian buffer is not specifically defined but is left up to the forest manager with the goal of maximizing the revenue obtained from a timber harvest while protecting the biological integrity of a stream. An educated decision involves balancing these two objectives. It is unknown, however, how the application of different buffers affects the forest landscape pattern and resulting timber volume over time. The purpose of this research project is to determine the effect that different riparian zone delineations, based on BMP, will have on landscape pattern and timber production over time.

Five scenarios were defined to represent the primary approaches behind the delineation of most riparian buffers. Two of the scenarios, “harvest all” and “no harvest”, were used as control situations to exemplify what would occur in the absence of a riparian buffer with and without harvest. Two fixed width buffers, 20 m and 100 m from the stream, were used to demonstrate a minimum and maximum for which a riparian buffer could be delineated. A GIS (Geographic Information Systems) based equation was used to determine the boundaries of a riparian buffer with variable distances from the stream based upon localized soil and topographic characteristics. These boundaries determined the extent to which even-aged harvesting practices would be applied.

Results indicated that the most influential variable in the simulation was the application of harvest. Areas within the buffer delineation, where no harvest regime was applied, had a great diversity of ages arranged in a fairly disaggregate pattern throughout the landscape. An even-aged harvest regime led to a general equilibrium of species and species ages present outside the buffer delineations.

The variable width buffer most efficiently protected the stream by widening the buffer from the stream at areas that are presumed to be more susceptible to erosion or pollutant discharge. When compared with the other buffer scenarios the variable width buffer scenario protected the stream at values approaching that of the 100 m scenario while only harvesting 16,000 less board feet per year than the 20 m scenario.

Analyzing the effects of different buffering scenarios upon landscape pattern and timber volume provides forest managers with better tools for deciding the best action to take in balancing timber harvest with the biological integrity of streams.

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CHAPTER I INTRODUCTION

IMPORTANCE OF RIPARIAN MANAGEMENT

Rivers and stream systems are important components of landscapes. Not only do they contribute to society by providing a water supply as well as recreational uses, but the quality of a stream system is also an integral part of the quality of the surrounding ecosystems. Riparian forests, forests adjacent to a stream or river, are tied closely with the ecological processes of the stream. Riparian forests buffer against soil erosion and contaminants, provide shade to moderate stream temperature, supply organic matter as an energy source for aquatic biota, stabilize the stream channel, and contribute in-stream wood important for habitat complexity (Barker et al., 2002).

Extensive logging, the net-loss of grasslands and wetlands, urbanization pressure, and increases in anthropogenic sedimentation have accounted for dramatic changes in stream ecosystems in the last century (Freeman and Ray, 2001). Consequently, the need for managing riparian areas has increased. Monitoring land use activities and managing watersheds more holistically will insure the biologic integrity of the stream.

EFFECTS OF HARVESTING RIPARIAN AREAS

Riparian vegetation plays an integral part in the ecological processes of a stream. Harvesting these areas alters the vegetation and typically introduces a variety of indirect effects such as soil compaction and reduced soil infiltration capacity, both resulting from equipment use. Greater overland flow of water often results from such changes in soil structure and increases the probability of surface erosion (Brooks et al., 1997).

Water quality can be affected also by harvesting the timber from a riparian area. Water chemistry is modified as it moves through a forest canopy, organic layer, and soil allowing the stream to have reduced levels of sediment and fewer harmful chemicals relative to areas where vegetation is absent (Cheng et al., 2001).

Removal of trees that overhang the stream can dramatically alter microclimatic conditions. Lack of shade results in higher temperatures in the stream. This can have negative effects on the chemical and biotic components of the stream ecosystem (Brooks et al., 1997).

BEST MANAGEMENT PRACTICES

Because of the ecological importance and vulnerability of riparian forests, many states have adopted practices designed to protect streams, e.g. Best Management Practices (BMP) (Cubbage et al., 1993). BMPs are suggestions for the natural resource manager to take into consideration, with the goal of making responsible conservation decisions.

Best Management Practices (BMPs) are: "methods, measures, or practices to prevent or reduce water pollution, including but not limited to, structural and nonstructural controls, operation and maintenance procedures, other requirements and scheduling and distribution of activities (Palone and Todd, 1997)." BMPs originated as a result of the enactment of the Clean Water Act in 1972. "The objective declared in the 1972 act is to restore and maintain the chemical, physical, and biological integrity of the nation's waters" (Copeland 1999). Forestry BMPs are generally defined by the individual states, each having slightly varying requirements. Examples of BMPs include proper road placement, responsible pesticide application, or defining riparian forest buffers, among other practices.

Many states use BMPs to ensure forest manager compliance with the objectives of the Clean Water Act. Research has shown that in certain areas "BMPs reduced sediment yield increases ten-fold compared to the yields observed prior to BMPs" (Ice and Shepard, 2002).

Riparian buffers are of particular interest because there is no clear definition of the width of buffer required. Often fixed width buffers are utilized for ease of application. This can lead to adequate buffers in one area and inadequate buffers in another because soils, topography, and hydrology vary from place to place. Variable width riparian forest buffers can be defined by taking other characteristics such as stream order or terrain conditions into account (Palone and Todd, 1997). Terrain conditions such as topography, soil hydrologic properties, and surface vegetation can be assessed to vary the width of the buffer from the stream. Currently little is known about how fixed width buffers differ in size, shape, or impact from variable width buffer for a given stream system.

ROLE OF GIS AND LANDSCAPE MODELING

Geographic Information Systems (GIS) is defined as a set of tools for collecting, storing, retrieving, transforming, and displaying actual spatial data for a particular set of purposes or objectives (Burrough, 1987). A model is an abstract representation of a system or process (Turner et al., 2001). Landscape modeling specifically creates an abstract representation of the processes involved in landscape ecology.

GIS-based landscape models allow for the prediction of the interactions of ecological responses to various attributes. Predicting the ecological processes of a landscape can lead to better management decisions and new insights into dynamic pattern and process. Landscape modeling is needed because landscape interactions often extend beyond an ability to sample them in actual time and space. GIS allows researchers to compare varying scenarios using simulations. Consequently, by combining GIS with landscape modeling it is possible to examine a multitude of factors across extended spatial and temporal scales (Martin et al., 2002).

Subject matter devoted to these models is as diverse as the landscape itself (Goodchild et al., 1996). One landscape model in particular, LANDIS, is designed to simulate forest landscape change over large spatial and temporal domains (Mladenoff et al., 1996, Mladenoff and He, 1999). Using GIS and landscape modeling in the form of LANDIS allows for application of different scenarios to the same landscape to observe the effects that these applications will have over a long time period.

PURPOSE

Best management practices (BMPs) are essential guidelines that help the forest managers minimize negative impacts of management practices on the forest landscape and its water resources. One particular type of BMP is the application of buffers to riparian areas. Establishment of riparian buffers is the practice of maintaining the timber within a certain distance of a riparian area so as to protect the tributaries from various adverse effects. Often the width of a riparian buffer is not specifically defined but is left up to the forest manager. The width may be significant for ecological reasons, but also for economic reasons, particularly if the management goal is to maximize the revenue obtained from a timber harvest while protecting the water resource. An optimized decision involves balancing these two objectives. It is unknown how the application of different buffer widths affects the forest landscape pattern and resulting potential timber volume over time. The purpose of this research project is to determine the long term effect via modeling that different riparian buffer zone delineations, based on BMP recommendations, will have on landscape pattern and timber production.

LANDIS will allow for the application of various buffer scenarios upon the same landscape. LANDIS will also provide an analysis of the results that each scenario will have over a long period of time. Two of the scenarios involve the application of fixed width buffers. A variable width buffering method, previously only used on the east coast, will be examined. This approach combines the LANDIS simulation model with three riparian buffering techniques giving a unique examination of delineating these different management boundaries in the Midwest. Analyzing the effects of different buffering scenarios upon landscape pattern and timber volume provides forest managers with better tools for deciding the best action to take in balancing timber harvest with the biological integrity of streams.

CHAPTER II STUDY SITE DESCRIPTION

GEOGRAPHIC LOCATION

The Eleven Point River Watershed is located in the southern portion of the state of Missouri in the Ozark Highlands Section (Nigh and Schroeder, 2002). The specific area of interest is approximately 35 kilometers long (north to south) and 46 kilometers wide (east to west) and can be found in Shannon, Carter, Oregon, and Ripley Counties (Figure 1). The northwest and southeast coordinates of the area are, 91° 31' W 37° 0' N, 91° 4' W 36° 40' N, respectively (Figure 2). The focus of this research is the federal land within these coordinates, i.e. the Mark Twain National Forest.

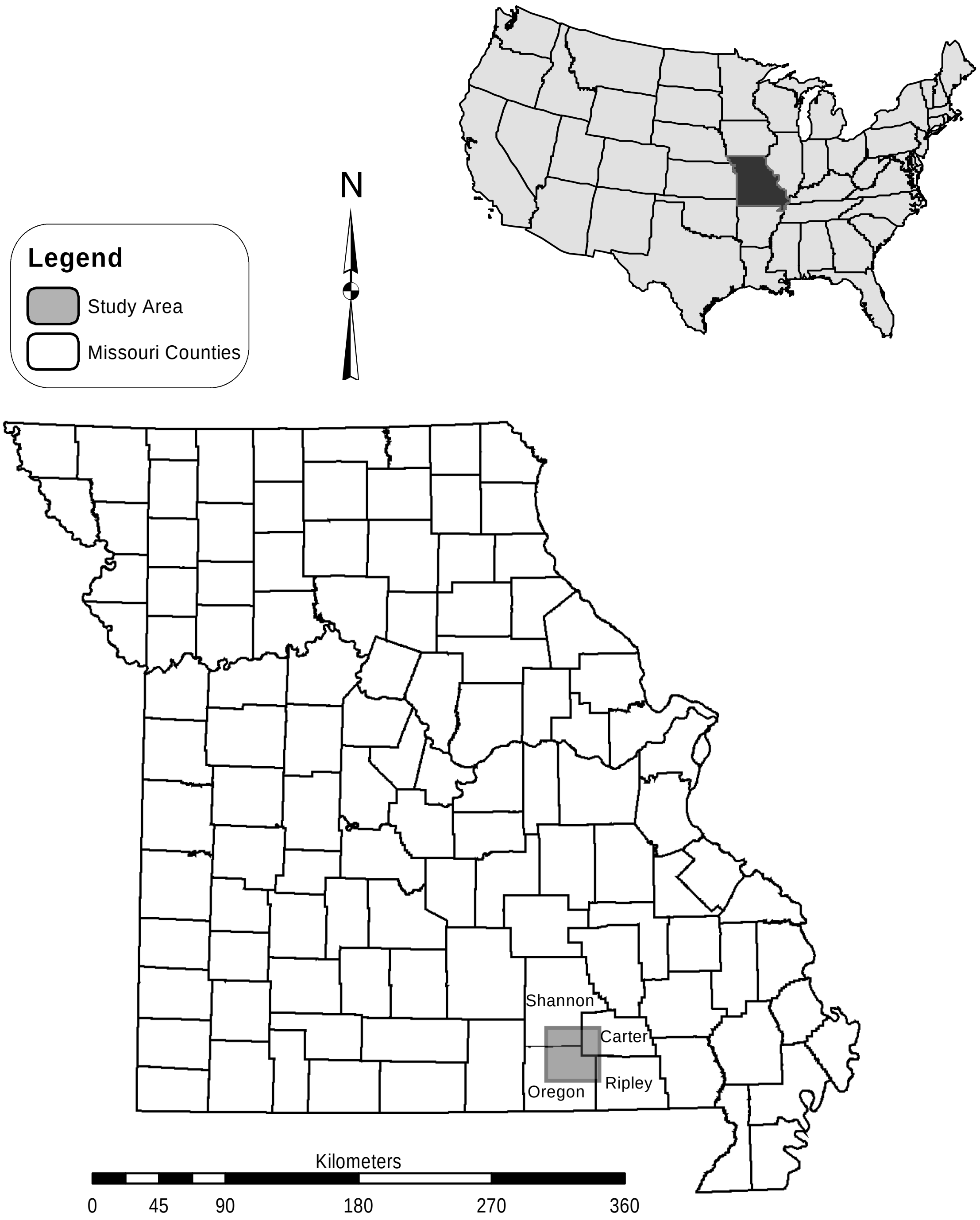


Figure 1. Location of the study area within the United States and the state of Missouri

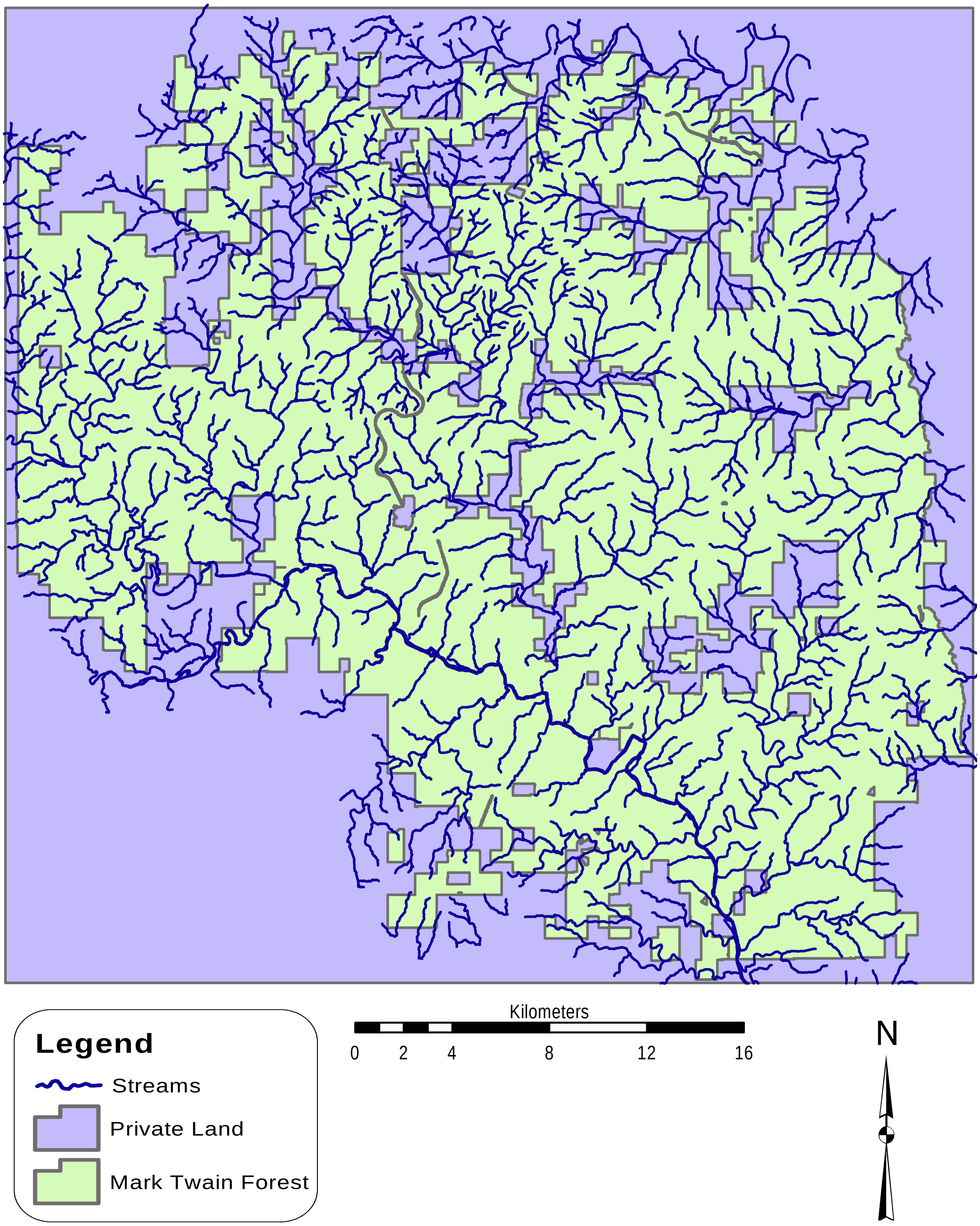
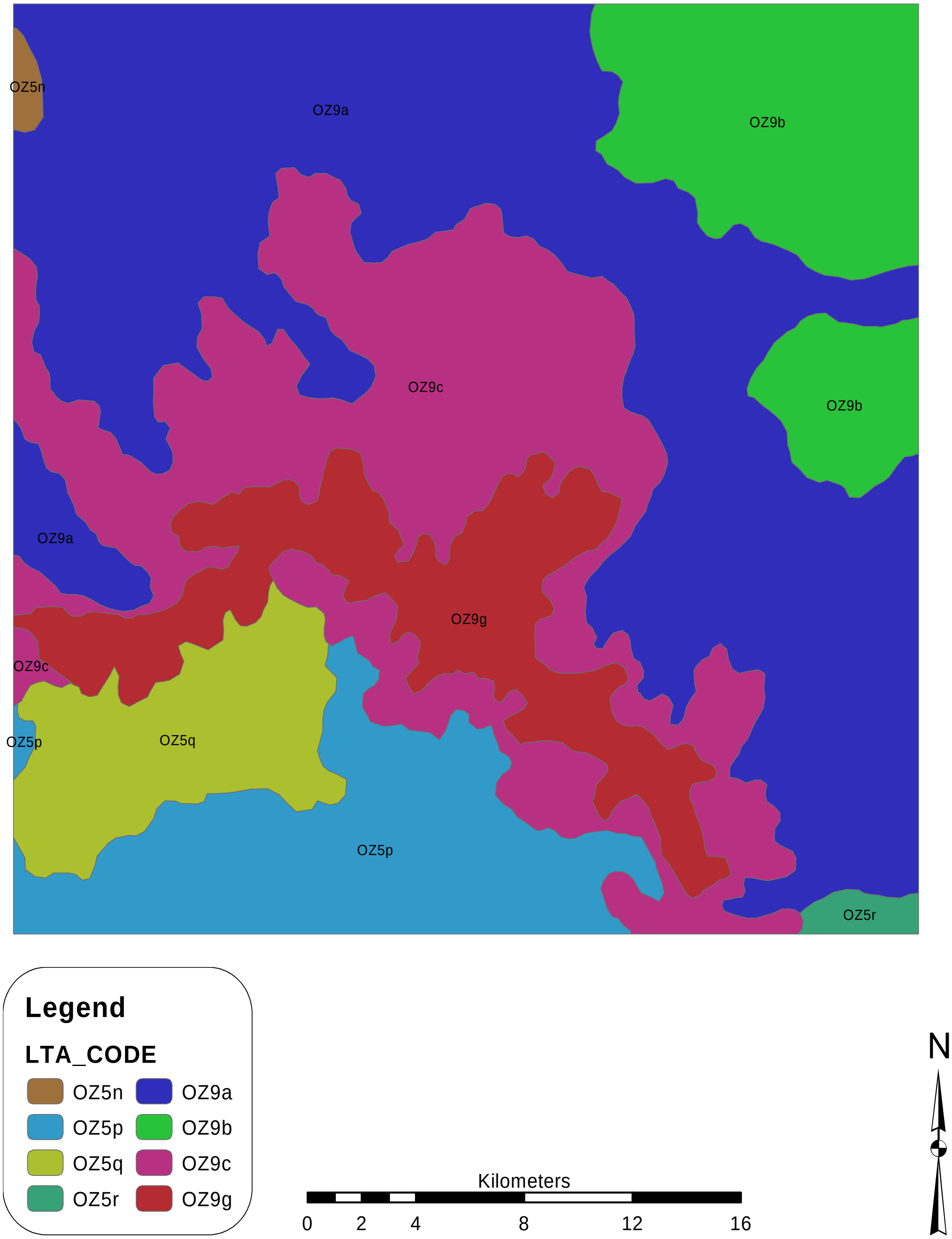


Figure 2. Study Area Delineation and associated Streams of the Mark Twain National Forest in southeastern Missouri

LTA ATTRIBUTES

Landtype associations (LTA) are used to classify ecological areas based upon associations in landform, topographic position, geologic parent material, soil, and potential vegetation associations (Grabner 2002). These classifications are utilized for local planning and assessment of the natural resources native to each site. There are 8 LTAs associated with this study area (Figure 3). The LTAs have a characteristic suite that distinguishes them (Table 1). LTA attributes are provided to supply background information for the study area. They are not directly used in the LANDIS simulation.



Refer to Table 1 for LTA code names

Figure 3. Landtype Association codes found in the study area in southeastern Missouri

Table 1. Landtype Associations description.

All LTA descriptions are courtesy of Nigh and Schroeder 2002.

Landtype Associations in the Central Plateau Subsection	Location and Boundaries	General Description
OZ5n Mountain View Oak Savanna/Woodland Plain	The LTA is a broad, flat divide between the Jack's Fork and Eleven Point Rivers, with Mountain View at its center. Boundaries are drawn to enclose a landform with relief of less than 100 feet, fragipan soils, and Jefferson City-Cotter dolomite. It is separated from the plain to its east by geology.	The LTA is a plain with relief of less than 100 feet. It is underlain by Jefferson City-Cotter dolomite substrate with thin loess at the surface. Soils are droughty with fragipans; tree growth is stunted. Historically, the LTA was post oak barrens; today fescue pasture dominates with considerable second-growth oak woods.
OZ5p Howell-Oregon Counties Oak Woodland Dissected Plain	The LTA occupies the moderately dissected upland surface in the southern half of Howell and Oregon Counties, where it is mostly associated with the upper reaches of the Spring River basin.	The LTA is a slightly to moderately dissected upland plain with local relief mainly between 100 and 150 feet, except near deeper valleys where relief of 200 feet occurs. The LTA in general serves as a source region for groundwater that emerges in springs in neighboring deep valleys. Soils are variable, from droughty fragipan soils to deep cherty silt loams. Historically the LTA was timbered in mixed-oak woodland with occasional prairie and savanna openings. Currently it is a mosaic of extensive fescue pasture and dense oak woodlots.
OZ5q Alton Oak Savanna/Woodland Plain	The LTA occupies a small upland plain between Alton and the Eleven Point River in central Oregon County. Boundaries are drawn to enclose a plain of less than 100 feet of local relief.	The LTA is a plain of low relief with loess over Jefferson City-Cotter dolomite. Droughty fragipan soils stunt tree height. It was formerly post oak barrens, but today it is mainly fescue pasture.
OZ5r Ripley County Oak Woodland Dissected Plain	The LTA is a dissected plain lying mostly in southwestern Ripley County from the Western side of the lower Eleven Point to the eastern side of the Lower Current River. The northern boundary marks a change to hills of noticeably higher relief. The eastern and western boundaries are changes to areas of lower relief and less timber.	The LTA is mostly a dissected plain of variable topographic expression from smooth uplands in headwaters of Fourche Creek to moderately and steeply sloping lands along the lower Eleven Point River. The region was formerly mixed-oak woodland with occasional glade and savanna openings. Today, it is a nearly even mix of fescue pasture and dense mixed-oak forest

Landtype Associations in the Current River Hills Subsection	Location and Boundaries	General Description
OZ9a Current River Pine-Oak Woodland Dissected Plain	The LTA is located in several separate tracts along the periphery of the Current River valley and in separate tracts on the divides between it and the Back and Eleven Point Rivers where the Roubidoux Formation has been only moderately dissected. Boundaries are drawn to include the dissected plains on the Roubidoux Formation with local relief of 50-150 feet.	The LTA consists of a moderately dissected upland plain associated with the Roubidoux Formation. Relief over large tracts averages less than 100 feet but increase towards the river margins. Karst occurs in several areas. The LTA was historically and is currently covered in pine and pine-oak woodland and forest associated with sandy soils.
OZ9b Current River Oak-Pine Woodland/Forest Hills	The LTA is located on both sides of the Current and Jack's Fork Rivers, where highly dissected lands occur. Boundaries are drawn where relief declines to less than 150 feet in dissected plains and where relief increases to more than 250 feet in rugged breaks. The northeastern boundary with the Black River Hills follows the drainage divide between the Current and Black Rivers.	The LTA consist of the strongly rolling to hilly lands associated with much of the Current River valley. Local relief averages 150-250 feet. Slopes are steep and there is very little flat land either on ridgetops or in valley bottoms. The LTA was historically covered in oak and oak-pine woodland and forest. Today the region is dominated by second-growth oak and oak-pine timber that is not as open as formerly.
OZ9c Eleven Point Oak-Pine Woodland/Forest Hills	The LTA occupies the hilly, thoroughly dissected lands on both sides of the Eleven Point River, mostly in Oregon County. Boundaries are drawn at the break in landforms and relief between flatter dissected plains and the more rugged breaks adjacent to the Eleven Point River.	The LTA consists of the strongly rolling to hilly lands with moderate slopes associated with the Eleven Point River valley. It was historically covered in oak and oak-pine woodland and forest on certy, low-base soils. Today it continues the same cover but with less openness and more second-growth timber.
OZ9g Eleven Point Oak-Pine Forest Breaks	The small LTA occupies a narrow belt of rugged land along the Eleven Point River in northeastern Oregon County. Boundaries are drawn to encompass a landscape of narrow ridges and sinuous valleys with relief higher than 250 feet.	The LTA consists of deeply dissected hills with narrow ridges, steep sideslopes, and narrow, sinuous valleys with very little flat land except in small patches along the river. Local relief is 250-400 feet or more. Hills are cut mainly in the Roubidoux and upper Gasconade Formations. Oak-pine and mixed-oak timber types occur on the mainly cherty, low-base soils derived from these formations. Outstanding springs, streams, cliffs, caves, fens, glades, and forest communities are present.

PHYSIOGRAPHIC, TOPOGRAPHIC, AND GEOLOGIC PROPERTIES OF THE SITE

The landtype associations within these boundaries consist mainly of oak and oak-pine woodland plains interspersed with oak-pine forest breaks and forest hills (Nigh and Schroeder, 2002) (Figure 3). The major tree species in this area include shortleaf pine (*Pinus echinata* Mill.), eastern redcedar (*Juniperus virginiana* L.), white oak (*Quercus alba* L.), northern red oak (*Quercus rubra* L.), post oak (*Quercus stellata* Wangenh.), pin oak (*Quercus palustris* Muenchh.), and black oak (*Quercus velutina* Lam.), and scarlet oak (*Quercus coccinea* Muenchh.). A mixture of oak and pine occur throughout most of the landscape, but concentrations of shortleaf pine are found in the northwestern portion of the study area and oak predominates in the southern region.

The slope characteristics of the area consist mostly of gently rolling hills that increase in steepness with proximity to the Eleven Point River. Slopes near the river range from 30 to 73% while the landscape farther from the main tributaries range from 5 to 35%. The elevations range from the highest points in the northwest corner at 340 m to the lowest portion in the outlet of the Eleven Point River at 135 m.

The basic geological composition of the watershed consists mainly of dolomite and sandstone/dolomite. Depth to bedrock averages around 142 cm. The dominant surface texture of the soil is a cherty silt loam. Soils found in the area are Clarksville-Goss-Doniphan near the Eleven Point River, Captina-Clarksville-Macedonia in the north, and Gepp-Doniphan-Agnos in the south (Nigh and Schroeder, 2002).

CLIMATE OF REGION

The relevant climate data were obtained from the Van Buren, Missouri, in the northeast corner of the study area in Carter County (Figure 1). Mean annual precipitation is approximately 120 centimeters. The wettest months of the year are March through May and November. Annual snowfall is 20.8 cm. Mean January minimum temperature is -7.66° C while the mean July maximum temperature is 33° C. Average growing season length is approximately 209 days. Significant microclimatic variations can occur in areas with high relief (Nigh and Schroeder, 2002).

LAND USE HISTORY

Before settlement by Euro-Americans, the Native American Indians lived on and hunted these lands, and to some extent influenced fire history (Guyette et al. 2002). Hunters, trappers and Indian traders arrived circa 1820. European settlers soon followed, setting up small patches of cropland along creek bottoms. Some used the open woodland to either graze cattle or raise hogs. At the end of the 19th century, large-scale timber exploitation began in this region. The harvesting of pine and hardwood species occurred until the supply was nearly exhausted in the 1920s (Nigh and Schroeder, 2002). Human density in the area steadily increased until the lumber boom ended. Population density declined until the 1970s when the number of people stabilized and the area has since seen a slight increase in population (Nigh and Schroeder, 2002). In the 1960s and 1970s land was acquired to be part of the Mark Twain National Forest. The economy of the area now depends on forest products and a tourism industry based on streams, caves, and springs. (Nigh and Schroeder, 2002)

WATERSHED DESCRIPTION

The Eleven Point River originates near Willow Springs, Missouri and flows southeasterly for nearly 160 km where it joins with the Spring River in Randolph County, Arkansas. A 71-km segment of the river is contained in the Eleven Point Scenic River area and is the main focus of the study area.

The Eleven Point River is characterized by clear, slow, free-flowing water. Portions of this part of the river contain shallow riffles and long deep pools. Attributes of the river change at the junction of the Greer Spring branch, which transforms the river into a swift-flowing cold river. Blue and Morgan Springs also contribute to the flow of the Eleven Point River. Along the river there are towering bluffs of dolomite and sandstone.

Vegetation in the watershed is characterized by shortleaf pine on the ridges, oak-pine forest on the hillsides, and sycamore and other bottomland hardwoods found in lower landscape positions (Nigh and Schroeder, 2002).

CHAPTER III METHODOLOGY AND ANALYSIS

METHODOLOGY

Data

GIS information initially gathered for this project was assembled from a variety of sources. A coverage file of streams in the area was acquired from the Center for Agricultural, Resource, and Environmental Systems (CARES). LANDIS input was provided by the United States Forest Service (Shifley et al., 2000). County information, Missouri LTA delineations, a 10 m Digital Elevation Model (DEM), and SSURGO (Soil Survey Geographic Database) soil attributes for the study area were obtained from the Missouri Spatial Data Information Service (MSDIS). The Soil Data Viewer from the Natural Resources Conservation Service (NRCS) was used to display and manipulate the wide array of information available from the soil survey.

Fixed Buffer Delineation

Fixed width stream buffers were designated at 20 meters and 100 meters on either side of the stream channel. Calculations were performed in ArcView using the "Create Buffers" wizard (ESRI 1998). The wizard allows the user to specify a distance from a feature with which to create the new buffer shape. This resulted in riparian corridors that were 40 m and 200 m in total width, respectively (Figure 4).

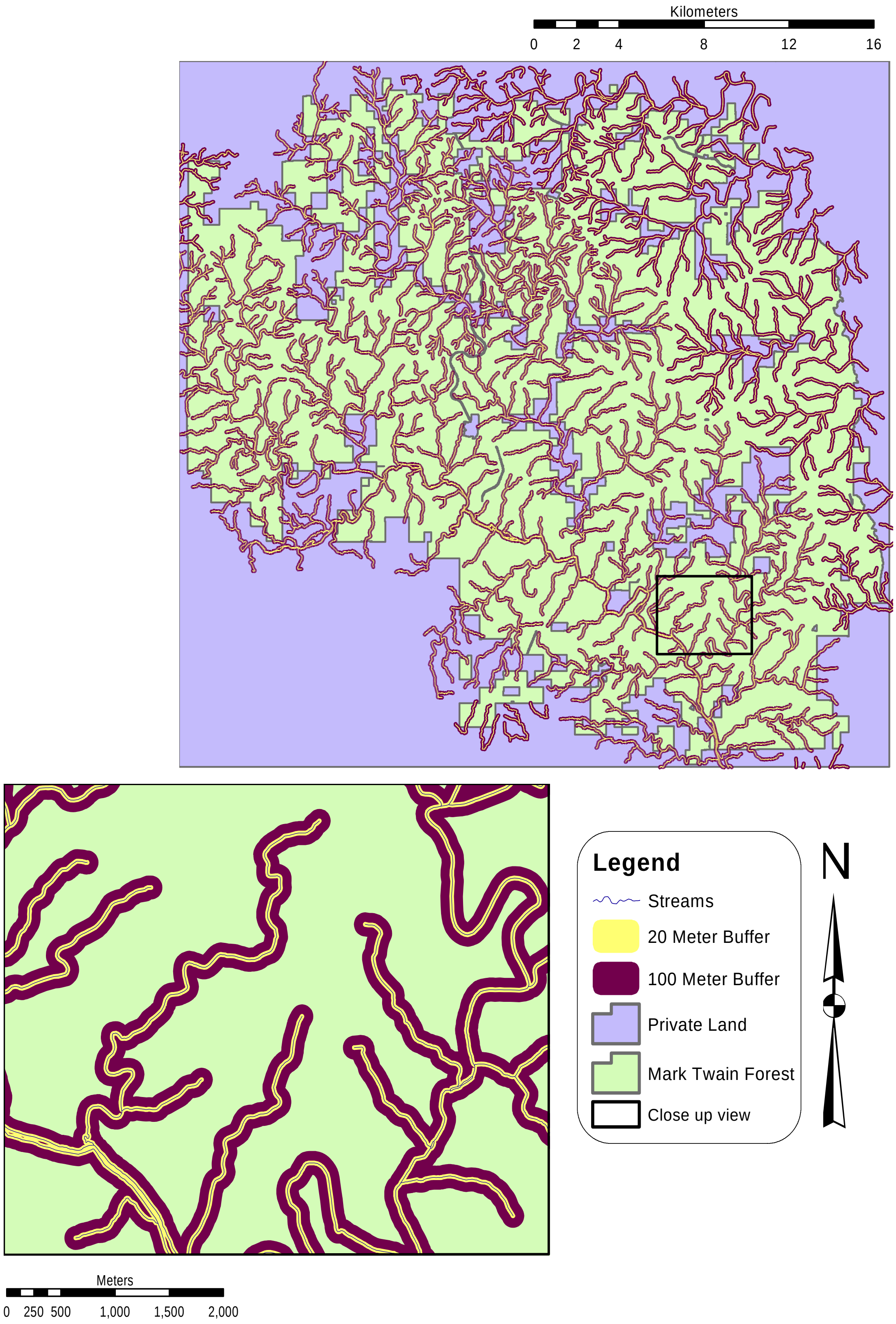


Figure 4. View of entire study area and close up view exhibiting extent of fixed width buffer delineations within the study area

Variable Buffer Delineation

The variable width buffering method was developed based upon work by Xiang (1993a; 1993b; 1996; Xiang and Stratton, 1996). This model integrates soil and topographic characteristics to create a buffer width delineation within a GIS framework.

The foundation of this buffering method assumes that a buffer's effectiveness relates directly to its ability to absorb or delay pollutants passing through it (Phillips 1989b). This detention of pollutants is a function of soil hydrologic properties, surface vegetation, and topography. A detention time model of buffer effectiveness can be described by the following equation (Phillips, 1988; 1989a).

$$ {}^{B_b}\!/_{B_r} = {}^{T_b^*}\!/_{T_r^*} = \left({}^{n_b}\!/_{n_r}\right)^{0.6}\left({}^{L_b}\!/_{L_r}\right)^{2}\left({}^{K_b}\!/_{K_r}\right)^{0.4}\left({}^{s_b}\!/_{s_r}\right)^{-0.7}\left({}^{C_b}\!/_{C_r}\right) $$

The subscripts *b* and *r* refer to the proposed buffer and the reference buffer, respectively; ${}^{B_b}\!/_{B_r}$ is the buffer effectiveness ratio; T^* is an index of relative detention time for a given imposed flow; *n* is the Manning roughness coefficient (Manning, 1891); *L* is buffer width (meters); *K* is saturated hydraulic conductivity (cm/hr); *C* is soil moisture storage capacity (cm). Soil moisture storage capacity is calculated by multiplying available water capacity by profile thickness above a confining layer. This information is derived from the SSURGO soil attributes. Slope percent was calculated in ArcView using the DEM (ESRI 1998). The resulting buffer effectiveness ratio is a quantitative dimensionless index. A value less than 1.0 indicates a buffer that is less effective than the reference while a value greater than 1.0 indicates a buffer that is more effective (Xiang, 1993a).

The detention time model of buffer effectiveness is the basis for the buffer width model. The original equation can be transformed as follows:

$$L_b = L_r\left[\left({}^{B_b}\!\big/_{B_r}\right)\left({}^{n_b}\!\big/_{n_r}\right)^{0.6}\left({}^{K_b}\!\big/_{K_r}\right)^{0.4}\left({}^{s_b}\!\big/_{s_r}\right)^{-0.7}\left({}^{C_b}\!\big/_{C_r}\right)\right]^{0.5}$$

Let p stand for the buffer effectiveness ratio

$$p = {}^{B_b}\!\big/_{B_r}$$

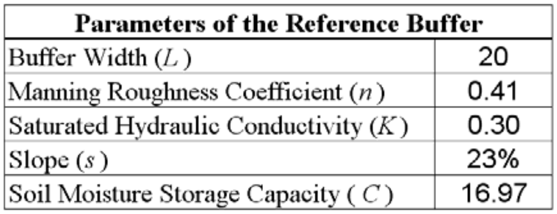
Then by substitution

$$L_b = p^{0.5}L_r\left[\left({}^{n_b}\!\big/_{n_r}\right)^{0.6}\left({}^{K_b}\!\big/_{K_r}\right)^{0.4}\left({}^{s_b}\!\big/_{s_r}\right)^{-0.7}\left({}^{C_b}\!\big/_{C_r}\right)\right]^{0.5}$$

L_b then stands for the appropriate buffer width for a land parcel with an effectiveness ratio of p.

The two criteria used to select the reference buffer (r) parameters were (Xiang, 1993a): 1. a reference buffer should be able to provide an effective filter under average conditions 2. a reference buffer should represent typical soil, surface cover, and topographic conditions for the study area. For these reasons mean values for C, K, and s were chosen. A reference buffer width (L_r) of 20 m was selected to represent a typical buffer in average runoff conditions (Table 2). A Manning roughness coefficient (n_r) of 0.41 was chosen because it is indicative of the roughness associated with full riparian forest cover (Engman and Asce 1986).

Table 2. Parameters of the reference buffer



Parameters of the Reference Buffer	
Buffer Width (L)	20
Manning Roughness Coefficient (n)	0.41
Saturated Hydraulic Conductivity (K)	0.30
Slope (s)	23%
Soil Moisture Storage Capacity (C)	16.97

The effectiveness ratio (p) and the roughness coefficient (n) of the proposed buffer are user defined variables that can be altered to accommodate various situations. An effectiveness ratio of 1.0 was chosen to reflect a buffer that is adequately effective (Xiang, 1993a). The proposed Manning roughness coefficient (n_b) of 0.45, which is equivalent to a riparian forest floor with dense undergrowth, abundant leaf litter, trees, and fallen woody debris, was obtained from a study on routing surface runoff (Engman and Asce, 1986). The input maps (C, K, and s) were overlaid in ArcView using the Geoprocessing Wizard (ESRI 1998), creating one shapefile table with all the necessary input variables. From the map overlay a buffer effectiveness grid was created using the buffer width model equation to develop the theoretical buffer widths needed for each respective parcel of land (Figure 5).

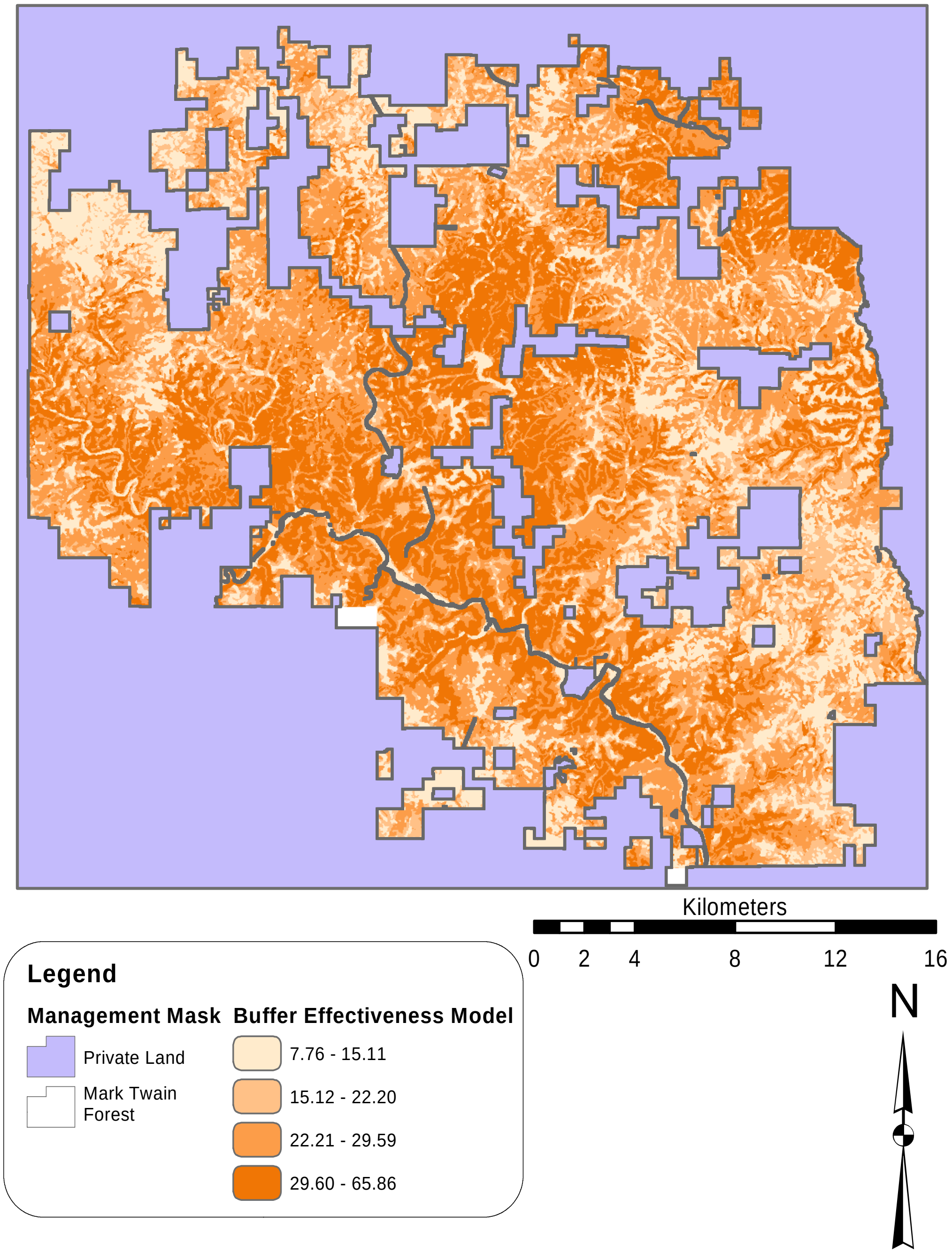


Figure 5. Visual representation of the buffer effectiveness model within the study area with Private Land masked for improved visualization

The variable width buffer extent was determined by applying an ArcInfo (ESRI 1996) “cost distance” function to the model and streams (Xiang and Stratton 1996). Every cell of the model grid has an associated buffer effectiveness value (L_p) associated with it. In other words each cell has a cost that is equal to $^{1}/_{L_p}$ and once the cost summation, beginning at the stream, reaches a value of 2 the buffer width is complete. The buffer effectiveness map (Figures 6) is the reciprocal geographical representation of the buffer effectiveness calculation.

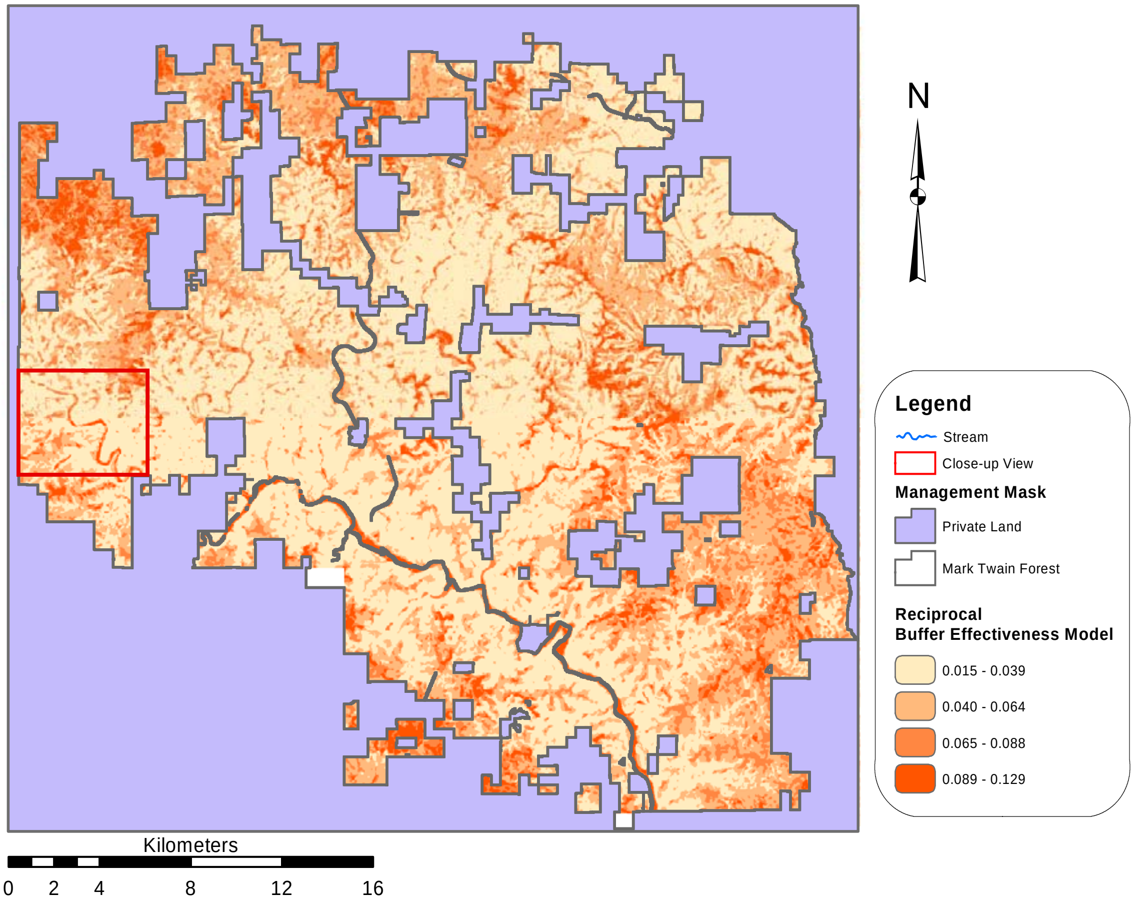


Figure 6. Visual representation of the reciprocal buffer effectiveness model within the study area with Private Land masked for improved visualization

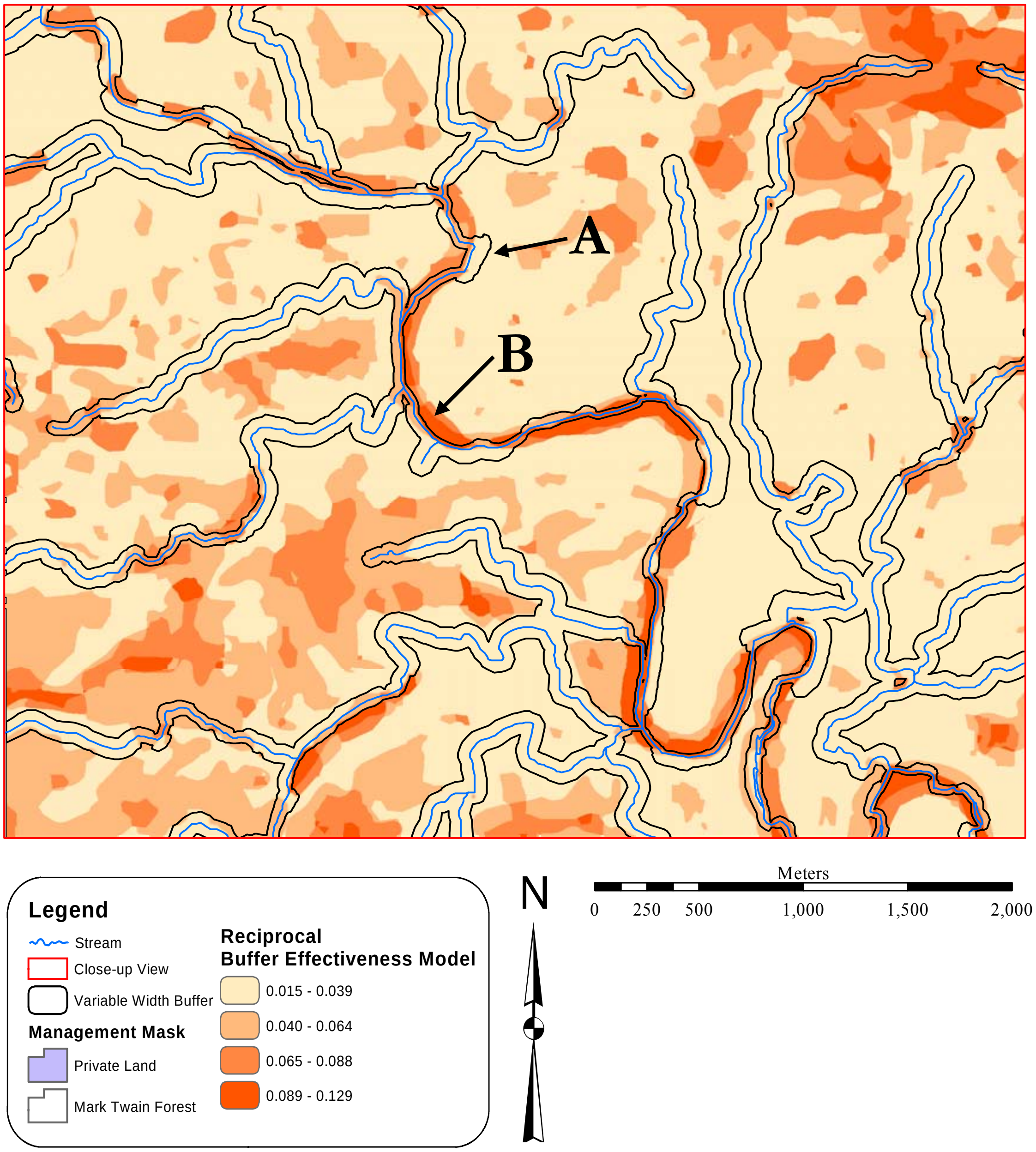


Figure 7. Close-up visualization of reciprocal buffer effectiveness model and resulting variable width buffer. Point "A" bulges from lower values of buffer effectiveness while point "B" is narrow due to higher values of buffer effectiveness.

A close-up of the reciprocal buffer effectiveness model (Figure 7) shows variation in buffer effectiveness and physical size of the buffer widths. At point "**A**" the variable buffer bulges as a result of the lower values of buffer effectiveness. On the other hand the buffer is relatively narrow at point “**B**” because of the higher calculated values of effectiveness found there. Consequently less distance is required to reach the appropriate buffer width.

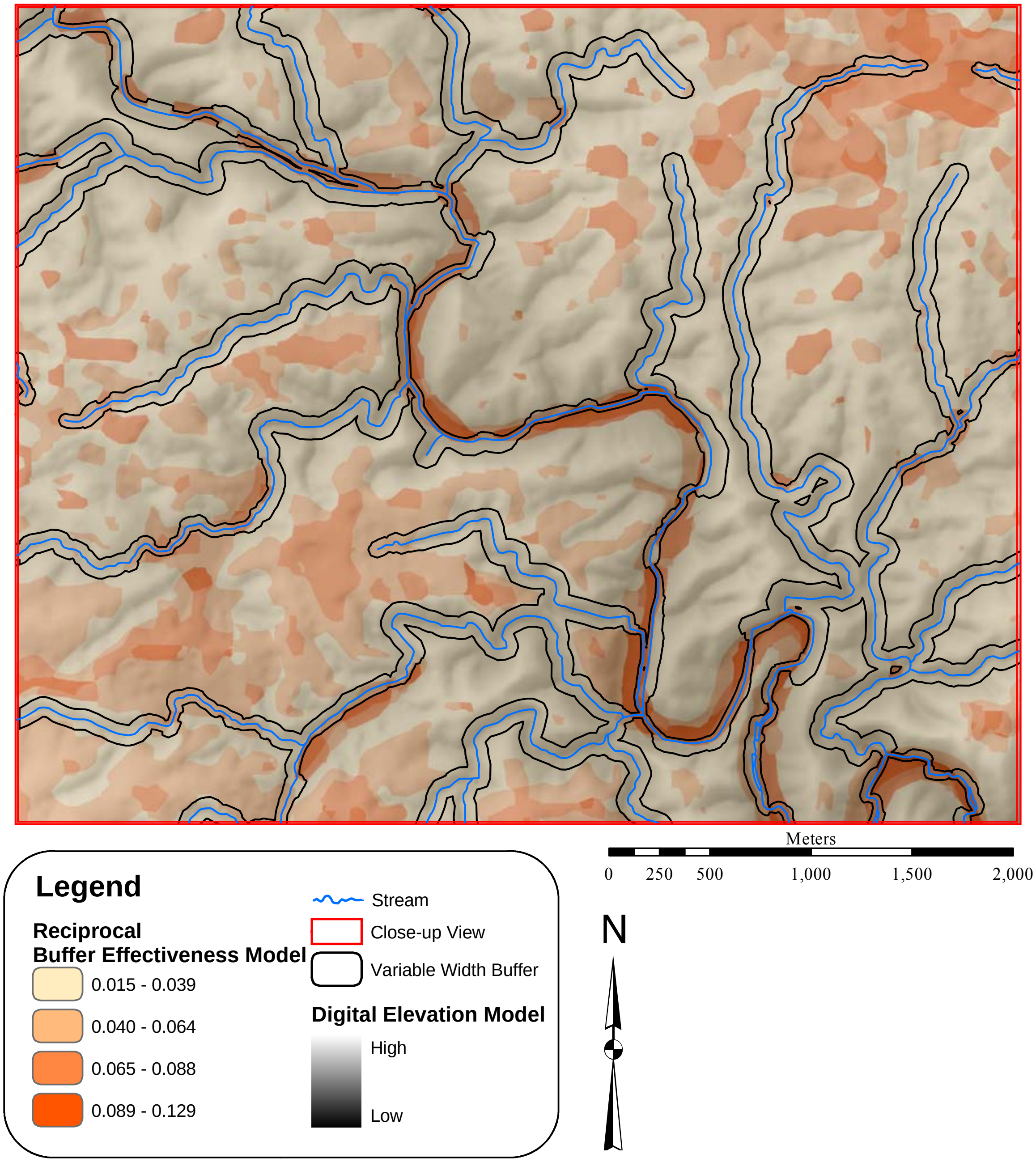
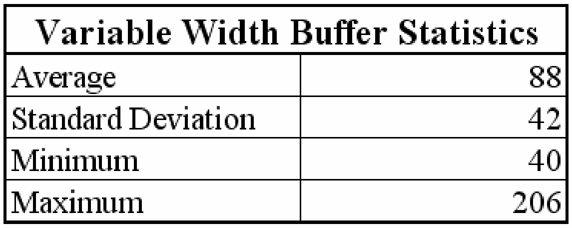


Figure 8. Close-up visualization of reciprocal buffer effectiveness model and resulting variable width buffer. A Digital Elevation Model is underneath a 50% transparent version of the reciprocal buffer effectiveness model.

Placing a 50% transparent version of the reciprocal buffer effectiveness model over a digital elevation model (DEM) the correlation of the effectiveness model with topography becomes evident (Figure 8). Flat areas have higher reciprocal values than those with increased slope. Consequently the flat areas have narrower buffers near the streams.

The resulting buffer varies in width from values near 200m to values near 40m in total width with an average width of 88m and a standard deviation of 42m (Table 3).

Table 3. Variable width buffer statistics



Variable Width Buffer Statistics	
Average	88
Standard Deviation	42
Minimum	40
Maximum	206

LANDIS Model

General description

LANDIS is a model designed to simulate forest landscape change over large spatial and temporal domains (Mladenoff et al., 1996, Mladenoff and He, 1999). The model takes into account fire, windthrow, and harvest disturbances along with species succession to simulate the resulting landscape patterns. The simulation runs with 10-year time increments and is effective in examining forest landscape change over long periods of time. Consequently this raster-based model is an efficient method for demonstrating forest dynamics at large scales (Mladenoff and He, 1999, He and Mladenoff, 1999a).

Succession

Forest succession at each site is influenced by species competitive processes driven by a combination of shade tolerance, longevity, vegetative reproduction capability, seeding capability, and land type suitability (He and Mladenoff, 1999a). LANDIS records species information as 10-year age cohort presence-absence for each cell.

Seeding capability is dependent on several factors. Seed dispersal distance for each species or species group is modeled as a function of the species' effective and maximum seeding distance. Effective seed dispersal distance is that for which the seed has a high probability of reaching a site. The maximum seed dispersal distance is that distance beyond which a seed has near zero probability of reaching the site (He and Mladenoff, 1999b). These distances are typically derived from previous research and literature (Shifley et al., 1997; 2000). The characteristics of trees already found on the site have an influence on the seeding capability in the form of their own seeds and the amount of shade they create. Shade tolerance determines which species, given that seed are present, have a higher probability of becoming established at a given location in the given landscape. A species with a higher shade tolerance has a greater chance to become established than one with a lower tolerance in an area that is already forested. These factors are expressed in terms of probability and modeled stochastically through draws from the probability density functions.

Other life history attributes such as age to sexual maturity, at which the tree begins to produce seed, and longevity contribute to determining the continuing dynamics of the forest landscape. Longevity is a significant factor not only because it reflects the maximum age that a species can reach but also as a tree approaches this age it becomes more likely to die or be removed as a result of windthrow or harvest. Vegetative reproduction probability determines the probability that a species will sprout and grow back after a disturbance. These parameters are also determined through review of prior research and literature.

Fire tolerance is used to determine whether a given species will survive a fire event. Survival following fire increases with higher fire tolerance and also with age.

Fire Disturbance

Fire is a key landscape process in the forest ecosystem. However the occurrence of fire is not a completely random event for a given cell; certain areas are more fire prone than others. Mean fire return interval (i.e. the average number of years for fire to reoccur in a given area) is the primary factor in determining fire frequency.

Fire is a bottom-up disturbance. Consequently fires of increasing intensity tend to affect younger age classes first. LANDIS uses species fire tolerance classes to demonstrate the effect of fire at the species level. Fire tolerance classes range from 1 to 5 with 1 being the youngest and most susceptible to fire, and class 5 being the oldest and least susceptible (He and Mladenoff, 1999a). All of these factors are combined in LANDIS to determine whether a species of a certain age cohort survives a given fire event.

Harvest Module

Management of a forested area may involve silvicultural treatments such as harvest activities, which ideally should correspond with forest species composition and site conditions. The harvest module within LANDIS is designed to allow for a wide array of harvest possibilities (Gustafson et al., 2000). This versatility provides the user with the ability to define specific management prescriptions that can differ among user-defined management areas. Each prescription can differ in its chronology as well as specific details pertaining to the removal of particular species and/or age classes.

In order to simulate a harvest treatment the module requires a stand coverage file and a management area coverage file. The stand coverage delineates the study area into individual stands, each having a unique numeric label. The management area coverage defines groups of stands that will receive the same type of management. This allows the user to define different management practices for each management area.

Because LANDIS does not simulate individual trees but instead simulates the presence or absence of 10-year age cohorts of the tree species in each cell, the harvest module removes specific cohorts of certain species on sites selected for harvest (He et al., 2000b). Within the module there are eight harvest regimes available for the user to choose from.

1. One-entry, stand-filling
2. Periodic-entry, stand-filling
3. Two-entry, stand-filling
4. One-entry, stand-spreading
5. Two-entry, stand-spreading
6. Periodic-entry, group selection
7. Periodic-entry fixed stand, two-entry, stand-filling
8. Periodic-entry-stand-resampling, two-entry, stand-filling

In stand-filling regimes a cohort is selected for harvest, and the entire stand is treated with the same harvest prescription. Stand spreading regimes may harvest a portion of the stand or might spread from the original harvested stand to adjacent stands of the same management area, depending on the harvest regime specifications. Group selection refers to the harvest of multiple patches within a stand.

One of the options common to all the regimes that helps to determine the order in which the stands are harvested is a rank-algorithm. The available algorithms are:

1. Random
2. Stand Age
3. Economic Importance
4. Regulate Distribution

“Random” randomly selects stands for harvest. With “Stand Age” the oldest stand in the management unit is harvested first. “Economic Importance” is defined within the module by a combination of assigning economic value to each species and determining the oldest cohorts. In this case, the oldest cohorts of the most valuable species are the sites harvested first. “Regulate Distribution” ranks each stand by age class and over the harvest period removes stands so as to leave an even distribution of age classes.

The other common factor in every harvest regime is the harvest mask. The harvest mask is a simple binary code representing 10-year age cohorts of specific species. There are 64 spaces (maximum longevity of 640 years) with either a 1, for harvest, or a 0, for no-harvest, to represent each 10-year age cohort beginning at age 10. This technique is often useful in eliminating undesirable species or restricting harvest to economically valuable age or size classes.

When prescribing simulated harvest treatments it is helpful to know the precise number of stands and sites in each management area, the species composition, and common silvicultural practices that are commonly applied in the region.

Model parameterization

LANDIS was previously parameterized for this study area (Shifley et al., 2000). Those parameters already defined include species and land type attributes which are described in the following sections. The new parameters defined specifically for this study involved the harvest module: stand identifier map, management map, and the harvest regime. The management area and stand maps were altered so that areas within the various buffer distances are unmanaged and all else is managed according to a harvest regime.

Species attributes

The species attribute file designates the life history traits for every species to be used (Table 4).

Table 4. Species attribute file

NAME	LONG	MATUR.	SHADE	FIRE	EFFD	MAXD	VEG_P	SP_AG	RCLS_COEFF
Acersacc	200	20	5	1	100	200	0.3	20	0.500
Pinuechi	200	20	3	4	40	80	0.5	20	0.680
Queralba	250	20	3	4	30	800	0.5	50	0.800
Quervelu	150	20	3	3	30	800	0.8	50	0.525
Privategreenland	200	20	3	3	30	800	0.8	30	0.000

The following is a description of each of the variables involved in the species attribute file. (He et al. 2000)

LONG - Longevity of the species in years.

MATUR - Maturity age of the species in years. The species will begin to seed when this age is reached.

SHADE - Shade tolerance value (1-5). 1 = least tolerant; 5 = most tolerant.

FIRE - Fire tolerance value (1-5). 1 = least fire tolerant; 5 = most tolerant.

EFFD - Species effective distance seeding range in meters. Within this distance species have a 95% chance of dispersing seed, beyond this distance species have a 5% chance of seeding out.

MAXD - Species maximum seed dispersal range in meters.

VEG_P - Probability of vegetative propagation following disturbance.

SP_AG - Maximum age to be able to re-sprout via vegetative propagation

RCLS_COEFF - Reclassification coefficient (0-1). This number is used in the output reclassification algorithm. Basically it is the theoretical importance coefficient of a species in comparison to other species. 0 = least important; 1 = most important.

For example, based upon this particular file, queralba (white oak) has a longevity of 250 years, reaches sexual maturity at age 20, has a moderate shade tolerance, a moderately high fire tolerance, an effective seeding distance of 30 meters, a maximum seeding distance of 800 meters, a 50% chance of vegetative propagation following disturbance, a maximum age of 50 at which the species will no longer be able to vegetatively propagate, and is the most important species in comparison to the other species at a reclassification coefficient of 0.8.

Land type attributes

The Land type attribute file designates a synthetic land type coverage based upon landscape position, geologic makeup, and potential vegetation in a LANDIS compatible format (He et al., 2000b). The model has three basic assumptions associated with this file.

1. Mean fire return interval is homogeneous within a land type.
2. Fuel accumulation and decomposition is similar within the land type

3. Species behave differently on different land types and consequently have corresponding establishment coefficients

Savanna is an example of one land type in the land type file that was used (Table 5). Other land types used were private, southwest slope, northeast slope, flat, upland drainage, limestone, and mesic (Figure 9).

Table 5. Example of parameter values for the Savanna Land type. Definition and detailed descriptions of parameters can be found in He et al. 2000b.

Savanna	
Variables	
100	minimum year of shade before most shade tolerant (5) species' establishment
20	mean fire return interval
0.9	fire ignition coefficient
90	fire probability coefficient
60	last windthrow disturbance
10	last fire disturbance

species establishment coefficients for land type	
acersacc	0.03
pinuechi	0.70
queralba	1.00
quervelu	0.74
prvtgrnlnd	0.00

Disturbance variables	**Severity class**				
	1	2	3	4	5
fire curve	10	30	60	90	150
fire severity classes	3	3	3	3	3
wind curve	10	20	60	80	100
modified fire classes	4	3	3	3	3

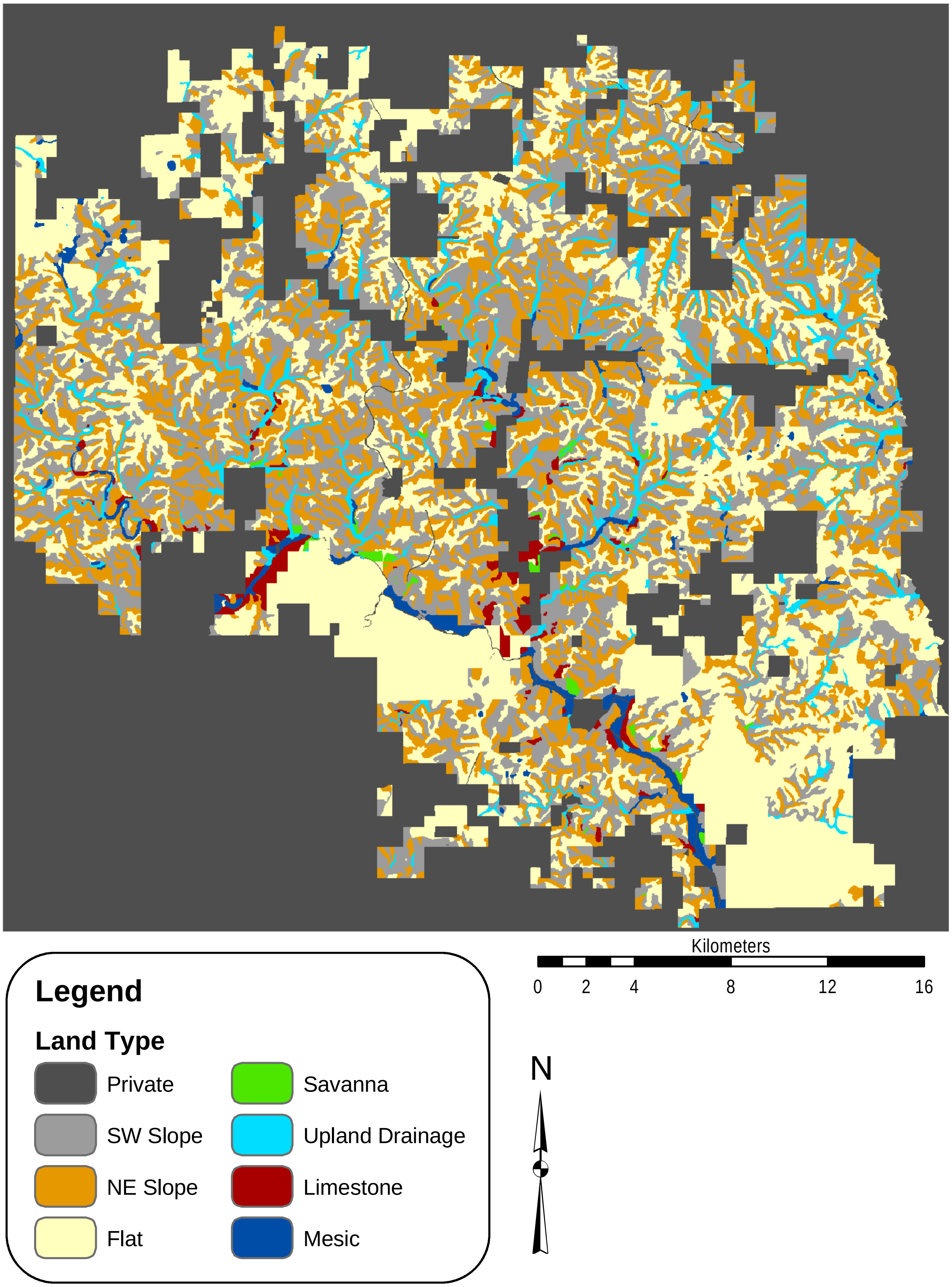


Figure 9. LANDIS Land Type delineations in the Study Area.

Management and stand boundaries

The original stand delineations in the area are defined based upon the boundaries set by the United States Forest Service (USFS) for the Mark Twain National Forest (Figure 10). The USFS stand delineations are based upon similarities in landscape position, vegetation, and occasionally anthropogenic delineations. The LANDIS harvest algorithms require that stands fall entirely within a single management area. In order to create new management area boundaries based on the buffer delineations, a procedure was developed to manipulate the original stand boundaries according to this restriction.

For each buffer scenario a new GIS shapefile was created that combined the original stand boundaries (Figure 10) with the buffer delineations. In order to allow the buffer delineations to coincide with the 30 m cell size of this LANDIS parameterization the buffers were converted into 30 m size grids. Consequently, in the case of the 20 m buffer delineation, the buffer is often only one cell wide. Stands that fell outside of the riparian buffers were designated as management area 1 while stands found inside the delineations were designated as management area 2 (Figures 11-13). In addition to attaching a management number to the stands, each stand was randomly assigned a unique numerical identifier. Each buffer scenario shapefile then has two essential columns of data: (1) a management area identifier and (2) a consecutive, randomized stand number identifier. The shapefiles were then converted into one grid each for stand and management boundaries. For LANDIS to recognize the stand and management grids they were converted into ASCII format and finally into a ERDAS 16-bit .gis file format using mapconvert (He et al., 2000b) .

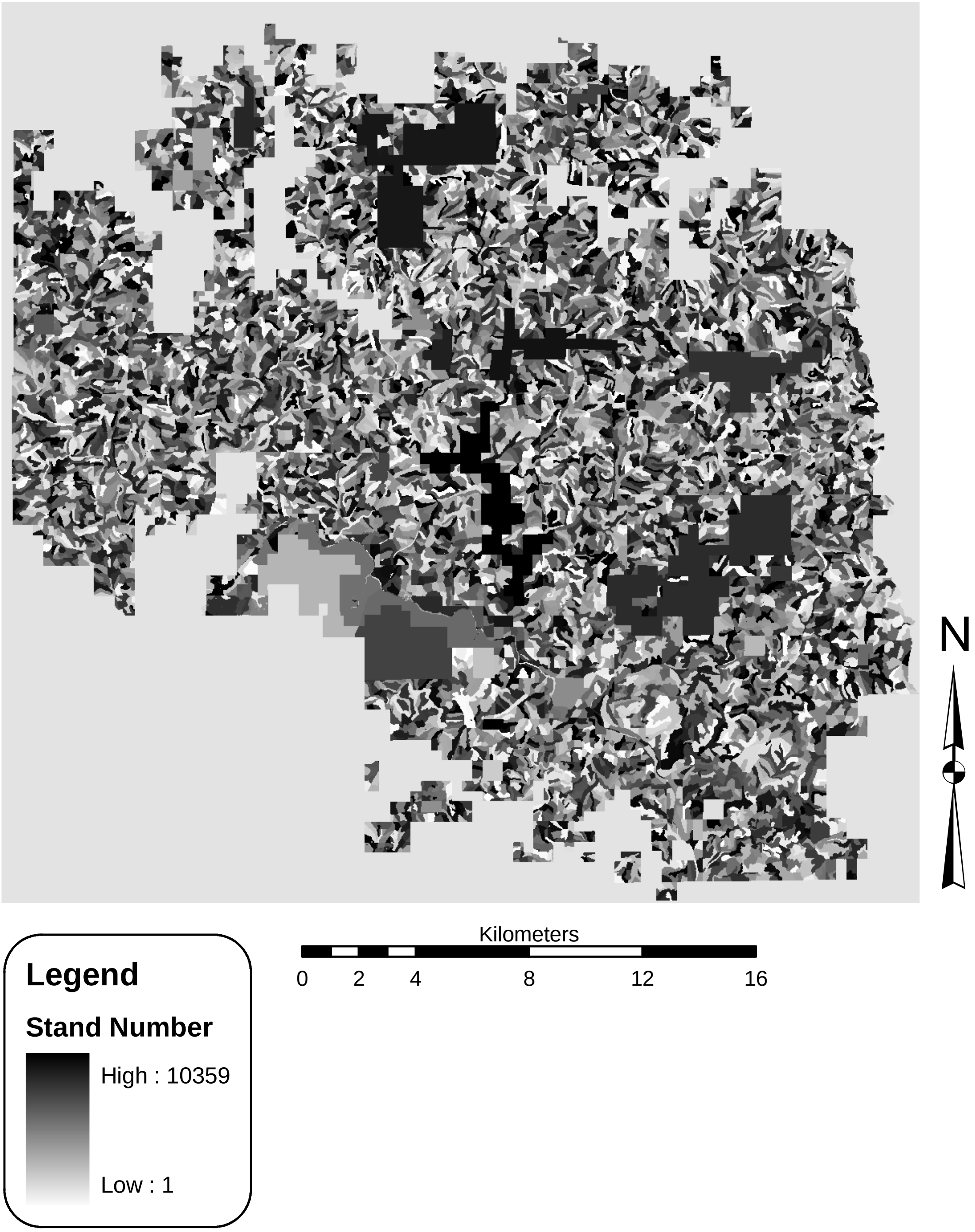


Figure 10. Stand delineations in the Study Area. Every stand has a unique consecutive numerical designation for a total of 10359 individual stands in the original LANDIS stand map.

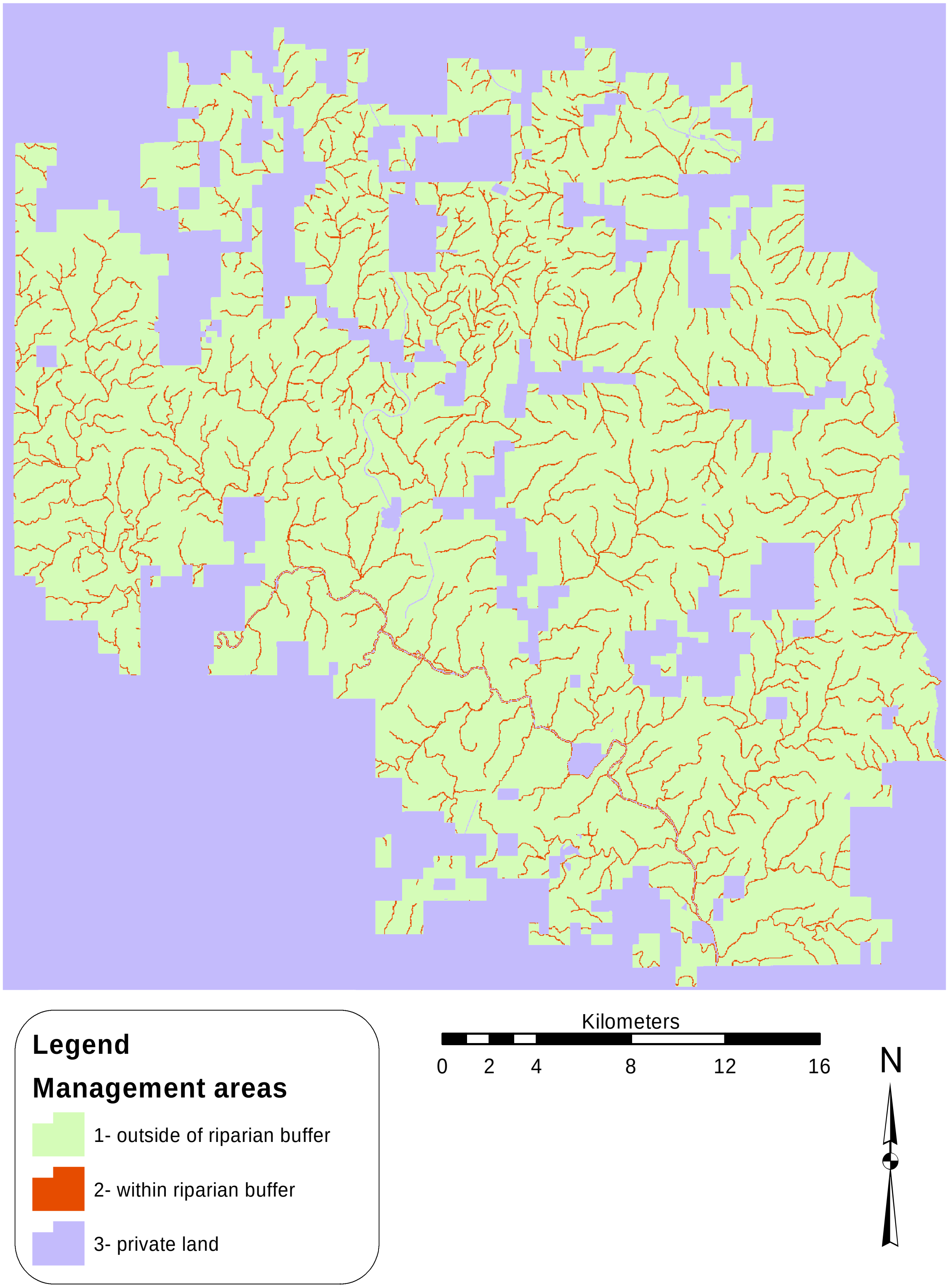


Figure 11. 20 m buffer management areas found within the study area as defined by the 20 m buffer scenario. No management within riparian buffer, management outside of riparian buffer, and private land is disregarded.

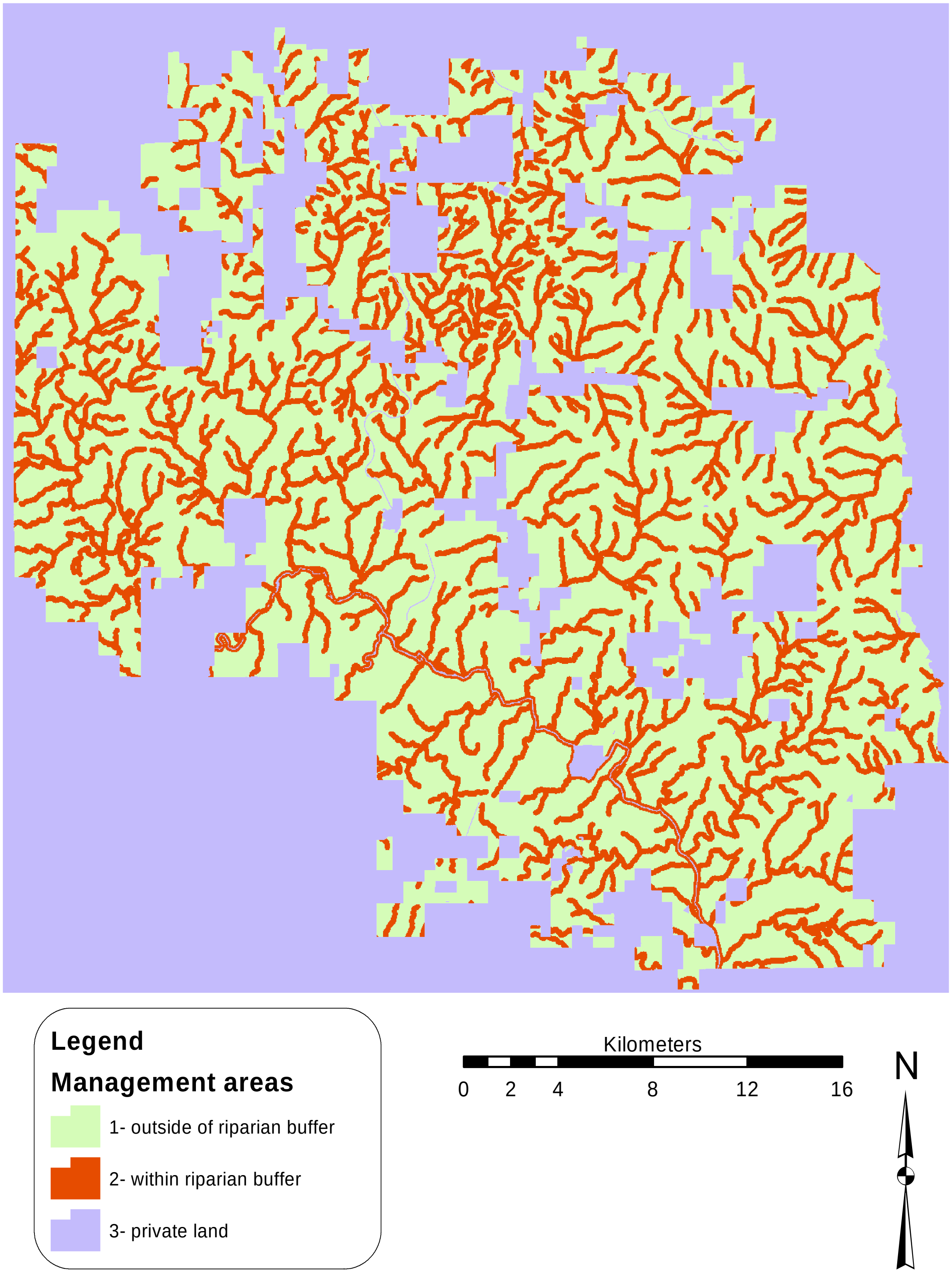


Figure 12. 100 m buffer management areas found within the study area as defined by the 100 m buffer scenario. No management within riparian buffer, management outside of riparian buffer, and private land is disregarded.

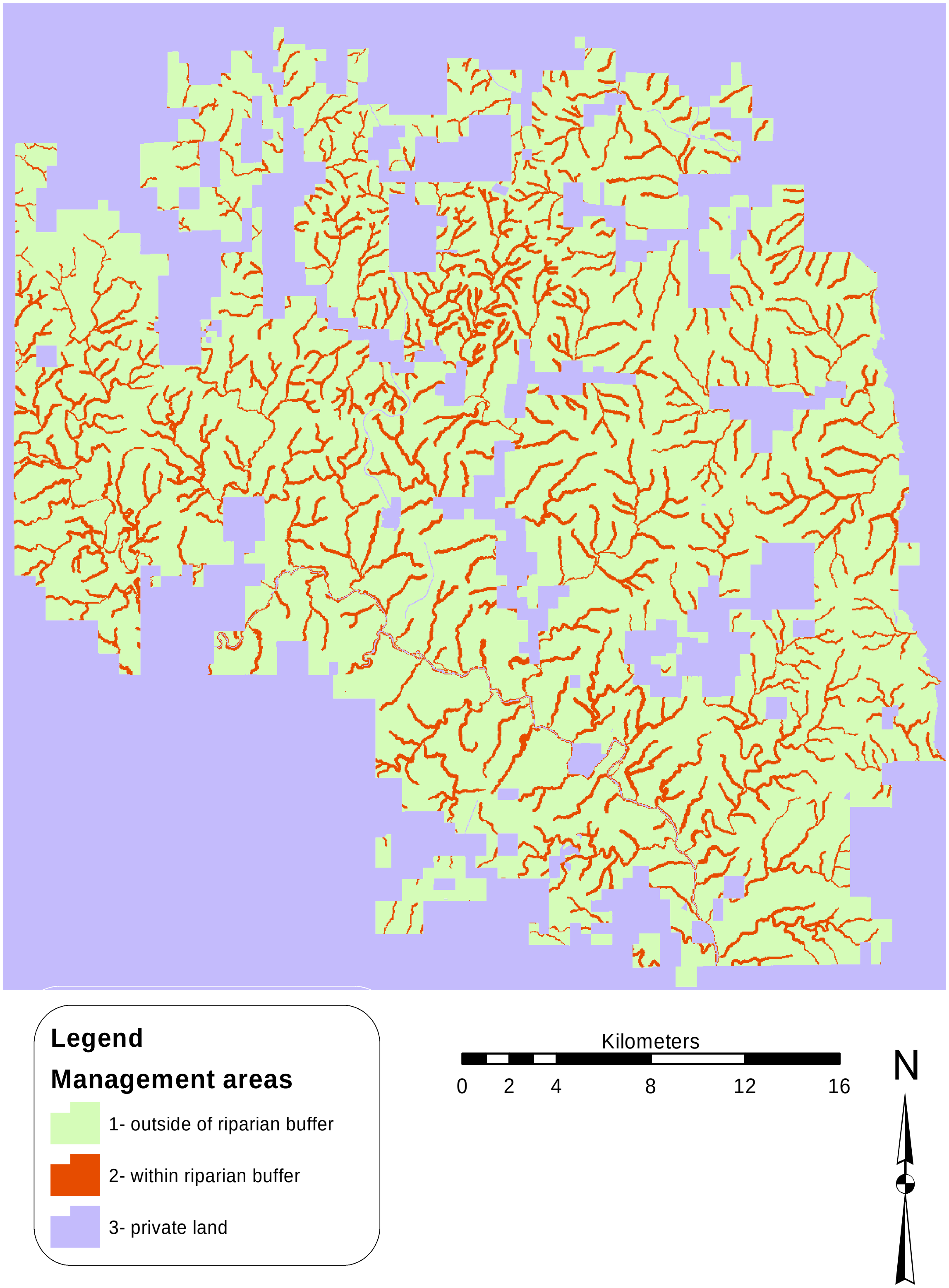


Figure 13. Variable width buffer management areas found within the study area as defined by the variable width buffer scenario. No management within riparian buffer, management outside of riparian buffer, and private land is disregarded.

Harvest Scenario

LANDIS was used to simulate even-aged management on the study area. Ten percent of the stands were clearcut each decade to simulate a 100 year rotation. All species and all age classes were removed from the harvested stands. Stands were selected for harvest by age, giving priority to the oldest stands. Stands younger than 50 years were not harvested. According to LANDIS terminology this would be called a periodic entry, stand-resampling, stand filling harvest.

Simulation scenarios

The proposed simulation scenarios based upon the previous decisions are as follows:

Table 6. Simulation scenarios

Simulation Scenarios			
#	Scenario type	Management prescription	
		Inside riparian zone	Outside riparian zone
1	Control w/ no mngmt	No management	No management
2	Control w/ mngmt	Even-aged management	Even-aged management
3	20m buffer	No management	Even-aged management
4	100m buffer	No management	Even-aged management
5	variable width buffer	No management	Even-aged management

Scenarios 1 and 2 are used to exemplify situations in which the whole landscape is either not managed or completely managed/harvested with no buffer delineations. The remaining three scenarios demonstrate no management within the buffer delineations and even-aged management on the remainder of the landscape.

ANALYSIS

LANDIS Output

The output of LANDIS consists mainly of ERDAS GIS files. The map format of these output files are grouped into four basic categories of species, species age, age, and harvest maps. Each group has a GIS map file that is created for every decade of the simulation. These maps were displayed using a LANDIS/ArcView Interface (LDAVI) (He and Mladenoff, 2000). Species maps display the presence or absence of species cohorts for each 10 m by 10 m pixel regardless of age. Species age maps exhibit each species according to 10 year age classes. Dominant age maps display the oldest age class by pixel regardless of species. Harvest maps show the number of years since last harvest for each pixel.

APACK Analysis

The APACK program was used to calculate a wide array of landscape metrics for the maps generated by LANDIS (Mladenoff and DeZonia, 2001). Area (AR) and aggregation index (AI) (He et al., 2000a) were used to quantify spatial pattern and landscape metrics for this study. Area is the absolute area of the attributes on the map.

$$AR_i = (\text{Cells of class } i) \times (\text{Area of one cell})$$

Aggregation index is a measure of the aggregation of an attribute in the map. The values range between 0 and 1. A value of 1 is returned when an attribute is aggregated into one single square patch. A value of 0 is returned when the patches of an attribute share no edges. Values move closer to 0 as patches become narrow in one direction and long in another. Values closer to 0 also indicate more fragmented landscapes than values near 1.

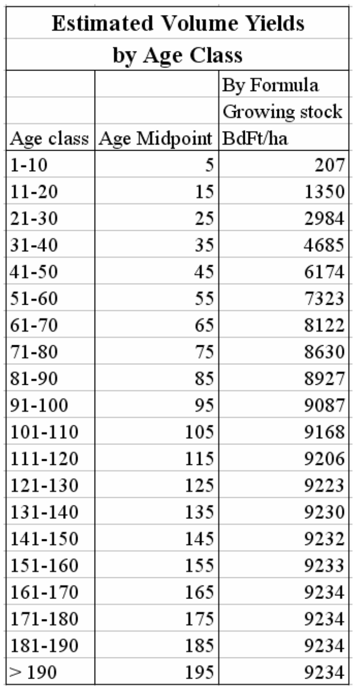
$$AI_i = \frac{\text{Total adjacent edges of class } i \text{ with itself}}{\text{Maximum adjacent edges of class } i \text{ with itself}}$$

AI is useful because it takes shape into consideration (He et al., 2000a). It is a class level spatial pattern metric that measures the degree of spatial aggregation for each class.

Harvest Analysis

The volume of harvest and residual volume on sites that were not harvested were estimated from a local yield table (Table 7). Volume yields by age class were estimated based on average yields by age class recorded during the 1989 inventory of the Mark Twain National Forest (Hansen et al., 1992; Kingsley and Law, 1991).

Table 7. Estimated volume yields by age class

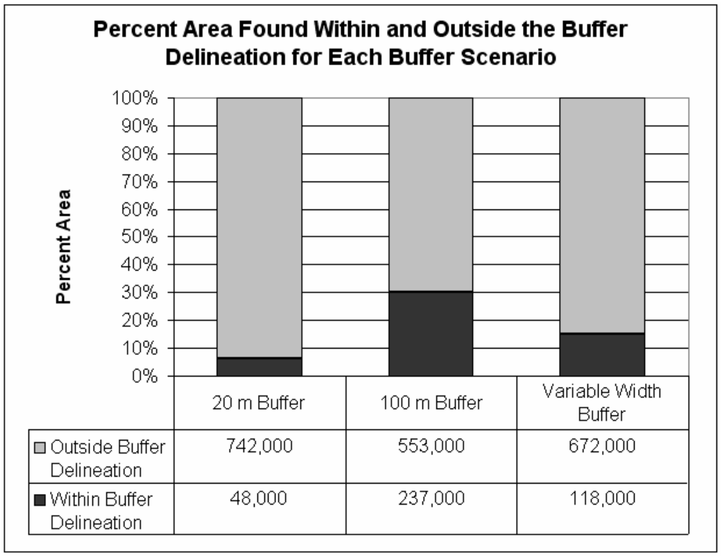


Estimated Volume Yields by Age Class

Age class	Age Midpoint	By Formula Growing stock BdFt/ha
1-10	5	207
11-20	15	1350
21-30	25	2984
31-40	35	4685
41-50	45	6174
51-60	55	7323
61-70	65	8122
71-80	75	8630
81-90	85	8927
91-100	95	9087
101-110	105	9168
111-120	115	9206
121-130	125	9223
131-140	135	9230
141-150	145	9232
151-160	155	9233
161-170	165	9234
171-180	175	9234
181-190	185	9234
> 190	195	9234

CHAPTER IV RESULTS

In order to more accurately compare species composition and species age composition among the different scenarios, the charts in these following sections show percent cover per year. Percent cover was calculated by dividing the pixel count of the value in question by the total number of pixels for that particular area. While this allows for a direct comparison it masks the fact that there are differences among scenarios in the amount of area found within the riparian buffer delineations (Figure 14). The pixel count for the study area is constant at approximately 790,000 for all five scenarios. The scenarios with buffers have the study area divided into two management areas: inside the buffer delineation with no management and outside the buffer delineation with management. Consequently the “Harvest All” and “No Harvest” scenarios are omitted because these scenarios have uniform management applied throughout the entire study area.



	20 m Buffer	100 m Buffer	Variable Width Buffer
▨ Outside Buffer Delineation	742,000	553,000	672,000
■ Within Buffer Delineation	48,000	237,000	118,000

Figure 14. Percent area and approximate pixel count found within and outside the buffer delineation for each buffer scenario

EFFECTS WITHIN RIPARIAN BUFFER DELINEATIONS

Species Composition

Species composition results are nearly identical within the three buffer scenarios (20 m, 100 m, and variable width). Consequently only one representative line chart from the 20 m buffer scenario was used to show the percent area covered by each species throughout the 300 year simulation (Figure 15). White oak initially occurred on about 40% of the area, increased to about 85% by year 130, and thereafter became fairly stable at approximately 88% for the remaining simulation years. Consequently white oak was the most abundant species within the buffer zones in all three buffer scenarios. Black oak abundance also increased from 38% at year 0 to 67% around year 200, but then steadily declined in abundance throughout the remainder of the simulation. Shortleaf pine abundance was initially 12% and increased to 52% by year 300 of the simulation. The sugar maple group was relatively stable increasing only slightly from 8% at year 0 to 15% at year 300. Since multiple species can be present on one cell (site), the sum of species percent cover for all for species can be larger than 100%.

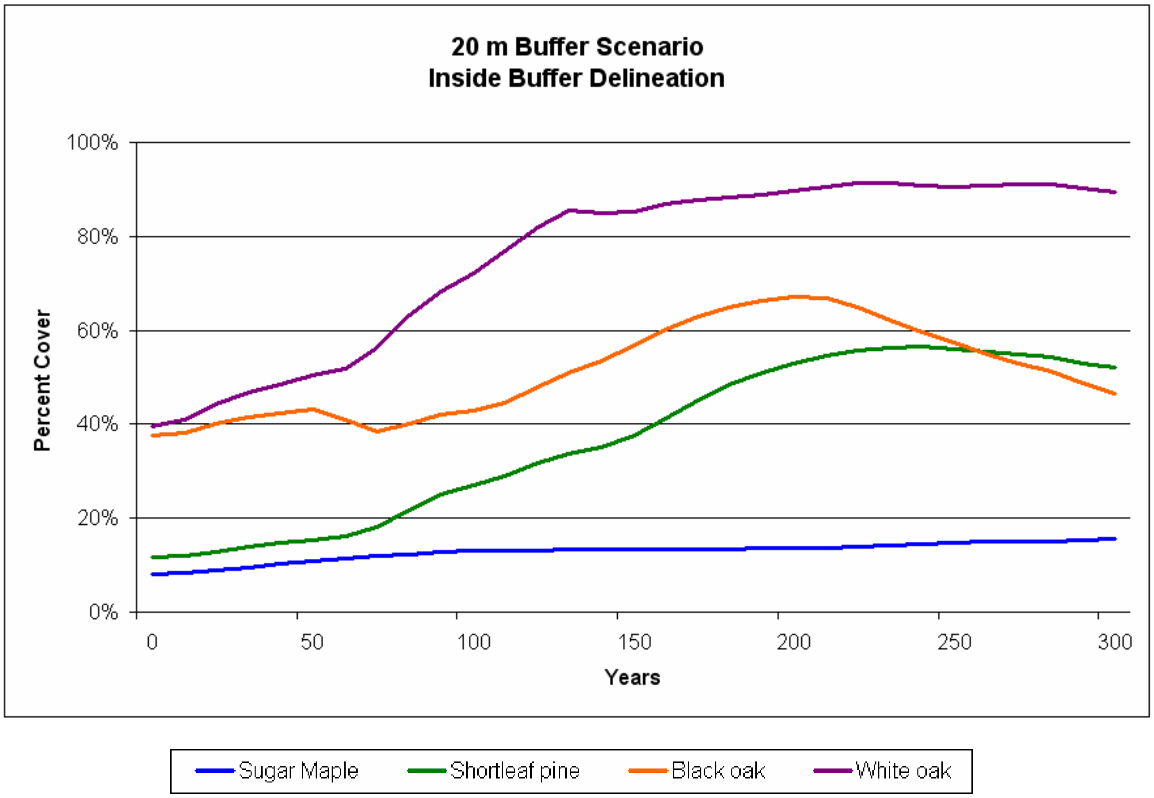


Figure 15. Percent cover by species found within the 20 m buffer boundary for the duration of the 300 year simulation.

Species Age Composition

The information on species by age class was summarized to produce charts of age composition by species. For improved visualization, these age groups were classified into seedling (1-10 years old), sapling (11-30 years old), pole (31-50 years old), sawlog (51-100 years old), and old growth (≥101 years old) categories based upon previous modeling work in this area (Shifley et al., 2000). Similar to the composite species composition charts, the age class summaries by species are nearly identical within the three buffer scenarios (20 m, 100 m, and variable width). Consequently only one representative line chart from each species group for the 20 m buffer scenario was used to show the percent area covered by each species by age group throughout the 300 year simulation (Figures 16, 17).

With the exception of sugar maple, the species age classes within the buffer boundaries fluctuate substantially over time. Sugar maple age classes become relatively constant after year 50 with the old growth group having the greatest percent cover at 8% at year 300 (Figure 17). The black oak age groups fluctuated with the sawlog group being the most common age group over the 300 year simulation. Seedling and sapling age groups increased during the first 100 years but declined slightly in the remaining simulation years due to an increase in abundance of the old growth group (Figure 16). White oak and shortleaf pine age class charts similarly show evidence of recruitment of younger age classes into the older age classes. For example, at simulation year 60 there is a decrease in white oak sawlog area as the amount of old growth increases. This indicates the progression of sawlog age trees into old growth. White oak consistently accounts for the greatest amount of old growth within the buffer boundaries, reaching its greatest total area at 56% in year 300. Sawlog and pole size shortleaf pine are the dominant age groups at year 0 (Figure 17). The old growth group for shortleaf pine exhibited a steady increase from 5% at year 150 to 27% percent cover at year 300. The species age composition for all four species age groups within the riparian buffer delineations demonstrated a dominance of the old growth age group at the conclusion of the simulation.

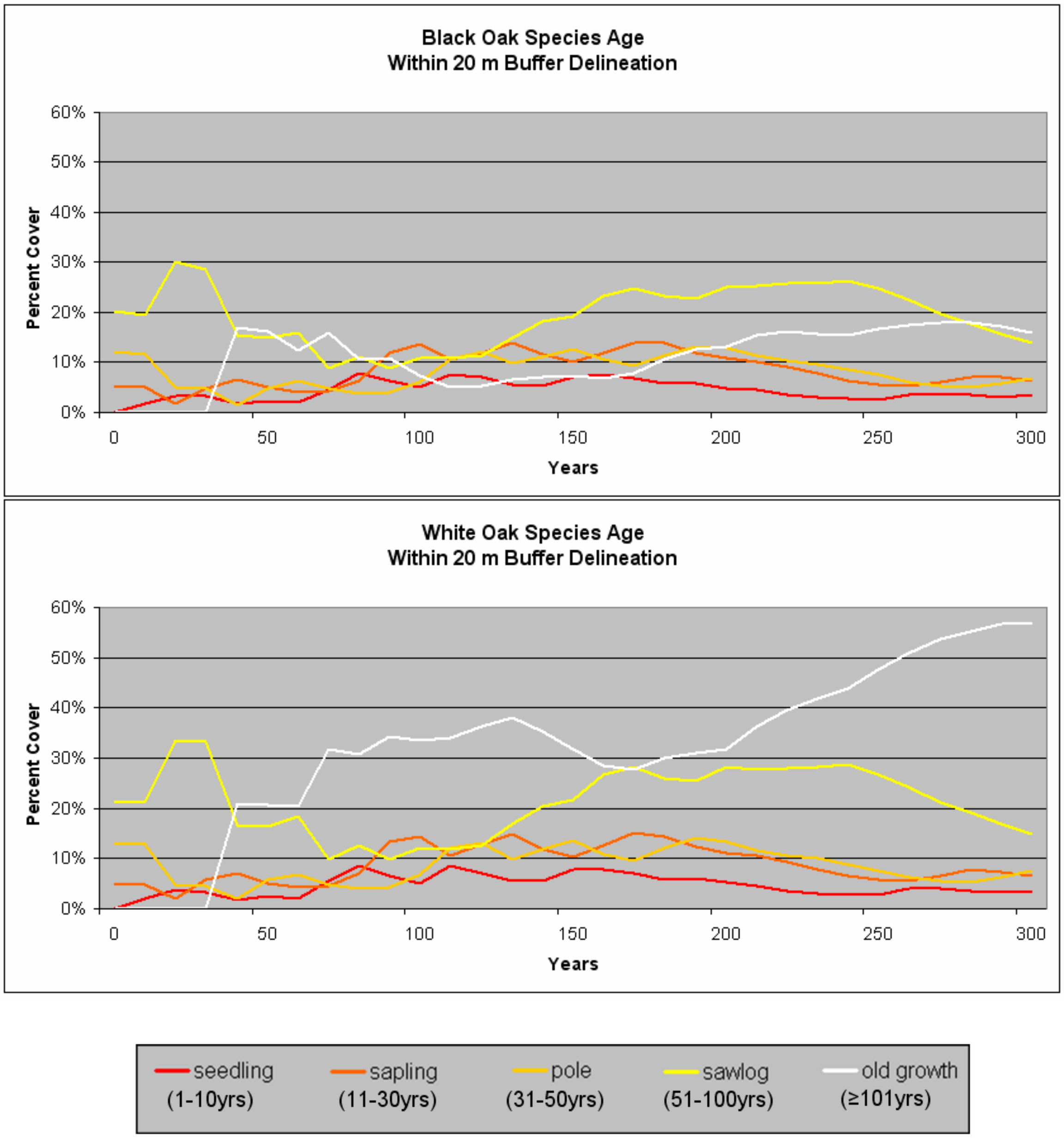


Figure 16. Percent cover of age classes of black oak and white oak within the 20 m buffer boundary for duration of the 300 year simulation.

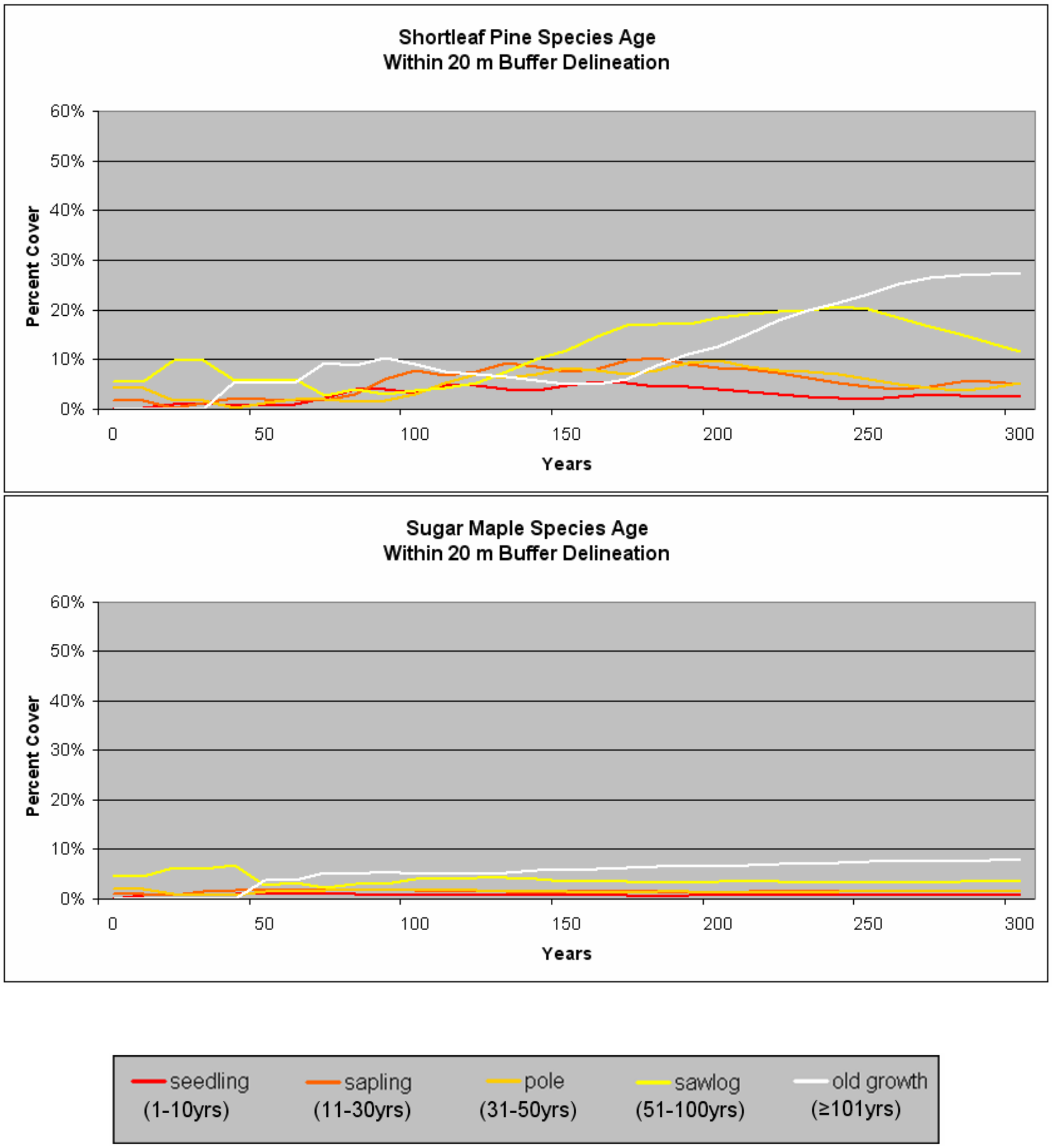


Figure 17. Percent cover of age classes of shortleaf pine and sugar maple within the 20 m buffer boundary for duration of the 300 year simulation.

Spatial Pattern

Spatial pattern of the landscape was quantified using the aggregation index. A lower aggregation index value indicates a more fragmented landscape. LANDIS is a raster-based model that converts the simulated landscape into cells or pixels, and each cell may contain more than one species and more than one age cohort. Dominant age maps, which use the oldest species age, were used to represent the age of a given cell. To reduce the total number of possible age classes, age classes were combined into 30-year groups. At year 0 age classes ranged from 0 to 90 years, older age groups appeared as the simulation progressed. For all simulation scenarios, the initial age classes became increasingly diversified as the simulation progressed. The diversification of the three initial age classes into many classes resulted in a decrease in their aggregation index values.

Overall there are lower aggregation values within the 20 m buffer delineation than the other two scenarios (Figure 18). Even though within the 100 m buffer scenario there is the highest amount of aggregation at a value of 0.5, within the variable width scenario the aggregation values are only approximately 0.1 lower than those of the 100 m values. All three scenarios have similar patterns of aggregation within the buffer delineations. The aggregation of species age groups declined until approximately year 120 when the values reached a general equilibrium. The youngest seven age classes after year 120 fluctuate within 0.1 of each other for all three scenarios. Consequently this shows that there is a fairly even distribution of age classes after year 120. The oldest age group (240-270) appears last at year 170 with values of aggregation that approach 0.

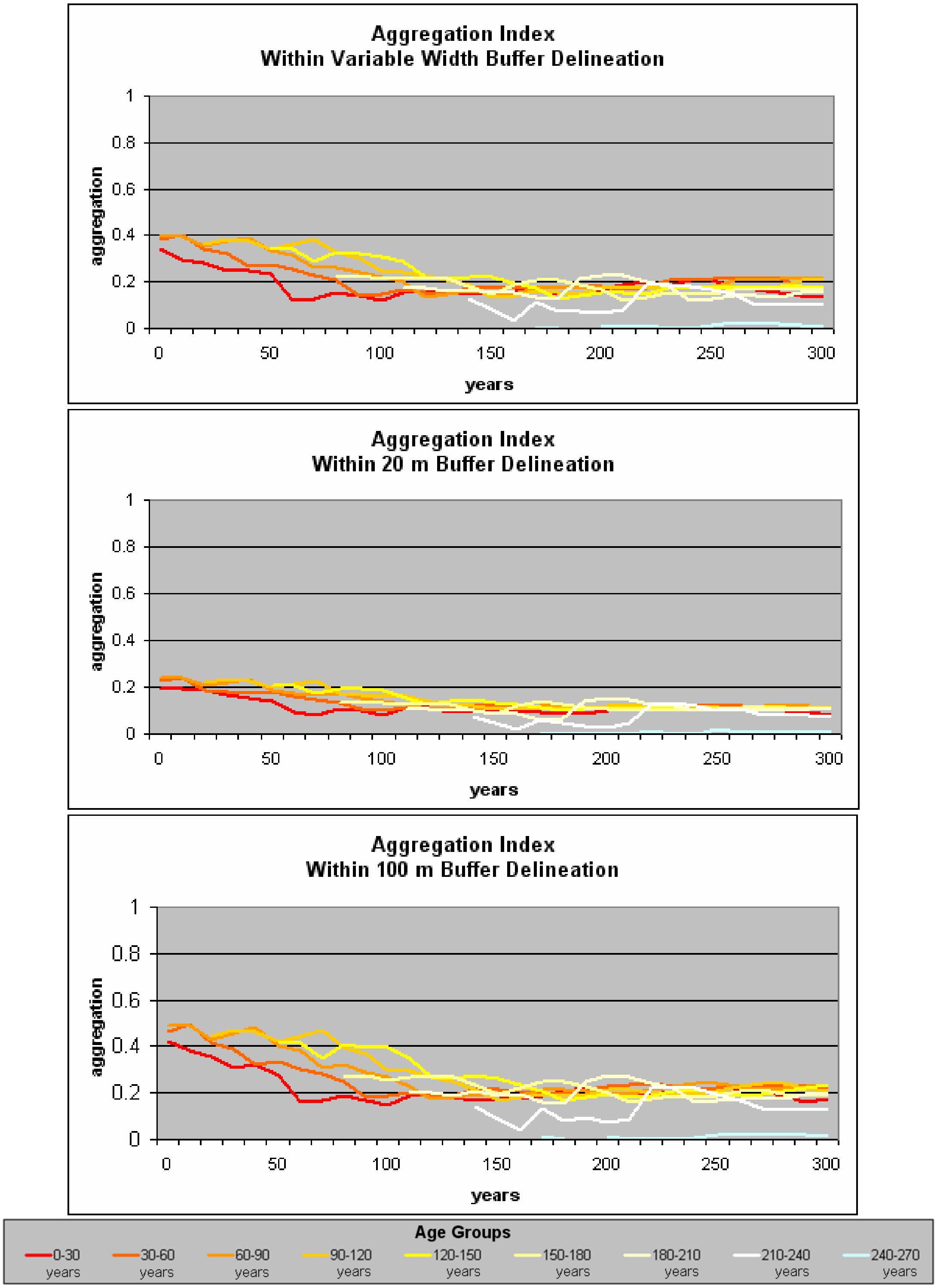


Figure 18. Aggregation index of age groups within the variable width, 20 m, and 100 m buffer boundaries for the duration of the 300 year simulation.

EFFECTS OUTSIDE RIPARIAN BUFFER DELINEATIONS

Species Composition

The total area outside the buffer delineation of each of the three scenarios decreases as mean buffer width increased from 20 m, to variable width, to 100 m (Figure 14). The pattern of species abundance derived from outside the riparian buffers was similar among all three scenarios and the 20 m scenario is used as the example chart. Even-aged harvesting was simulated on the areas outside of the buffer delineations resulting in more even species abundance (Figure 19). Shortleaf pine, white oak, and black oak all increased in abundance while sugar maple showed a slight decrease to values less than 1%. White oak and black oak both increased significantly in percent cover for the first 100 years. White oak reached equilibrium at approximately 98% while black oak values approached 90% cover. Abundance of shortleaf pine steadily increased throughout the 300 year simulation starting at 15% and ending with a value of 83%.

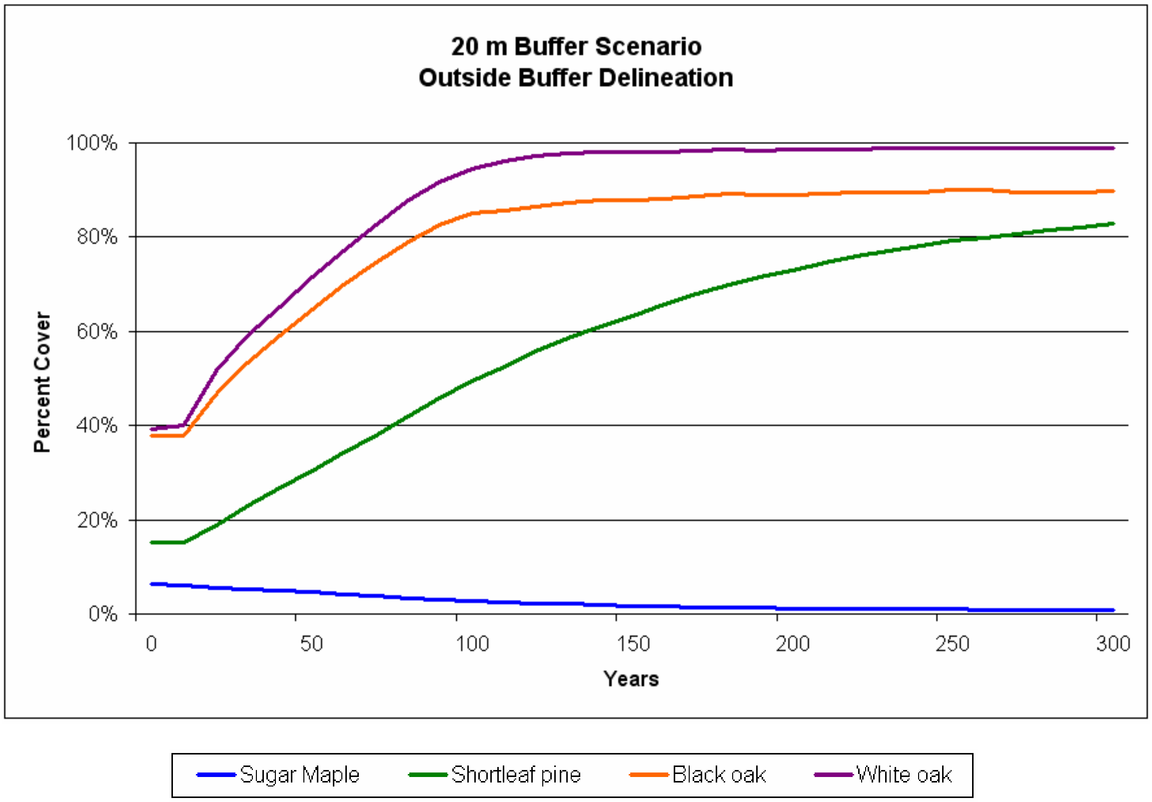


Figure 19. Percent cover by species found outside the 20 m buffer boundary for the duration of the 300 year simulation.

Species Age Composition

The pattern of species age composition for all three buffer scenarios outside the buffer delineation is similar and the 20 m scenario is used as the example scenario. The even-aged management performed outside of the buffer delineations specified that the harvest of stands was prioritized by oldest stands first. This caused the age class structure within and outside riparian buffers to be significantly different (Figures 16, 17, 20, 21). The presence of all sugar maple age classes declined less than 1% cover by year 90 and remained insignificant throughout the remainder of the simulation (Figure 21). The percent cover of the old growth age group outside the riparian buffer was significantly lower than inside the riparian buffers. The old growth age group became the least abundant age class for all species outside the riparian buffer. The old growth age group for black oak and shortleaf pine was less than 5% of the total area and the old growth group of white oak was less than 7%. The sawlog age class was the most abundant species age class outside the buffer delineations and ranged between 30%-41% of the area. Shortleaf pine area by age class was fairly constant for most age classes after year 100, although the sawlog age class increased steadily in abundance throughout the simulation.

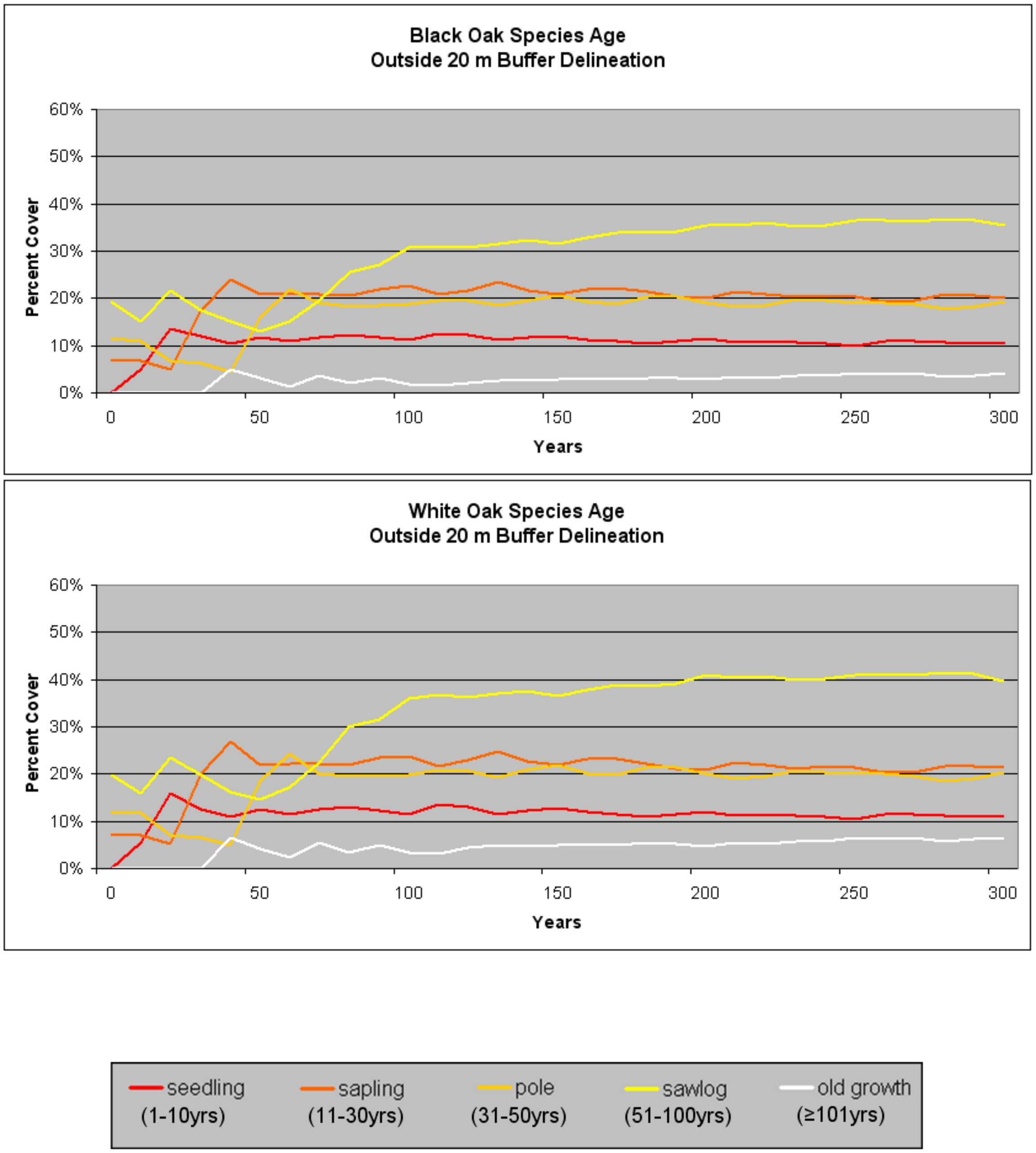


Figure 20. Percent cover of age classes of black oak and white oak outside the 20 m buffer boundary for duration of the 300 year simulation.

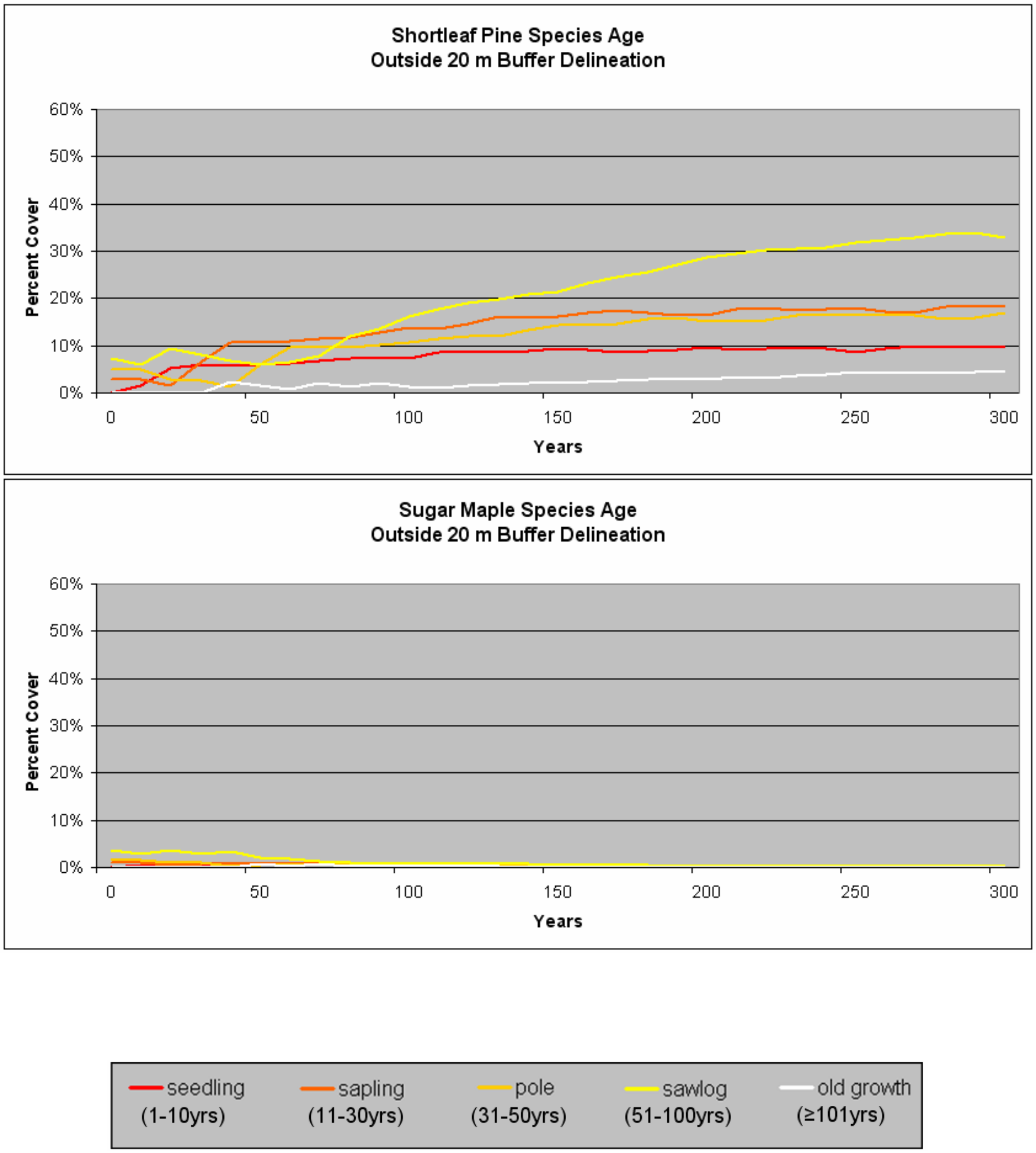


Figure 21. Percent cover of age classes of shortleaf pine and sugar maple outside the 20 m buffer boundary for duration of the 300 year simulation.

Spatial Pattern

There was little difference between the three scenarios when considering the aggregation of species age groups outside the buffer delineations (Figure 22). The youngest four age groups exhibit very uniform but relatively high aggregation after year 100. The most aggregated age group is 30-60. With the exception of the youngest age group (0-30), the age groups get less aggregated as age increases. Year 0 begins with age groups ranging from 0-90. As the simulation progresses older age groups are added as cohorts become older.

Comparing the aggregation index measured from within the riparian buffer with that measured for outside the riparian buffer would be misleading. The linear outline shapes created by the riparian boundaries for the inside riparian scenario confounds the measurement of aggregation. Linear shapes tend to have low aggregation measurements compared to squared or round shapes (He et al. 2000). Thus, aggregation indices from within the riparian buffers consistently have lower values than those from outside the riparian buffers. Comparing aggregation indices within the same scenario are still valid however.

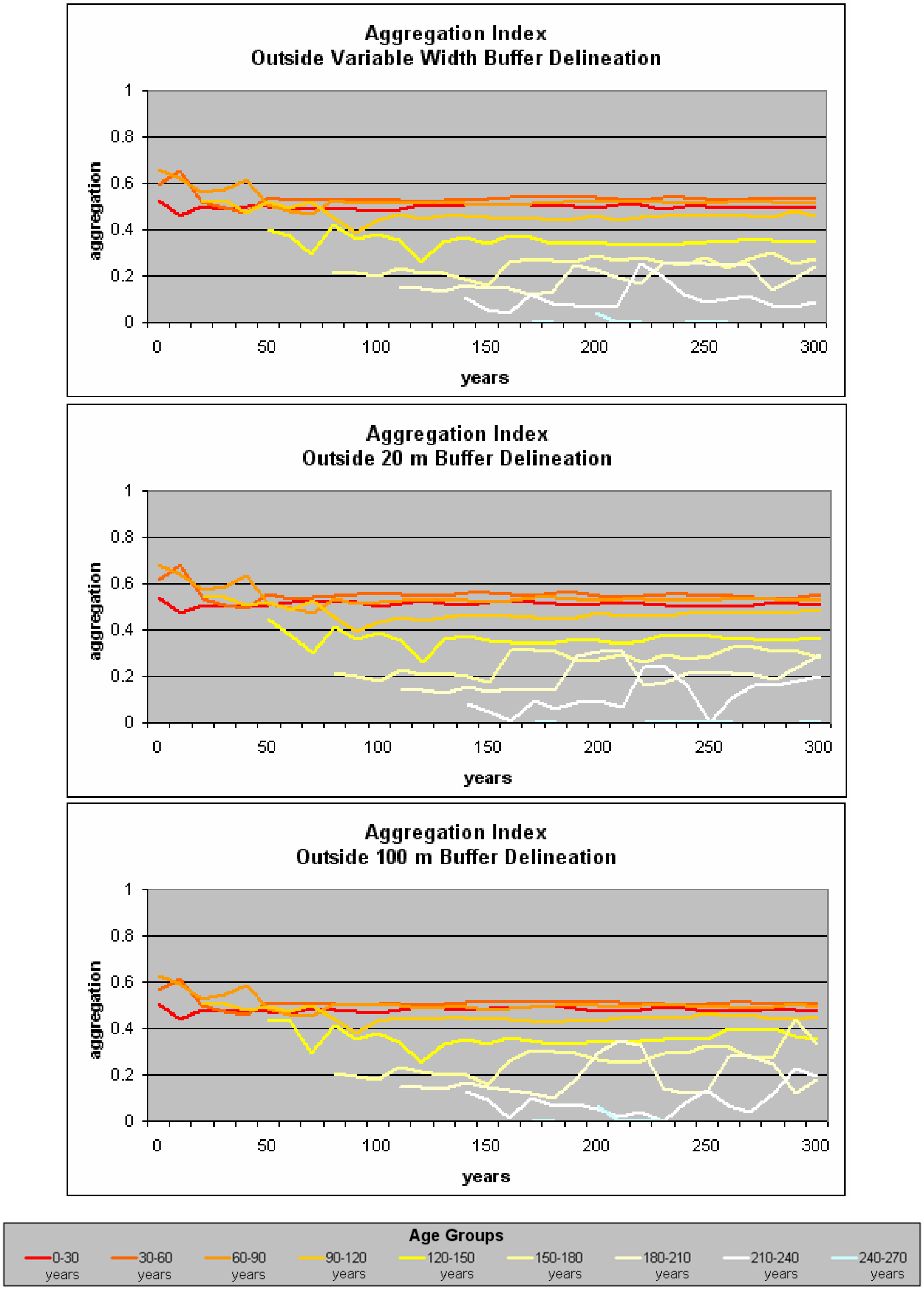


Figure 22. Aggregation index of age groups outside the variable width, 20 m, and 100 m buffer boundaries for the duration of the 300 year simulation.

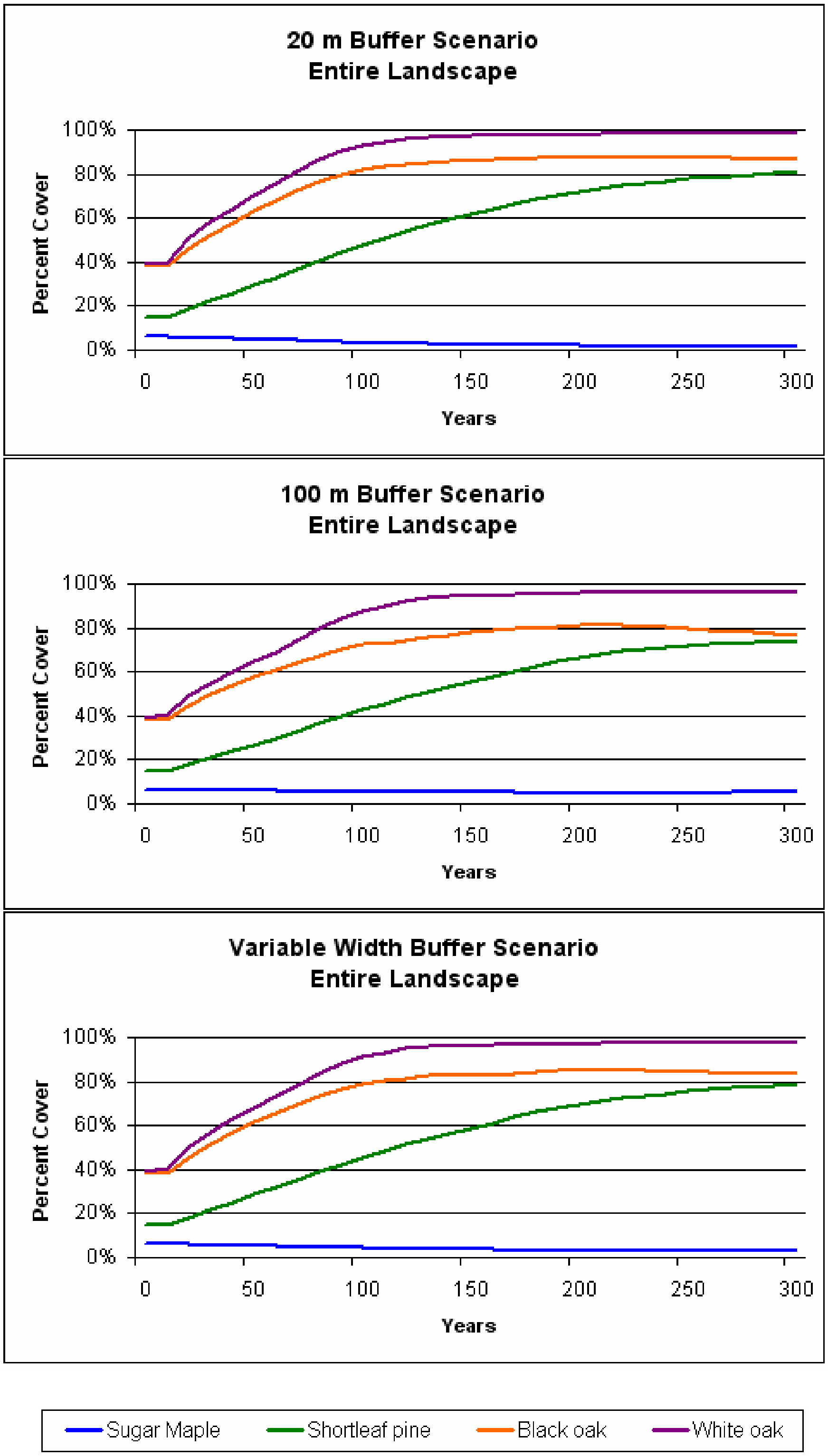
EFFECTS OF RIPARIAN BUFFERS ON THE ENTIRE LANDSCAPE

Species Composition

The presence of species on the entire landscape for the scenarios in which riparian buffers are applied are displayed in Figure 23. The presence of species on the whole landscape for the two control scenarios in which either the whole landscape has a harvest regime applied or not, referred to respectively as “harvest all” or “no harvest”, demonstrates a variation in response among species (Figure 24).

All five scenarios had a distinct increase in abundance for white oak. The buffer scenarios (variable width, 20 m, and 100 m) resemble that of the “harvest all” scenario. Shortleaf pine and white oak increased in abundance while sugar maple showed a slight decrease. The amounts of white oak and sugar maple became constant after year 100. Species abundance for all but the “no harvest” scenario had a relatively uniform pattern.

The widest buffer delineation at 100 m shows a slight difference in the species abundance pattern that resembles that of the “no harvest” scenario. Black oak increased for most of the simulation but showed a slight decrease in abundance after year 200 for the 100 m and “no harvest” scenarios. The “no harvest” scenario shows more variation in species presence over time than the other four scenarios. Conversely related to the other four scenarios, sugar maple showed an increase in abundance in the “no harvest” scenario.


20 m Buffer Scenario
Entire Landscape

100 m Buffer Scenario
Entire Landscape

Variable Width Buffer Scenario
Entire Landscape

Figure 23. Percent cover by species for the entire landscape for the100 m, 20 m, and variable width buffer scenarios for duration of the 300 year simulation.

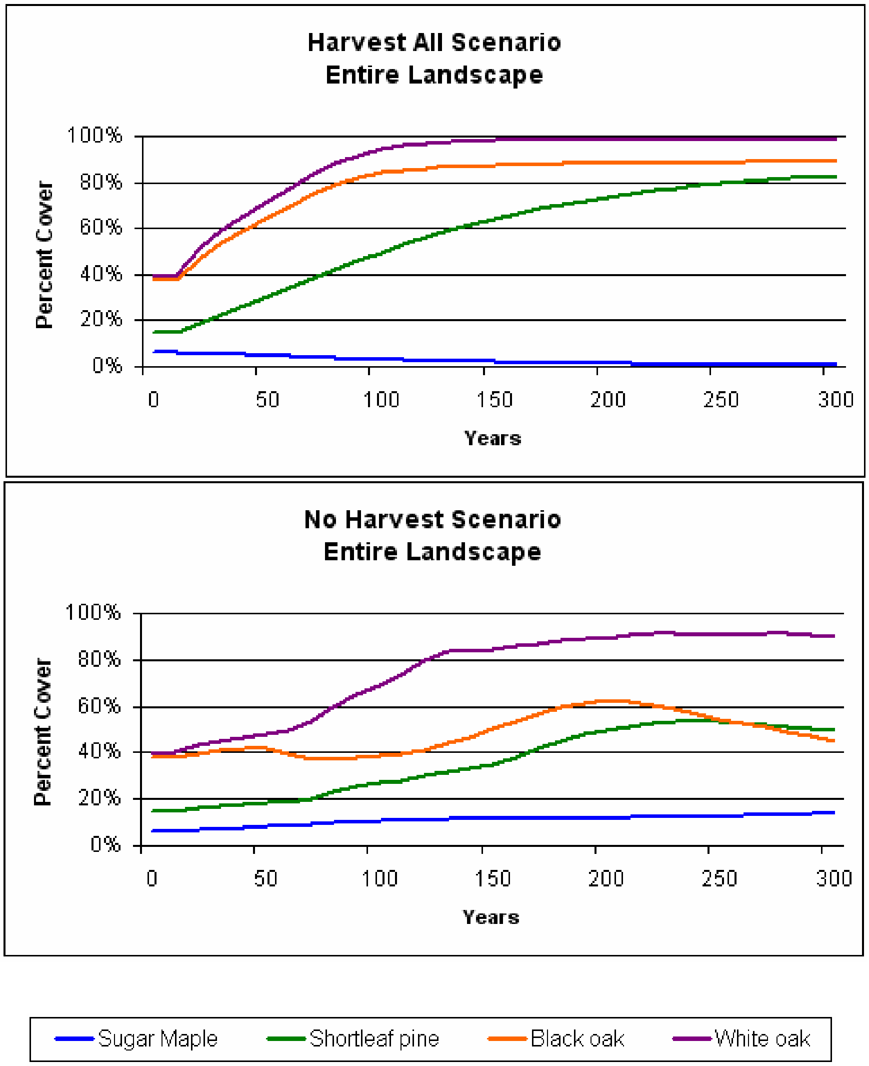


Figure 24. Percent cover by species for the entire landscape for the harvest all and no harvest scenarios for duration of the 300 year simulation.

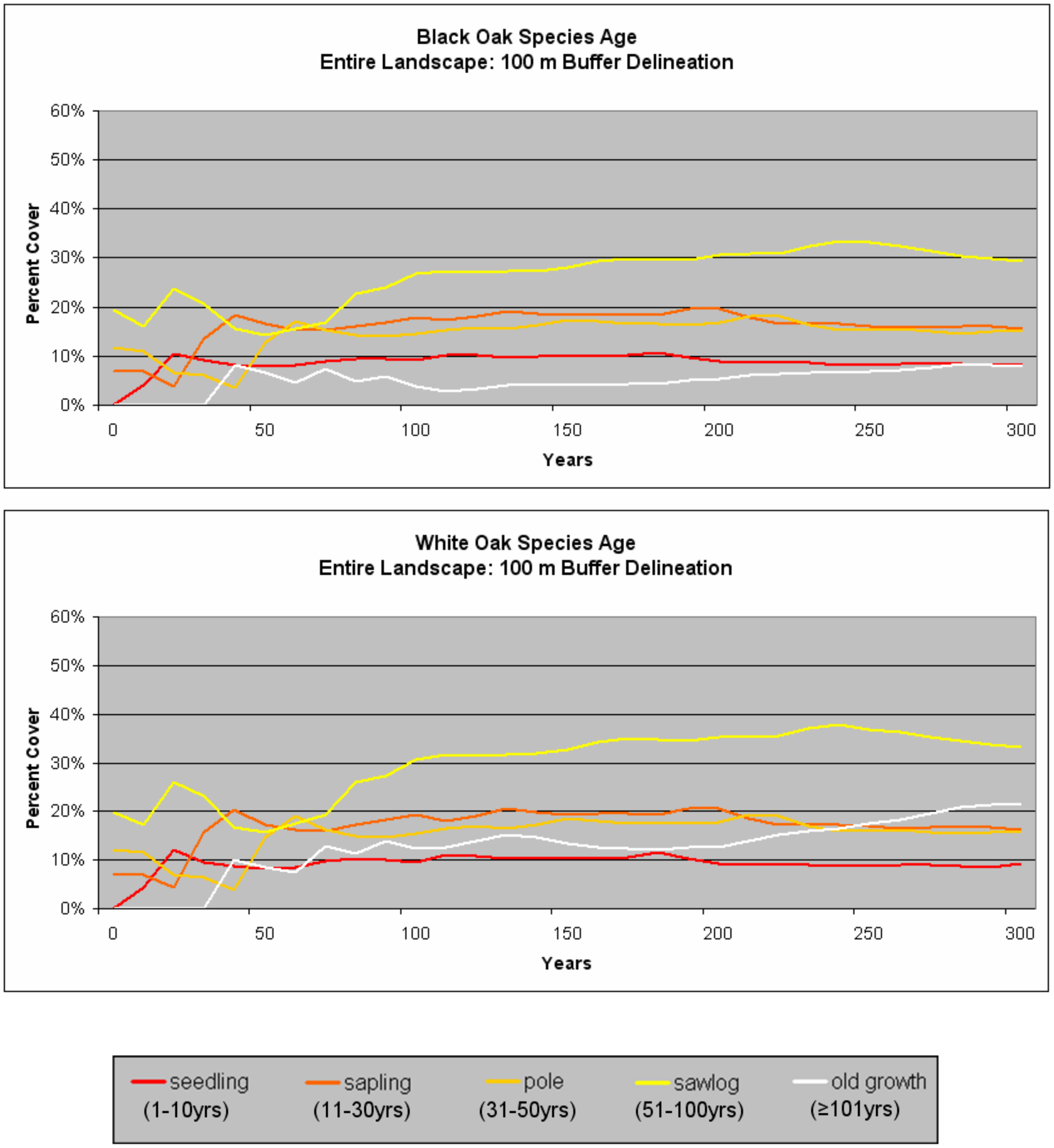
Species Age Composition

The following charts (Figures 25-30) represent age groups by species throughout the landscape for three of the five scenarios (100 m, “harvest all”, and “no harvest”). The variable width buffer and 20 m buffer scenarios were similar to the “harvest all” scenario. Consequently only the “harvest all” figures are shown in representation of those three scenarios.

For the “harvest all” scenario (and by association the variable width and 20 m scenarios) black oak, white oak, and sugar maple display a trend of constant species abundance after year 100. The sawlog age group of shortleaf pine steadily increased throughout time while the other age groups became constant after year 100. The sawlog age group was the most prevalent for black oak, white oak, and shortleaf pine. Species abundance for sugar maple was low for all age groups of these scenarios.

Figures 25 and 26 represent the landscape species age composition for the 100 m buffer scenario and are similar to the variable width, 20 m, and harvest all scenarios with a couple exceptions. White oak exhibits a higher amount of old growth after year 260 than the previously described scenarios. The sugar maple age group has a higher overall abundance throughout the simulation.

Species abundance for the “no harvest” scenario bears little resemblance to the other four scenarios (Figures 29, 30). Black oak, white oak, and shortleaf pine age groups are highly variable throughout the 300-year simulation. Sugar maple has a fairly even distribution of age groups after year 70 and has more abundance than the other four scenarios. The old growth age group was much more prevalent in the “no harvest scenario” than the others. Most notably, the white oak old growth age group reaches a peak of approximately 58% coverage at year 300.



Black Oak Species Age
Entire Landscape: 100 m Buffer Delineation

White Oak Species Age
Entire Landscape: 100 m Buffer Delineation

Figure 25. Percent cover of age classes of black oak and white oak for the entire landscape of the 100 m buffer scenario for duration of the 300 year simulation

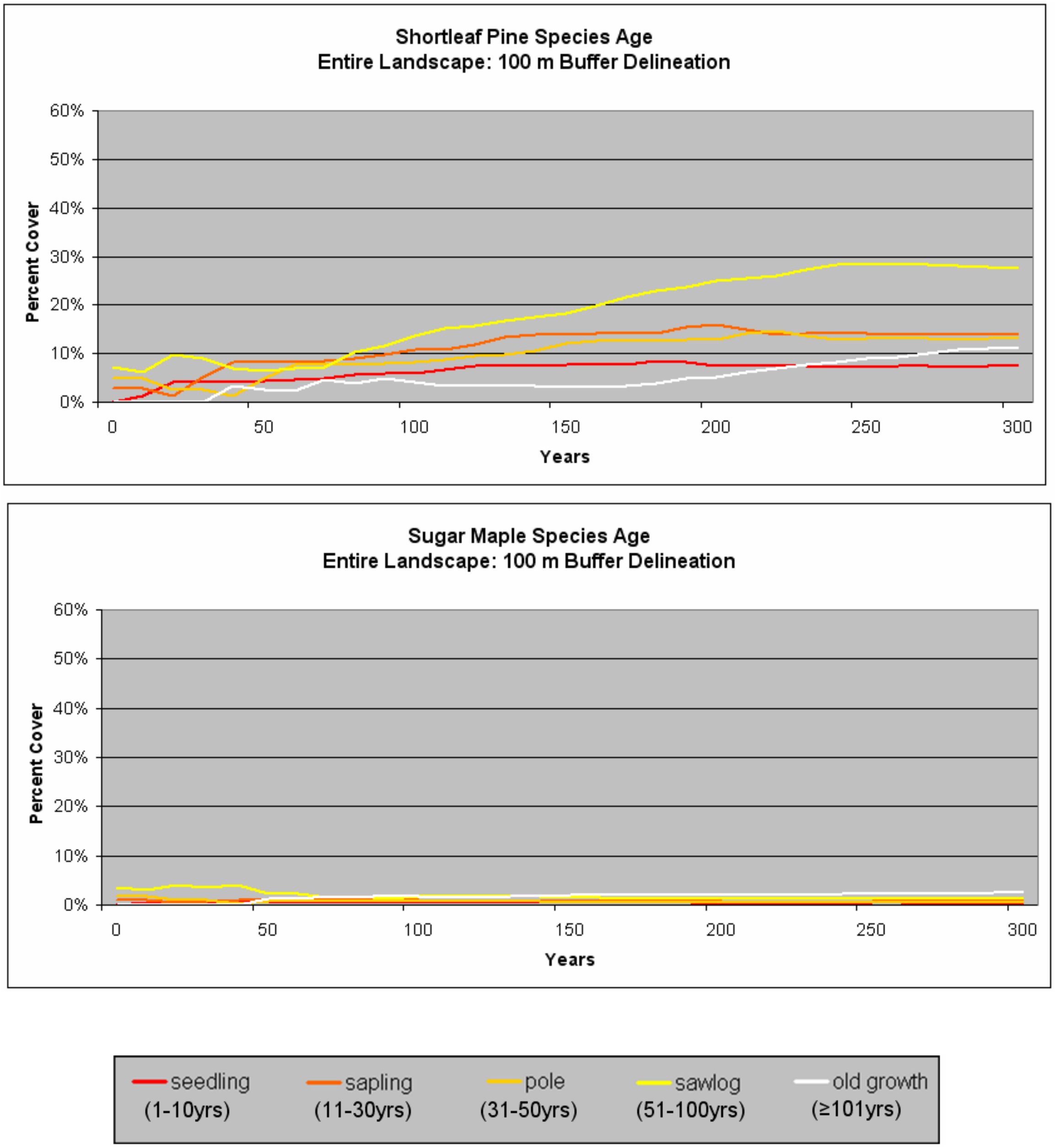


Figure 26. Percent cover of age classes of shortleaf pine and sugar maple for the entire landscape of the 100 m buffer scenario for duration of the 300 year simulation.

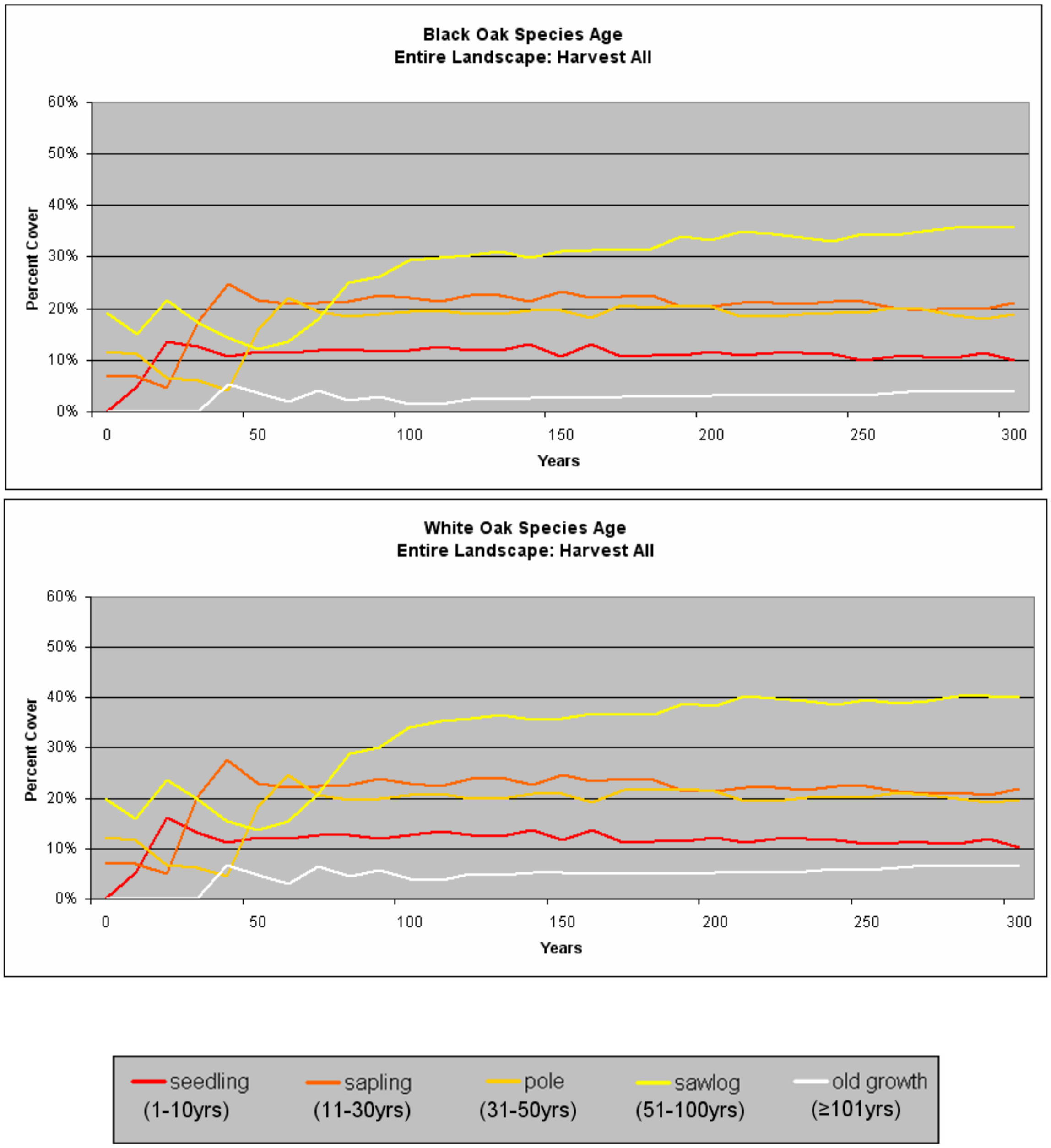


Figure 27. Percent cover of age classes of black oak and white oak for the entire landscape of the "harvest all" scenario for duration of the 300 year simulation.

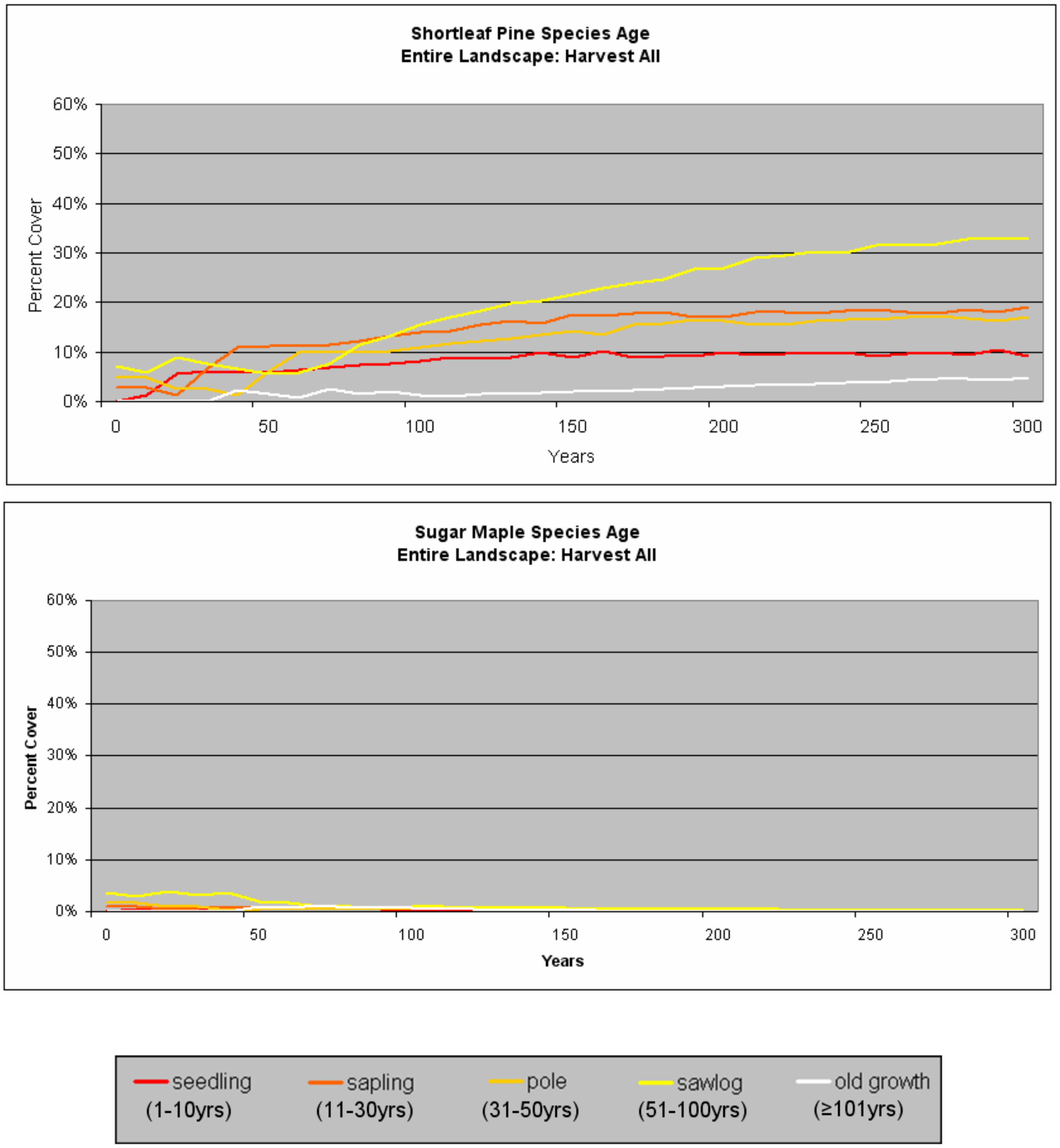


Figure 28. Percent cover of age classes of shortleaf pine and sugar maple for the entire landscape of the "harvest all" scenario for duration of the 300 year simulation.

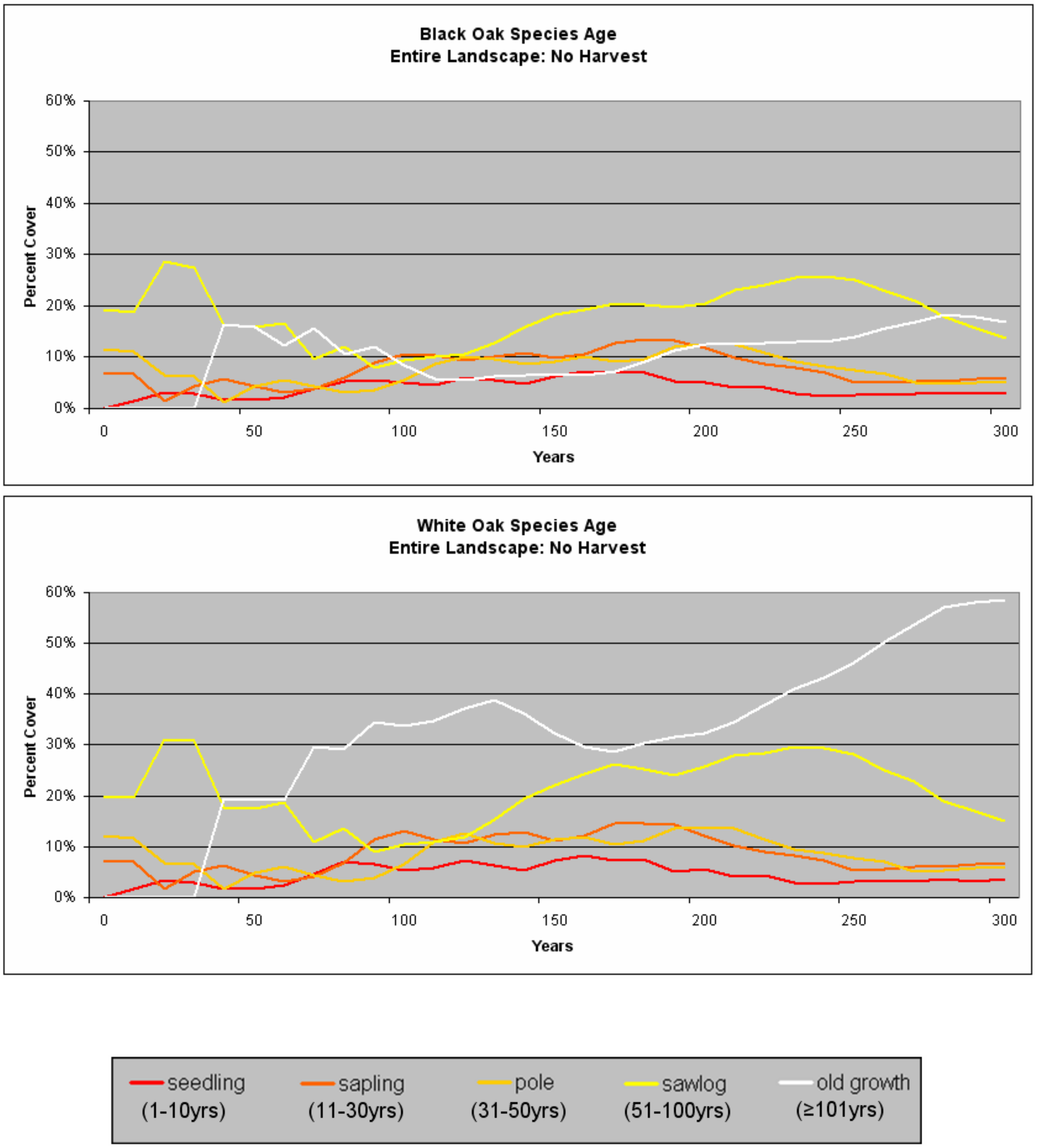


Figure 29. Percent cover of age classes of black oak and white oak for the entire landscape of the no harvest scenario for duration of the 300 year simulation.

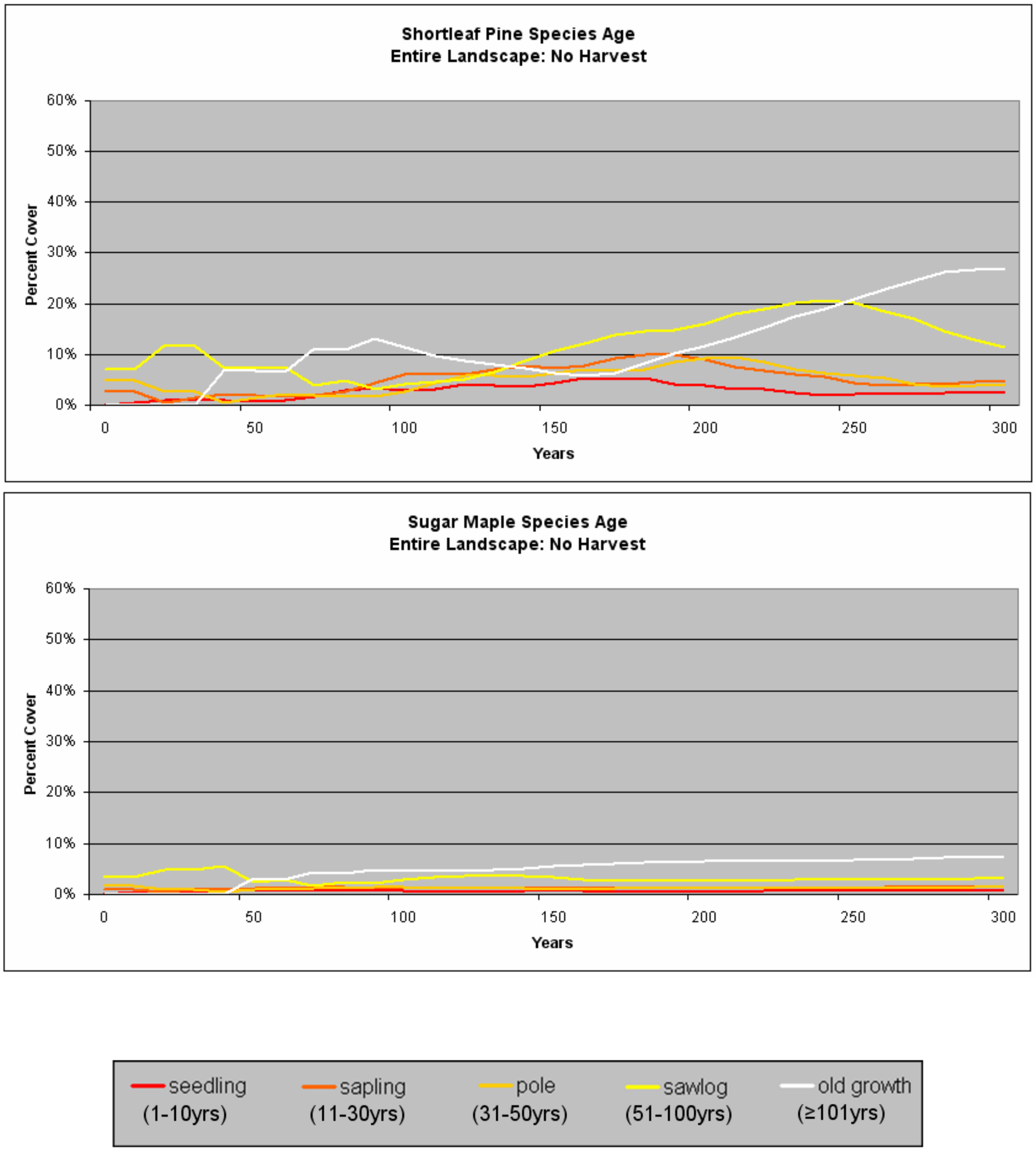


Figure 30. Percent cover of age classes of shortleaf pine and sugar maple for the entire landscape of the "harvest all" scenario for duration of the 300 year simulation.

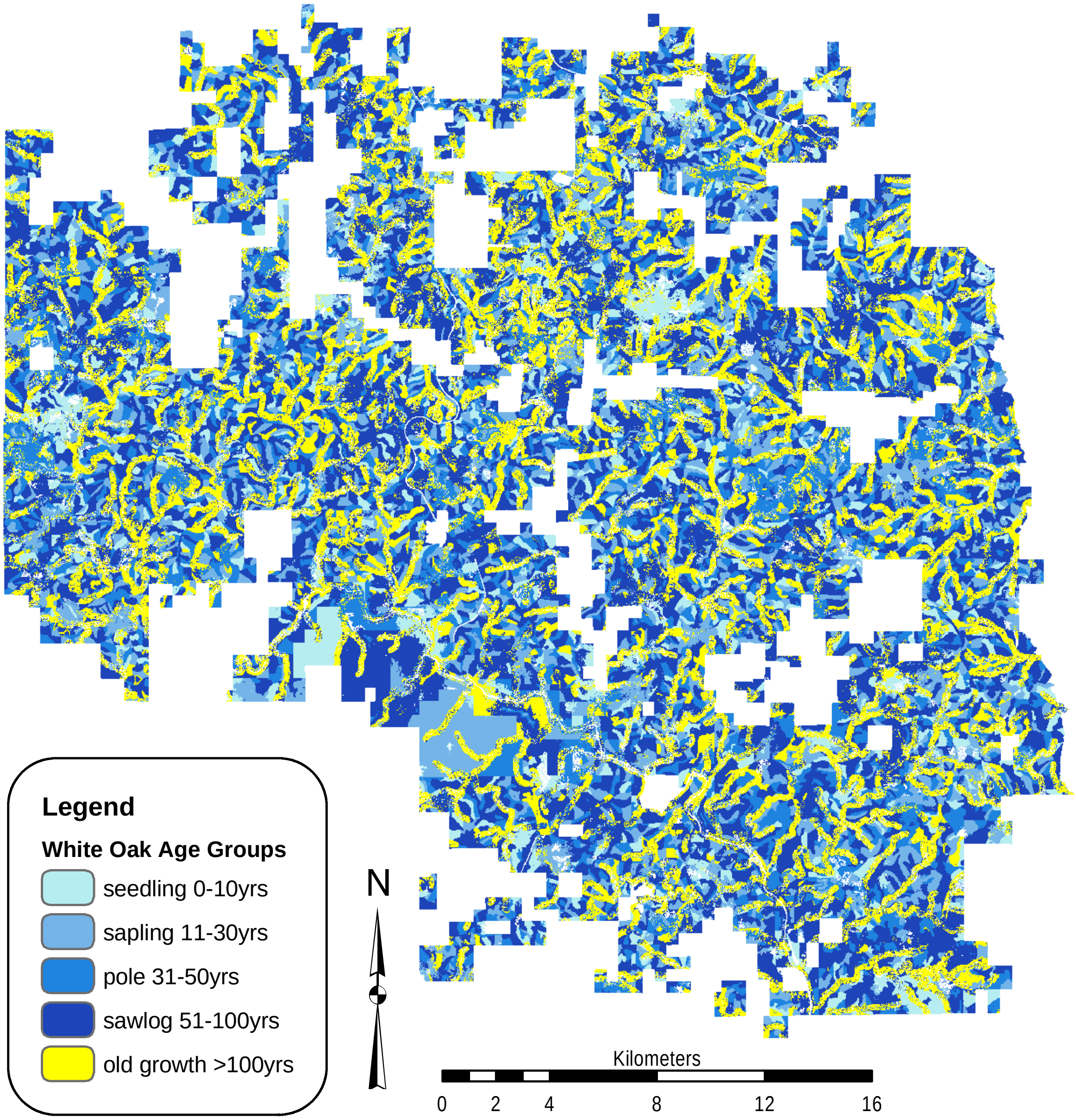


Figure 31. White Oak age groups for the 100 m buffer scenario at year 300.

The differences in age classes can be clearly demonstrated using a map at simulation year 300 (Figure 31). This map shows that most streams are well protected by the old-growth forest cover shown in yellow, while outside the riparian buffer age class distribution is fragmented due to the forest harvest.

Spatial Pattern

The following charts display the aggregation index of age groups for the entire landscape for the five simulation scenarios (variable width, 20 m, 100 m, harvest all, and no harvest) (Figures 32, 33). All five scenarios begin with year 0 having age groups ranging from 0-90. As time progresses older age groups appear approximately every 30 years as the forest ages.

The scenarios in which buffer delineations are applied (variable width, 20 m, and 100 m) exhibit age group aggregation patterns that are nearly identical. After year 40 the youngest four age classes reach an equilibrium aggregation index ranging between 0.4 and 0.6. As the remaining age groups, ranging from 120-240 years old, appear they are less aggregated than the younger age groups. The 240-270 age group remains insignificant with aggregation values at or near 0 throughout the simulation.

The pattern of the "harvest all" and "no harvest" aggregation indices (Figure 33) resemble that of the aggregation indices of the within and outside buffer delineation charts respectively (Figures 18, 22). Resembling the buffer scenarios (variable width, 20 m, and 100 m) the "harvest all" index has higher values of aggregation for the younger age groups than the "no harvest" index. The youngest four age groups exhibit uniform aggregation after year 40. The most aggregated age group is 30-60. With the exception of the youngest age group (0-30), the age groups became less aggregated than the age group before it.

For the "no harvest" scenario the aggregation of species age groups decline until approximately year 120 when the values reach a general equilibrium. The youngest seven age classes after year 120 fluctuate within 0.1 of each other. This shows a fairly even distribution of age classes after year 120. The oldest age group appears at year 170 and remains insignificant with aggregation values at or near 0 throughout the simulation

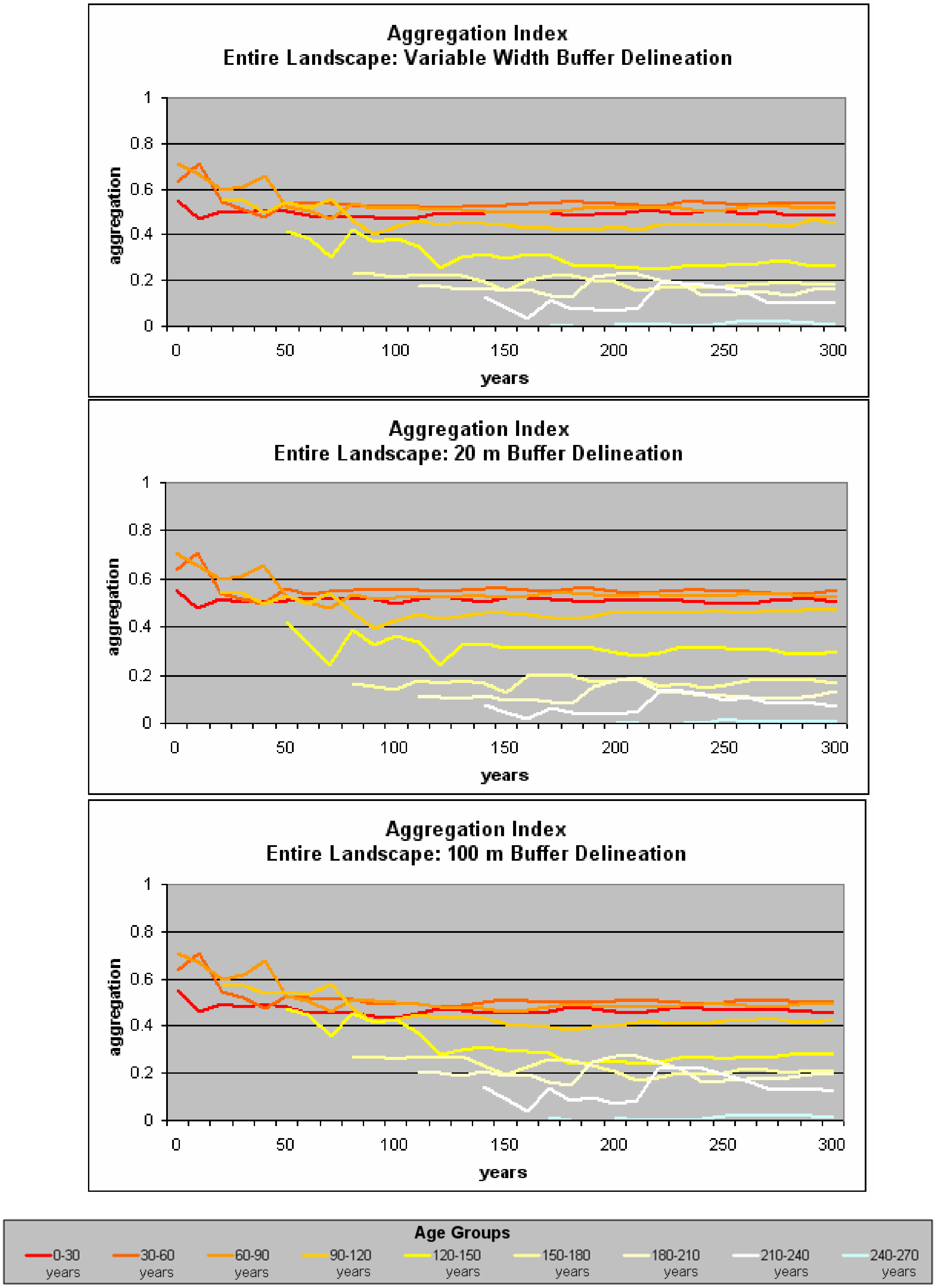


Figure 32. Aggregation index of age groups for the entire landscape for the variable width, 20 m, and 100 m buffer scenarios for the duration of the 300 year simulation.

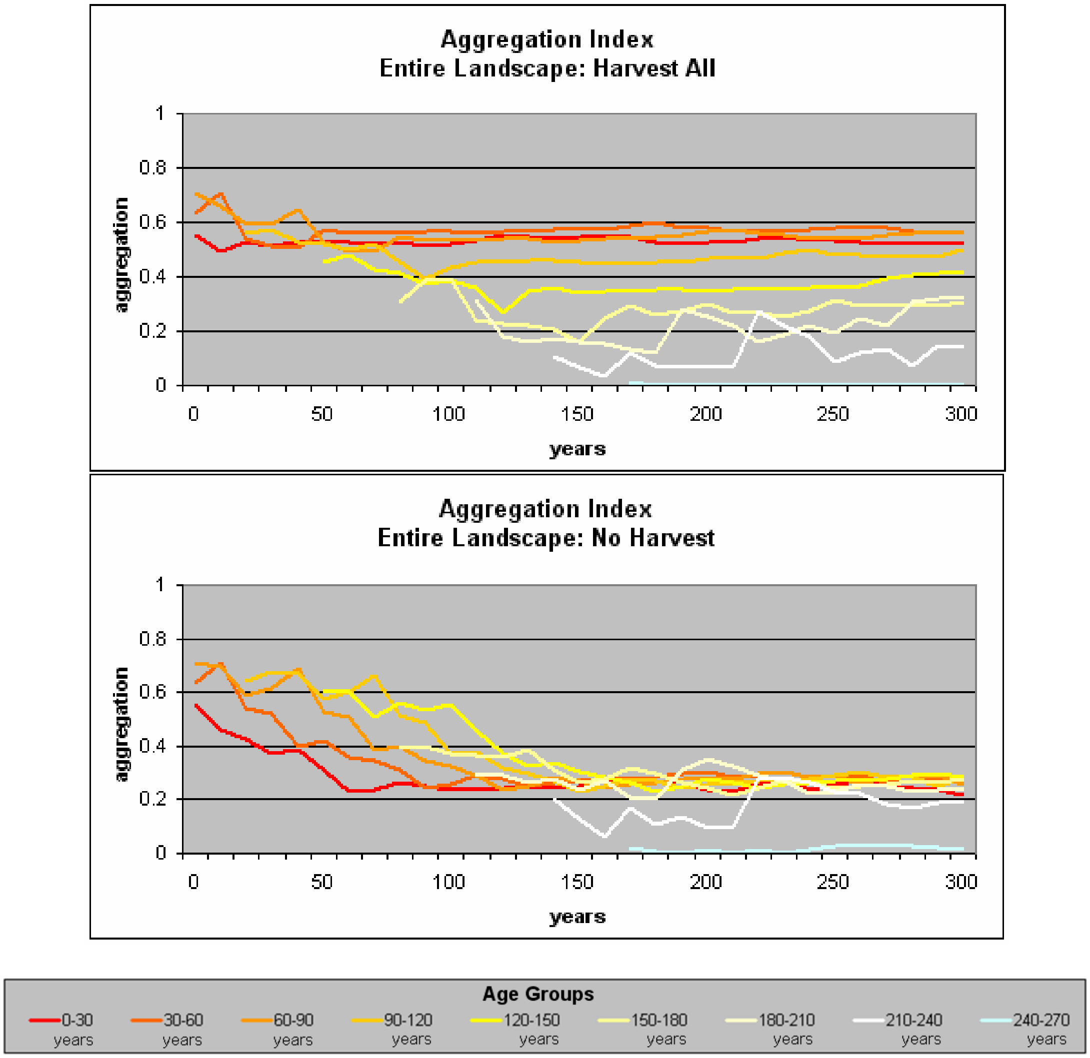


Figure 33. Aggregation index of age groups for the entire landscape for the harvest all and no harvest scenarios for the duration of the 300 year simulation.

HARVEST VOLUME

The harvest scenario for the variable width, 20 m, 100 m, and harvest all simulations specified that ten percent of the area to be harvested have all species and all age classes removed from the stand. The areas harvested in the simulations included the stands of the study area found outside the buffer delineations. Consequently total board feet harvested for the 300 year simulation is inversely related to the area unavailable for harvest within the riparian buffers (Figure 34). The “harvest all” scenario with no riparian buffer yields the highest total board feet harvested. Board feet harvested decreases from the 20 m scenario to the variable width scenario with the 100 m scenario having the smallest amount of board feet harvested.

Simulated Board feet harvested per decade (Figure 35) is similar to the “Simulated Total Board Feet Harvested…” in that the amounts harvested are in the same sequence of greatest to least: “harvest all” > 20 m > variable width > and 100 m. All scenarios display a general increase in board feet harvested over time in relation to the initial harvest at year 10 (Figure 35).

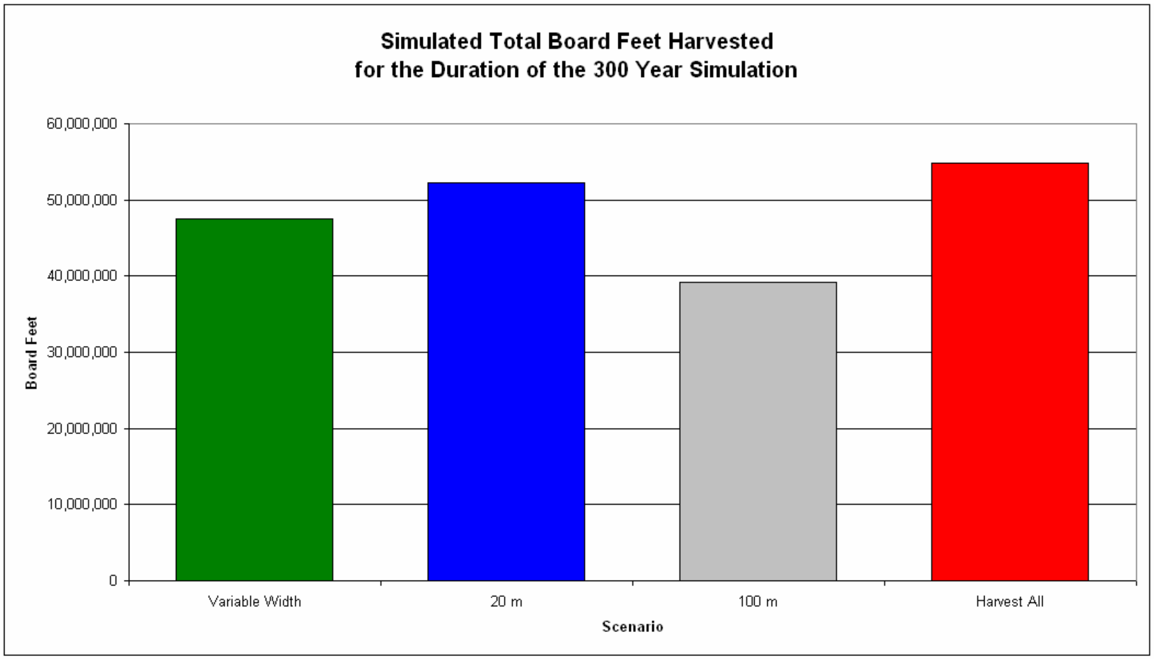


Figure 34. Simulated total board feet of wood harvested for the harvest all, 20 m, variable width, and 100 m scenarios.

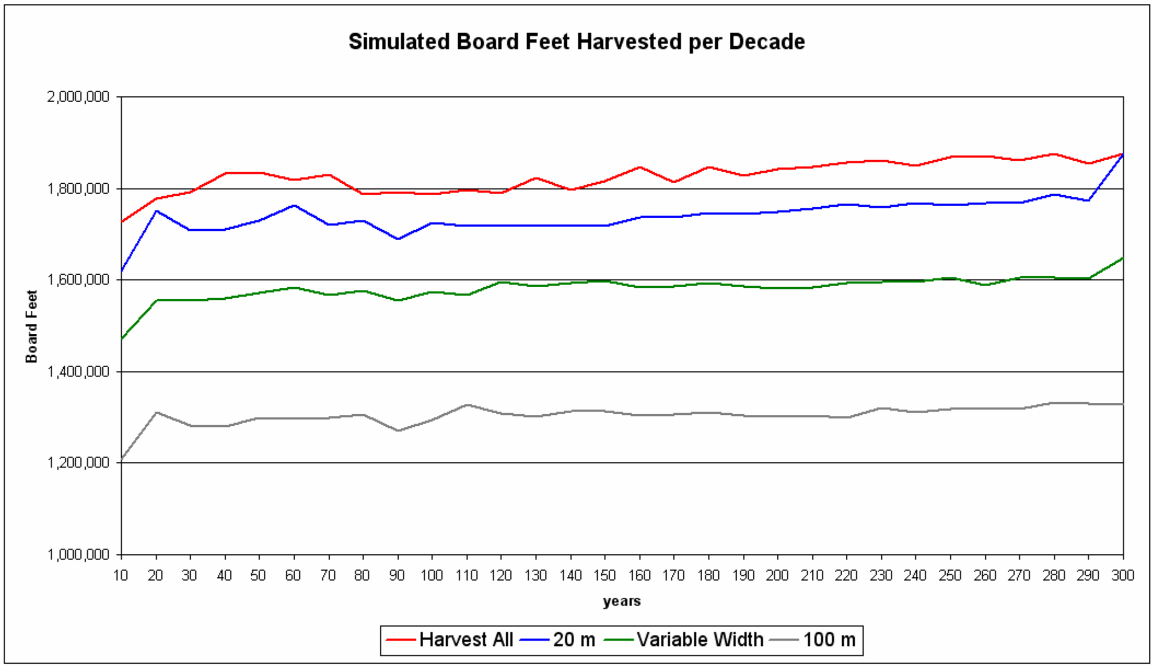


Figure 35. Simulated board feet of wood harvested per decade for the harvest all, 20 m, variable width, and 100 m scenarios.

CHAPTER V DISCUSSION

The abundance of species present within the boundaries is influenced by the width of the buffer established. The 100 m buffer delineation has the greatest number of cohorts, with the variable width buffer being the next smallest and the 20 m buffer having the fewest number of cohorts present within the buffer delineation.

SPECIES COMPOSITION

Species composition is most influenced by whether or not the landscape is harvested. For 20 m, 100 m, and variable buffer width scenarios the patterns of species composition within the riparian boundaries are similar because of the lack of harvest while the patterns outside the buffer boundaries are similar due to the influence of harvest. Black oak and sugar maple were the species most influenced by a lack of harvest. Black oak longevity is defined as 150 years in the LANDIS species attribute file (Table 4). This is 50 years less than sugar maple and shortleaf pine and 100 years less than white oak. Black oak is also a less shade tolerant species when compared to sugar maple. Consequently in the absence of harvest, black oak species percent cover declines after year 220 when older cohorts are eliminated faster than new cohorts are introduced (e.g., Figure 15). The absence of harvest allows sugar maple, a more shade tolerant species, to slowly increase in percent cover throughout the simulation (e.g., Figure 15). However with harvest, sugar maple is nearly eliminated at the end of the simulation (e.g. Figure 19).

The species composition for the landscape as a whole resembles most the species composition found outside the buffer boundary. This is due to the fact that the physical area found outside the buffer delineations exceeds that found within the buffer delineation (Figure 14). The 20 m and variable width buffers are small enough that their presence has little influence. The 100 m buffer delineation is large enough so as to have a slightly more significant influence on the whole landscape than the other two buffer scenarios. This is most evident when black oak exhibits a slight decline in abundance on the entire landscape after year 210 of the 100 m buffer scenario (Figure 23), a pattern similar to that found within the 100 m buffer delineation (Figure 15). Since harvest is the most influential factor in determining species composition, it follows that species composition for the “harvest all” scenario resembles most the pattern found outside the riparian buffer delineation while species composition for the “no harvest” scenario resembles most pattern found inside the riparian buffer delineation.

SPECIES AGE COMPOSITION

Species age composition was most influenced by the application or absence of harvest. The even-aged management performed outside the buffer delineations specified that the harvest of stands was prioritized by oldest stands first at a harvest rate of 10% of the management area every decade.

The absence of harvest allowed the old growth age group to become the most abundant age group within the riparian buffers and throughout the no harvest scenario. This absence of harvest allowed for a general abundance of older age groups. The younger age groups were present, contributing to the recruitment of older age groups but always at lower percentages (e.g., Figure 16). This particular age structure within the riparian buffers means that there is an abundance of large trees contributing shade, coarse woody debris and stabilizing the stream banks. This is particularly evident when examining the map showing older age cohorts along the riparian area (Figure 31).

Conversely related to the values inside the buffer delineations, old growth was consistently the least present age group outside the buffer delineations and throughout the “harvest all” scenario (e.g., Figure 20). A harvest rotation of 10% of the management area per decade led to a consistent abundance of age groups after year 100. The sawlog age group became the most abundant due to the harvest of the oldest stands first which in turn reduced values for the old growth age group. The constant application of even-aged harvesting resulted in a greater abundance of the younger age groups of seedling, sapling, and pole than those values found within the buffer delineations. This particular age structure near the stream could mean that the banks and the streams would not be well protected due to the lack of large trees contributing shade, coarse woody debris, and soil stabilization.

The species age composition for the entire landscape mostly resembled that of the values found outside the buffer delineations. The “no harvest” scenario resembled the values within the buffer due to the lack of harvest (e.g., Figures 16, 29) while the “harvest all” scenario resembled the values outside the buffers due to the application of harvest (e.g., Figures 20, 27). Although there is a distinct difference in the amount of area covered by the no harvest scenario versus within the riparian buffers, this had little bearing on the percent cover of the relative species age groups. The 20 m and variable width buffers were small enough that their inclusion into summary statistics for the entire landscape had little effect. However the 100 m buffer is wide enough that its inclusion into the entire landscape results in higher values of the old growth age group.

SPATIAL PATTERN

Spatial pattern of the landscape was quantified using the aggregation index. A lower aggregation index value indicates a more fragmented landscape. The index values for the age classes within the buffer delineations were similar in pattern, with differences only in overall aggregation. Within the 20 m buffer delineation the aggregation values were the lowest because the area covered by the 20 m buffer was the smallest. This suggests that the lowest spatial aggregation or highest fragmentation of the measured age classes occurs under this buffer scenario. The 100 m buffer, the widest buffer delineation, had the highest aggregation values which indicate the least fragmentation.

The pattern of aggregation for all age groups within the buffer delineations of all three buffer scenarios becomes fairly close to each other and remains at the same level after year 120. This means that there is an equal representation of all of the age groups found throughout the areas inside the buffer delineations. These low levels of aggregation also indicate that all the age groups can be found in small dispersed patches. After year 120 this part of the landscape has progressed into a general cycle of one age group growing into the next and the youngest age group (0-30 years) replacing cohorts where mortality has occurred (e.g., Figure 16).

The aggregation index values found outside the buffer boundaries, where harvest was performed, is much different from those found within the buffer boundaries. These values were naturally higher than those within the buffers simply because the larger area allows for larger patches of aggregation. The highest values of aggregation occurred for the younger age groups (<120 years) due to the even-aged harvesting performed and seedling reestablishment after harvests. When stands are harvested by clearcutting they are repopulated with the youngest age group which steadily progresses into the next oldest age group over time. This method of harvest means that older age groups have lower aggregation values (e.g., Figure 22). Mortality also plays a role in the lower aggregation values of older age groups. As the cohorts progress in age their likelihood of mortality increases just as their likelihood of harvest increases.

Due to the simple fact that the area outside the buffer delineations is larger than the area found within, the aggregation index values for the entire landscape resembled most the values for outside the buffer delineations. Because harvest was the primary disturbance on the landscape the “harvest all” scenario resembled the pattern of values outside the buffer delineations while the “no harvest” scenario resembled the pattern of values found inside the buffer delineations. The “no harvest” scenario generally had higher values of aggregation when compared to the values found inside the buffers because the area sampled permitted larger patches to occur.

HARVEST VOLUME

The amount harvested is directly related to the amount of area available for harvest as delineated by the riparian buffer boundaries. At the conclusion of the 300 year simulation each scenario had millions of board feet harvested. The 100 m scenario had approximately 13 million and 8 million fewer board feet harvested than the 20 m and variable width scenarios respectively. This difference breaks down to an average difference of 44 and 28 thousand board feet per year. The difference between the 100 m scenario and the other harvest scenarios is substantial; the difference between the 20 m, variable width, and "harvest all" scenarios was less substantial (Figure 34).

The 20 m buffer was designed to allow for the greatest amount of harvest while providing a minimal amount of protection for the riparian system. The variable width buffer used a buffer effectiveness equation to designate areas near the stream or river that were in need of wider riparian buffers due to soil and/or slope conditions. That there is not a substantial difference between the volume harvested between the 20 m and variable width scenarios demonstrates that adding the extra distance from the stream to protect certain areas sacrifices relatively little timber volume while increasing the protection of the riparian system.

CHAPTER VI CONCLUSIONS

The purpose of this project was evaluate via simulation the effects that different riparian buffering techniques, using established harvest practices, would have on forest pattern, composition, and timber volume. LANDIS, a landscape model, allowed for the simulation and comparison of these scenarios over a long period of time and all originating from the same landscape.

Five scenarios were defined to represent the primary approaches behind the delineation of most riparian buffers. Two of the scenarios, “harvest all” and “no harvest”, were used as control situations to exemplify what would occur in the absence of a riparian buffer with and without harvest. Two fixed width buffers, 20 m and 100 m from the stream, were used to demonstrate a minimum and maximum for which a riparian buffer could be delineated. A GIS (Geographic Information Systems) based equation was used to determine the boundaries of a riparian buffer with variable distances from the stream based upon localized soil and topographic characteristics. These boundaries determined the extent to which even-aged harvesting practices would be applied.

Results indicated that the most influential variable in the simulation was the application of harvest. Areas within the buffer delineation, where the “no harvest” regime was applied, had a great diversity of ages arranged in a fairly disaggregate pattern throughout the landscape. This sort of pattern means that the stream receives protection from soil erosion, while also receiving shade, organic matter, stream channel stabilization, and in-stream wood from older cohorts. While the percent cover within these areas is nearly identical, the absolute values are related to the width of buffer defined. For example the 20 m buffer has lower diversity of cohorts observed near the stream than the variable and 100 m buffers. The variable and 100 m buffers are closer to each other for these values than to the 20 m buffer.

After one hundred years of simulation, one full rotation of harvest was completed for the portion of the landscape outside the buffer delineations. The even-aged harvest regime led to a general equilibrium of species and species ages present outside the buffer regardless of buffer width applied to the stream.

The variable width buffer most efficiently protected the stream by widening the buffer from the stream at areas that are presumed to be more susceptible to erosion or pollutant discharge. When compared with the other buffer scenarios the variable width buffer scenario protected the stream at values approaching that of the 100 m scenario while harvesting 16,000 less board feet per year than the 20 m scenario. Assuming the soil and topographic inputs are available, modern GIS and Global Positioning Systems (GPS) techniques allow the variable width buffering method to be applied to any watershed.

In conclusion, this project modeled the effects that riparian zone delineation and management practices would have on landscape pattern and timber production. Using this approach, the model predicted the impact that typical forest practices would have over an extended period of time on an existing landscape in southern Missouri. This provides insight into ways to manage riparian zones.

However, it is important to realize that LANDIS is purely a model of landscape processes. Models are useful but do not represent true ecological processes. While the model may produce useful qualitative and quantitative results the analyst must realize the limitations that such a model might have. For example, certain bottomland species are absent from the simulation, such as sycamore and cottonwood, due to their general lack of abundance throughout the landscape. Also the vegetation dynamics of LANDIS are limited due to a lack of a disturbance module that simulates flooding. This kind of disturbance can lead to mortality related to floodplain land types and species that have difficulty surviving flood conditions. Species level succession characteristics such as the competition between established tree species to become dominant or the impact of understory species upon the landscape is similarly insufficient in this simulation. More specifically, a 30 m cell size, while computationally efficient in simulating processes in large landscapes it may be too coarse to accurately simulate ecological dynamics at an individual species level.

Despite these limitations, this approach is valuable because it allows the manager to examine landscape interactions that extend across broad spatial and temporal scales. With the assistance of GIS and Landscape modeling, complicated tasks such as delineating variable width buffers can become feasible. Future studies may involve the validation and verification of the simulation results. Other future endeavors may include the combination of LANDIS with a water quality model to determine the processes and reactions of the stream to the forest practices implemented in LANDIS. This ability to predict the dynamic pattern and process of the landscape makes LANDIS a useful management tool.

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