REGIONAL AND GEOMORPHIC INFLUENCE ON THE PRODUCTIVITY, COMPOSITION, AND STRUCTURE OF OAK ECOSYSTEMS IN THE WESTERN CENTRAL HARDWOODS REGION

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Abstract.—The steeply dissected glaciated landscapes of the Chariton River Hills Ecological Subsection (CRHES) in northern Missouri have extensive, but largely unmanaged, oak forests that are relatively unstudied. There is increasing interest in these forests for oak ecosystem restoration, ecological site description, and production of oak timber for biofuels. Our objectives were to determine how productivity, composition, and structure varied across the CRHES and locally by slope position and aspect. We inventoried vegetation and soils at 48 sites on upper and lower slope positions paired by northeast-facing and southwest-facing aspect classes on six minimally disturbed sites across the CRHES. Among sites, the site index of the two most abundant species ranged from 51 to 58 feet (white oak) and 51 to 62 feet (northern red oak) For white oak, site index was significantly greater on north-facing aspects ($P<0.01$) and lower slopes ($P=0.1$). White oak stocking was greater on southwest-facing aspects ($P<0.01$) and on upper slopes ($P=0.2$). White oak, northern red oak, and black oak make up the majority of the overstory; however, ironwood, blackhaw, white ash, and other species make up most of the understory and the large advance reproduction layer. Meeting typical oak ecosystem restoration or oak regeneration objectives will require the application of prescribed fire or other disturbances to reduce the understory density to provide light and growing space for a variety of woodland ground flora and oak seedlings, particularly on lower northeast-facing slopes.

INTRODUCTION

Geomorphic factors such as the land surface shape, slope position, and aspect have long been recognized to influence soil properties as well as forest composition and productivity (Carmean 1975, Fu et al. 2004, Hicks and Frank 1985, Pregitzer et al. 1983), particularly in landscapes having steep slopes and a high degree of topographic relief. The Chariton River Hills Ecological Subsection (CRHES) within the Iowa and Missouri Heavy Till Plain Major Land Resource Area (MLRA) is characterized by its steep slopes and extensive oak forests covering a large portion of northern Missouri (Fig. 1). The CRHES has the greatest topographic relief of interior northern Missouri (up to 250 feet), and is bordered on the east and west by more gently sloping lands predominantly used for agriculture. However, the forests in the CRHES are rarely subjected to manipulative treatments and consequently little is known about their productivity, composition, and structure.

Interest is increasing in the forests of the CRHES from private landowners and public land management agencies for oak forest and woodland restoration and for production of oak timber and biofuels. In addition, the Natural Resources Conservation Service (NRCS) of the U.S. Department of Agriculture has an interest in improving its understanding of the vegetation-site relationships in this MLRA to develop ecological site descriptions (ESDs) and to update the National Cooperative

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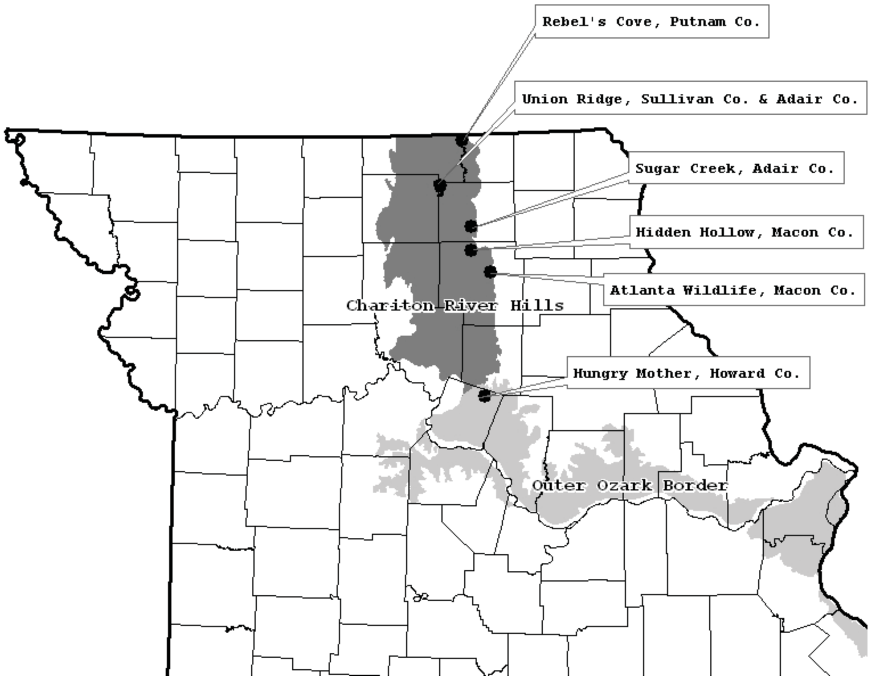

Figure 1.—Chariton River Hills Ecological Subsection (dark gray); Outer Ozark Border (light gray); filled black circles indicate project locations listed from south to north: Hungry Mother Conservation Area (CA), Atlanta Wildlife Area, Hidden Hollow CA, Sugar Creek CA, Union Ridge CA, and Rebel's Cove CA (Nigh and Schroeder 2002).

Soil Survey. Ecological site descriptions are a level of ecological land classification analogous to ecological landtypes (ELTs) used by the U.S. Forest Service. Geomorphic factors are important site-level determinants of site productivity and species composition used in both of these classification systems. Our study objectives were to determine how the productivity, composition, and structure of oak ecosystems vary regionally across the CRHES and locally by slope position and aspect.

STUDY AREA

Six sites (Fig. 1) were selected from central Missouri north to the Missouri-Iowa border. Sites were selected based upon a number of criteria including: (1) locality within or near the CRHES, (2) similarity of soils and topography, (3) accessibility, and (4) absence of recent timber harvesting, burning, or other anthropogenic disturbances. Consequently, all six sites were located on land owned by the Missouri Department of Conservation. All sites, except Hungry Mother Conservation Area, were within the CRHES. The site at Hungry Mother Conservation Area was included because its soils and physiography closely resembled that of the CRHES.

Study soils included the soil series Winnegan and Lindley. These soils were benchmark series due to their ecological significance and large mapping extent. Winnegan and Lindley soils are formed in calcareous Pre-Illinoian (2.5 million to 500,000 years ago) glacial till, and developed under humid climate conditions. Common characteristics of these soils include a well-expressed argillic horizon and soft masses of calcium carbonate commonly found in the lower part of the profile (Soil Survey Staff 2011). Differences between distinguishing characteristics of these soil series are slight. Winnegan soils are classified as very deep, moderately well drained, fine, Oxyaquic Hapludalfs, and Lindley soils are classified as well drained, fine-loamy, Typic Hapludalfs. These soils presently support central hardwood species such as white oak (*Quercus alba* L.), black oak (*Quercus velutina* Lam.), northern red oak (*Quercus rubra* L.), and hickory (*Carya* L. spp.).

Pre-European settlement vegetation of the study area was largely fire-adapted woodlands, with forests on steeper slopes and narrower valleys (Nigh and Schroeder 2002). Schroeder (1982) found that the presence of an intricate pattern of prairie and forests in Missouri was a major factor in the richness of wildlife in presettlement Missouri, and that the CRHES had the most intricate prairie-forest pattern in the state. Conversion of uplands for agricultural production began in the late 1800s (Schroeder 1982). Agricultural and developmental pressures have reduced much of the original forested structure in northern Missouri, and many once forested slopes are now cleared for grazing. The current landscape is mostly pasture with many tracts of second-growth oak-hickory forest on the steepest areas (Nigh and Schroeder 2002), which contain soil map units of either Winnegan or Lindley soil series as the dominant component.

METHODS

To encompass forested portions of the CRHES that were affected by differences in aspect, sampling was done on two slope positions (upper and lower positions of backslopes, (slopes >15%)) and two aspect classes (protected (north to northeast-facing) and exposed (south to southwest-facing)) at two random locations within each of the six sites (conservation areas) for a total of 48 samples. Plots were not placed on neutral aspects (115 to 155^{o} and 295 to 335^{o}).

Nested, concentric vegetation plots were used to inventory woody vegetation for each combination of slope position by aspect class at each location. Trees 1.5 inches diameter at breast height (d.b.h.) or larger were inventoried in a circular 0.12-acre plot and trees less than 1.5 inches d.b.h but larger than 1.5 feet tall were inventoried in a circular 0.012-acre subplot by height classes: 1.50 to 2.99 feet, 3.00to 4.49 feet, and >4.5 feet. Trees up to 1.5 feet tall were inventoried in a 0.006-acre subplot.

Site index data were collected on overstory plots by sampling up to three trees of each of the most abundant tree species present: white oak or northern red oak. Trees selected were (1) dominant or codominant, (2) had no indication of being open grown, and (3) had no indication of suppression (Carmean et al. 1989). For selected trees, height was estimated using a clinometer and the age at d.b.h. was determined from a single core sampled with an increment borer 4.5 feet above ground. Site index was computed using equations formulated for forest tree species in the eastern United States (Carmean et al. 1989) and parameters from oak species in Missouri (McQuilkin 1974, 1978). Trees per acre and basal area per acre were calculated and used to determine percent stocking (Gingrich 1964, 1967).

To quantify site variables, a soil pit was excavated within each overstory plot to a depth of 80 inches; genetic horizons were morphologically delineated and described according to the NRCS Soil Survey Field Book for Describing and Sampling Soils (Schoeneberger et al. 2002). Soil samples were collected from each horizon for full soil characterization analysis by the University of Missouri Soil Characterization Laboratory and select data are presented in Table 1. Percent slope, aspect, and slope morphometry were also recorded at each plot.

To examine the effects of aspect and slope position, data were analyzed using the MIXED procedure (SAS Institute Inc., 2002-2008). We used a hierarchical linear mixed model with aspect and slope position as nested, crossed, fixed effects and location, and location within site as random effects. This model tested the effect of aspect or slope position using the aspect*slope position*site interaction

Table 1.—Summary of average values for select site variables by diagnostic horizon for the epipedon (0 inches to the top of the argillic horizon) and upper and lower subsurface horizons (divided at the midpoint from the top of the argillic horizon to the bottom depth of 80 inches) (Standard deviation is given below each average)

Diagnostic horizon	Texture	Clay %	Sand %	AWC[a] in.	CEC[b,c]	Ca[b]	Mg[b]	K[b]	Bs[c,d] %	pH (H_2O)
Epipedon	Loam	14 ±4.2	41 ±12	1.1 ±0.50	14 ±3.9	6.3 ±3.8	1.2 ±0.53	0.25 ±0.09	51 ±19	5.2 ±0.52
Upper subsurface	Clay loam	36 ±5.1	33 ±8.6	4.2 ±0.85	23 ±4.1	12 ±7.7	2.7 ±1.2	0.27 ±0.07	58 ±16	5.2 ±0.65
Lower subsurface	Clay loam	28 ±4.9	37 ±9.2	6.9 ±0.75	16 ±2.7	33 ±13	3.7 ±2.0	0.18 ±0.08	94 ±11	7.3 ±0.91

[a] Estimated available water capacity.
[b] Units are in $cmol_c/kg$.
[c] Extracted by ammonium acetate.
[d] Base saturation.

at the 0.05 significance level. We also examined regional differences in site index using the REG procedure (SAS Institute Inc. 2008) by including the variables: percent clay, percent silt, available water capacity, cation exchange capacity, and percent base cation saturation averaged by location.

RESULTS

Site Productivity

Across the CRHES, site index ranged from 51 to 58 feet (white oak) and 51 to 62 feet (northern red oak) (Fig. 2). Site index was slightly lower on the southernmost and northern most locations but regression analyses between site index and site variables (percent clay, percent silt, available water capacity, cation exchange capacity, and percent base cation saturation) did not show significant relationships, suggesting some other cause for regional differences. We observed that sites with lower site index values had older, slower growing trees (particularly the white oaks) including Hungry Mother (average age 128 years), Atlanta Wildlife (average age 88 years), and Union Ridge (average

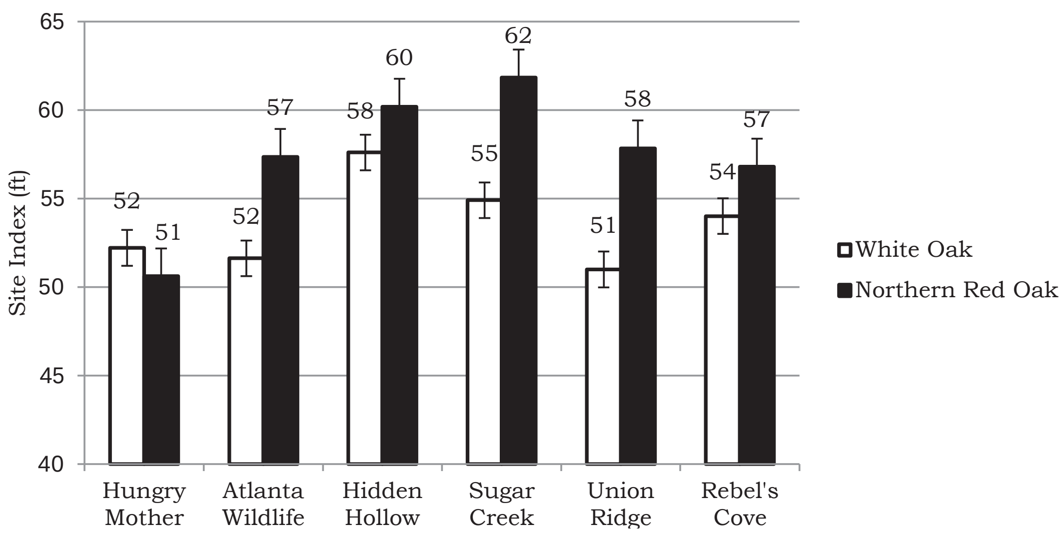

Figure 2.—Average estimated site index (feet) for white oak and northern red oak by site listed from south to north. Bars represent standard error.

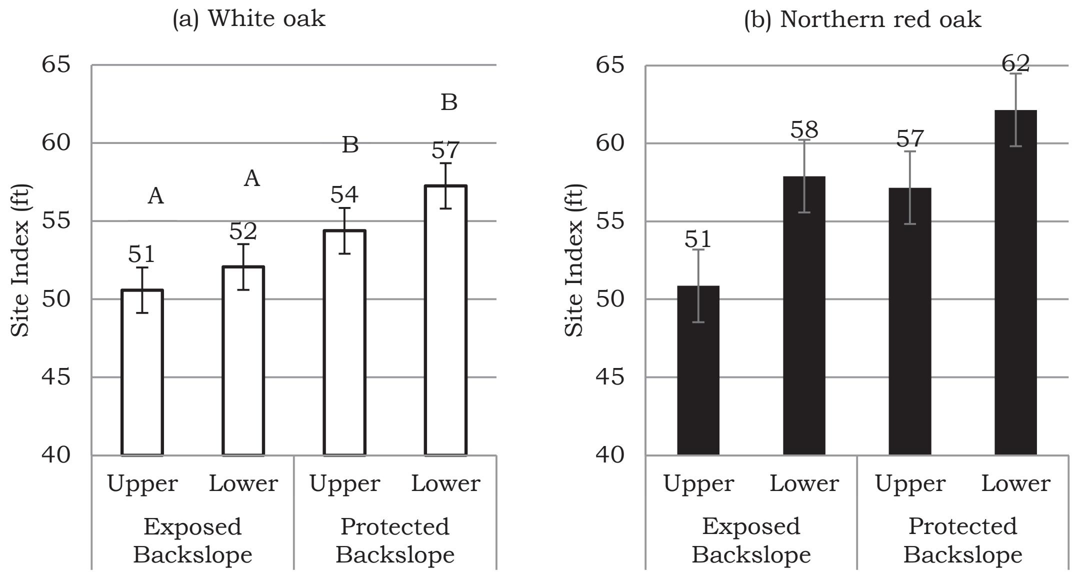

Figure 3.—Estimated site index for (a) white oak and (b) northern red oak by geomorphic component. Site index is significantly greater (P<0.01) for white oak on protected topographic aspects and nominally greater (P=0.1) on lower hillslope positions. Letters represent unique populations by topographic aspect (P<0.05). Bars represent standard error.

age 85 years), suggesting that site index may have been underestimated because ages were beyond the range at which site index curves were developed. Despite the lack of regional trends, there was a distinct geomorphic effect on the site index. Site index values for white oak were significantly greater on protected aspects (P<0.01) and nominally greater (P=0.1) on lower slope positions (Fig. 3). For northern red oak, site productivity appeared greater on lower slope positions and protected aspects, but due to an imbalance in the dataset the model was not run (Fig. 3). This imbalance was most likely a result of red oak species (northern red oak and black oak) not occurring on every plot. However, because northern red oak and black oak site index values were nearly equivalent (Johnson et al. 2009), the values of these species were averaged and results were significantly (P<0.01) greater on lower slope positions. Results indicated that slope position and aspect had a greater influence on site productivity than regional factors and that the greatest productivity was on lower slope positions of protected aspects.

Composition and Structure

All stands were in the understory re-initiation stage of stand development (Johnson et al. 2009, Oliver and Larson 1996) and were fully or overstocked (Gingrich 1967). Stocking ranged from 78 to 112 percent (Table 2). On a stocking basis, white oaks (dominantly white oak) were the most abundant overstory species at every site, followed by red oak species (mainly northern red oak and some black oak), ironwood (*Ostrya virginiana* (Mill.) K. Koch), hickories, and white ash (*Fraxinus americana* L.). Much as with productivity, we found that aspect and slope position had a significant effect of the stocking of white oak and red oak species (Fig. 4). White oak stocking was significantly greater on exposed slope aspects (P<0.01) and nominally greater on upper slope positions (P=0.1). Red oak stocking was nominally greater on protected aspects and lower slope positions.

Table 2.—Average percent stocking for overstory species (>1.5 in. d.b.h.) listed by location from south to north

Species group	Hungry Mother	Atlanta Wildlife	Hidden Hollow	Sugar Creek	Union Ridge	Rebel's Cove	Average stocking
White oak spp.	53	83	47	60	51	88	63
Red oak spp.	12	20	25	16	21	8	18
Ironwood	9	1	<1	4	7	4	4
Hickory spp.	7	5	3	3	2	2	4
White ash	<1	4	<1	<1	9	<1	3
Other Spp.[a]	1	<1	1	<1	0.0	<1	<1
Elm[b]	2	<1	<1	<1	<1	1	1
Sugar maple[c]	3	0.0	0.0	0.0	0.0	0.0	<1
Black cherry[d]	<1	<1	<1	<1	1	<1	<1
Black walnut[e]	1	0.0	0.0	0.0	0.0	<1	<1
Serviceberry[f]	<1	0.0	<1	0.0	<1	<1	<1
Ohio buckeye[g]	<1	0.0	0.0	0.0	<1	<1	<1
Total Stocking	89	112	78	84	92	105	94

[a] Mainly composed of red mulberry (*Morus rubra* L.), eastern redbud (*Cercis canadensis* L.), and hackberry (*Celtis occidentalis* L.).
[b] *Ulmus spp.* L.
[c] *Acer saccarrinum* L.
[d] *Prunus serotina* Ehrh.
[e] *Juglans nigra* L.
[f] *Amelanchier arborea* Michx. f.
[g] *Aesculus glabra* Willd.

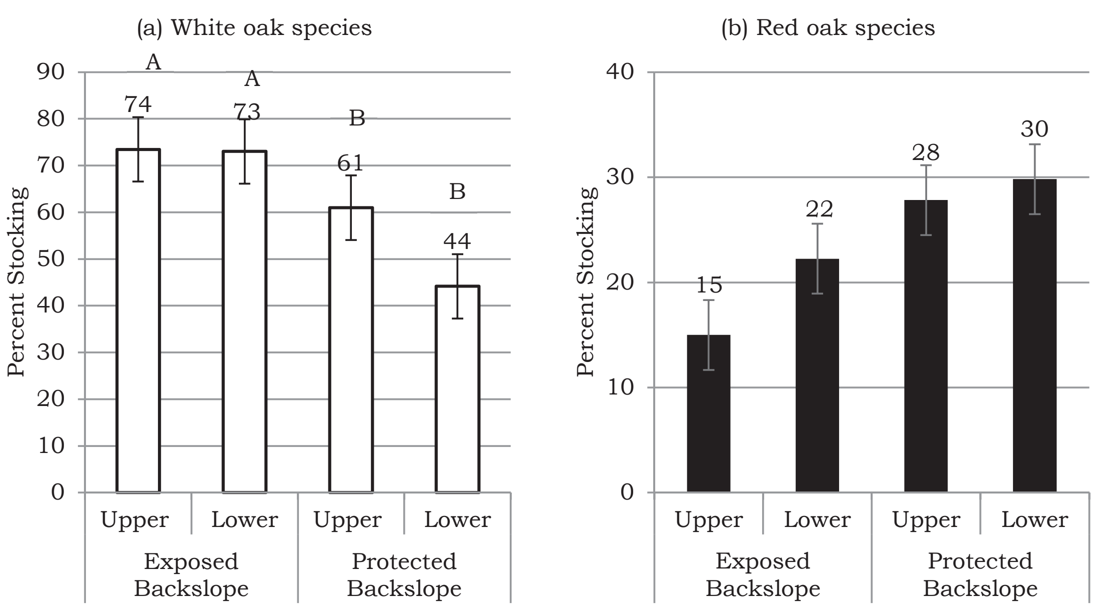

Figure 4.—Average percent stocking for (a) white oak species and (b) red oak species groups by geomorphic component. Stocking was significantly higher for white oak species on exposed topographic aspects (P<0.01) and nominally higher for upper hillslope positions (P=0.2), and red oak species stocking was nominally greater on lower northeast-facing slopes. Letters represent unique populations by topographic aspect (P<0.05). Bars represent standard error.

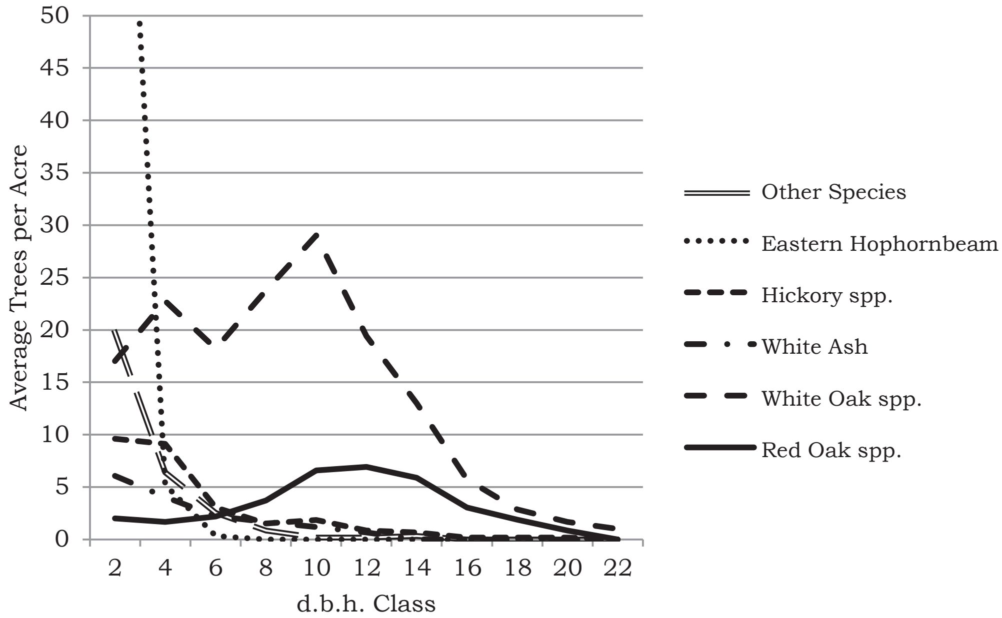

Figure 5.—Average trees per acre by diameter class for eastern hophornbeam, hickory species, white ash, white oak species, red oak species, and the “other species” category. The y-axis has been adjusted to illustrate species less abundant than eastern hophornbeam, which is most abundant in the 2- to 4-inch diameter class with a total of 92 trees per acre.

The diameter distribution (Fig. 5) indicated that oaks exhibited a more normal or bell-shaped distribution; white oak species were greatest in the 8- to 10-inch diameter class and red oak species were greatest in the 10- to 14-inch diameter class. Other species demonstrated a reverse-J distribution, including ironwood, the category “other species” (mainly elm, black cherry, and serviceberry), hickory, and white ash. Ironwood was the most abundant species in the 2- to 4-inch diameter class, reaching an average of 92 trees per acre in this class. In the overstory, ironwood stocking was significantly (P=0.03) greater on lower slope positions, regardless of aspect.

The large advance reproduction class (species >1.5 feet tall and <1.5 inches d.b.h.) was mostly made up of the category ”other species” consisting mainly of blackhaw (*Viburnum prunifolium* L.), redbud, serviceberry, and elm species followed by white ash and ironwood (Table 3). White oak advance reproduction was highly variable from site to site; on sites with below average amounts of white oak, ironwood or the category ”other species” make up most of the advance reproduction class with smaller amounts of white ash.

For the large advance reproduction, variation by location lacked clear trends; however, there were some differences by aspect and slope position for this class (Fig. 6). For example, white oak reproduction was greatest on exposed aspects and upper slope positions, the category “other species” was more abundant on lower slope positions, and white ash was greater on upper slope positions.

Table 3.—Average trees per acre (TPA) for the large advance reproduction class[a] for locations listed in order from south to north

Species group	Hungry Mother	Atlanta Wildlife	Hidden Hollow	Sugar Creek	Union Ridge	Rebel's Cove	Avg. TPA
Other spp.	3,087	759	982	1,943	395	1,579	1,457
White ash	405	1,427	1,984	1,164	516	962	1,076
Ironwood	881	587	374	1,134	1,579	911	911
White oak spp.	10	891	1,306	1,619	81	324	705
Blackhaw	506	972	263	121	182	71	353
Hickory spp.	0	91	617	0	20	51	130
Red oak spp.	40	20	46	30	30	10	29
Elm spp.	0	0	132	0	0	0	22
Total TPA	4,929	4,747	5,704	6,011	2,803	3,908	4,683

[a] Species >1.5 feet in height and <1.5 inches d.b.h.

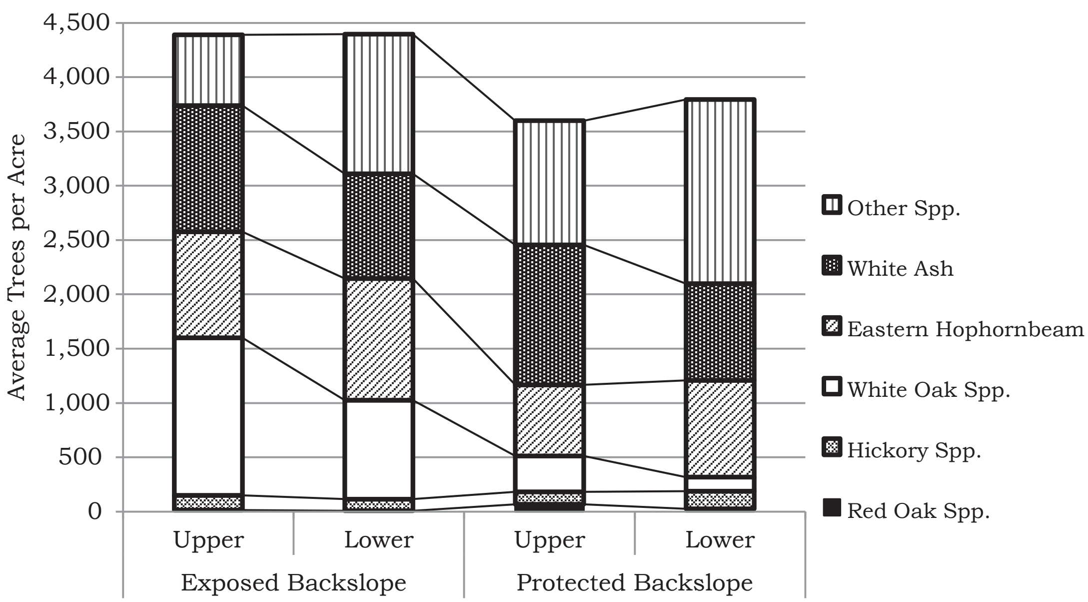

Figure 6.—Average trees per acre by geomorphic component for the large advance reproduction class (species greater than 1.5 feet in height and less than 1.5 inches d.b.h.).

DISCUSSION

The oak forests of the CRHES exhibit low to moderate productivity as indicated by site index values ranging from 51 to 62 feet across the region. These values are lower than oak site indices reported elsewhere in the Central Hardwoods Region. For example, oak site index in West Virginia ranges from 65 to 83 feet (Yawney 1964), and in southern Indiana ranges from 47 to 77 feet on slopes (Jose and Gillespie 1997). Even in the nutrient-poor and droughty soils of the Missouri Ozarks, site index values for oaks equals (54 to 66 feet (Hartung and Lloyd 1969) or exceeds (60 to 70 feet (Kabrick et al. 2004) those observed in the CRHES. This finding was surprising considering the relatively high nutrient and water supply capacity of the glacially derived soils of the CRHES (Table 1) compared to the highly weathered and droughty soils of the Ozark Highlands (Kabrick et al. 2008). This suggests that the low to moderate site productivity of our study region is likely due to factors other than to soil properties such as seasonal rainfall patterns or other factors related to climate. Undoubtedly, genetic degradation due to past management (i.e., potential high-grading) would affect site index values; however, detailed historical information was unknown. Between 2001 and 2005, average annual rainfall in the study area averaged 4 inches less than rainfall in the Missouri Ozarks (National Agricultural Statistics Service 2011). Moreover, regression analyses indicated that regional site index patterns were not related to differences in soil properties or other site factors.

Our analysis demonstrated that locally, geomorphic factors play an important role in governing site productivity because we found the range of average site index on different slope positions and aspects was as great as the average range among all sites across the CRHES. Correlations between aspect and slope gradient with site quality have been well documented (Brown 2007, Hannah 1968, Hartung and Lloyd 1969) and in general north- to east-facing slope aspects exhibit greater productivity than south- to west-facing slope aspects in the Northern Hemisphere (Johnson et al. 2009). Our results were consistent with these trends and indicated that the most productive sites in the CRHES are found on lower slope positions of protected aspects.

Topographic differences in site productivity in the CRHES were reflected in species composition. We found red oak stocking was greater on lower, north-facing slopes and white oak stocking was greater on upper, south-facing slopes. Northern red oak is reportedly more abundant in coves or lower north-facing slopes where water supply is generally greater than on other slopes (Johnson et al. 2009, Sander 1990) and white oak is reportedly much more broad in its distribution with respect to site factors (Rogers 1990). Oaks in the CRHES also exhibited classic bell-shaped diameter distributions as they typically do in mesic natural mixed-oak stands in the Central Hardwoods Region (Roach and Gingrich 1968, Schnur 1937). Commonly, more shade-tolerant species occupy smaller diameter size classes making up the tail of the reverse-J-shaped diameter distribution that is observed when all species are included (Johnson et al. 2009). This finding was in contrast to drier oak ecosystems such as those of northern Lower Michigan (Johnson 1992) or the Ozark Highlands (Loewenstein et al. 2000) where site conditions such as low nutrient status and water holding capacity (Kabrick et al. 2004) limit the number of shade-tolerant species in the understory allowing moderately tolerant white oaks to accumulate in the understory and develop a reverse-J distribution.

Despite their abundance in the present-day overstory, oaks may not be abundant in the future forests of the CRHES. Successful oak regeneration requires the accumulation of advance reproduction before recruitment following a canopy-removing disturbance (Johnson et al. 2009). In comparison to upper slope positions of exposed aspects, large advanced reproduction of white oak was less abundant on all other positions with the smallest amounts on lower slope positions of north-facing aspects. Before European settlement, fire was an important disturbance factor in the CRHES (Schroeder 1982). With about 50 percent of the area in prairie and an intricate pattern of prairie and forest (Schroeder 1982), it is likely that fire periodically spread to forested slopes of the CRHES. This fire likely favored the accumulation of oak seedlings by reducing the density of fire-sensitive oak competitors, positioning oaks to recruit into the overstory following larger, canopy-removing disturbances. Fire suppression, especially, since the early 20th century (Nowacki and Abrams 2008), has allowed shade-tolerant, fire-sensitive species to accumulate. Returning fire to these forests would likely reduce the density of fire-sensitive species and increase the density of oak advance reproduction and some of the forbs, legumes, sedges, and grasses characteristic of fire-dependent woodland ecosystems (Taft 2009).

In the absence of fire, it is unclear what species would eventually recruit into the forest overstory in this region following a canopy-removing disturbance. For example, of the two most abundant species in the advance reproduction layer, ironwood is not an overstory species and as such would not be a long-term competitor. Likewise, white ash is seldom abundant in the overstory of Central Hardwoods forests (Kabrick et al. 2004, Schlesinger 1990, Yaussy et al. 2003). In addition, white ash has an indeterminate future throughout North America because of the increasing spread of emerald ash borer (*Agrilus planipennis* Fairmaire), which may eventually extirpate ash species in the Central Hardwoods Region. Due to low quantities of oaks in the large advance reproduction and the limitations of oak regeneration from stump sprouting (Johnson et al. 2009), decreased oak stocking from current levels would be likely.

CONCLUSIONS

This study demonstrated that the geomorphic factors of aspect and slope position are important determinants of productivity, composition, and structure in the dissected glacial till plain forests of the CRHES. The role played by local geomorphic factors in vegetation-site relationships will remain an important consideration for refinements to the National Cooperative Soil Survey and other land classification systems, especially during the development of landform-scale management tools such as ESDs and ELTs. These geomorphic differences are also important considerations for cost-effective land management decisions. For example, in the CRHES, management efforts (e.g., thinning, prescribed fire) may be most needed on protected aspects and lower slope positions to promote oak accumulation in the understory. Additionally, results from this study have provided baseline data for understanding the present-day productivity, composition, and regeneration potential for land managers and landowners seeking critical information about forests in an otherwise under studied region of Missouri.

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