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Analysis of Forest Structure Among Management Types at Land Between the Lakes, Kentucky

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10 RH: Thompson and Gagnon • Vegetation Analysis of Oak Forest Management

11 **A Vegetation Analysis of Management Regimes that use Prescribed Fire in an Oak**
12 **Forest**

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17 **ABSTRACT** Fire is a dynamic disturbance that once created and maintained the oak
18 savannas and oak forests of the Southeast. These ecosystems maintain open forest
19 structures with herbaceous understories that provide significant habitat and food for
20 native game and non-game wildlife species. In the absence of fire, canopies close, and
21 fire-intolerant and shade-tolerant species begin to crowd the understory of traditionally
22 open oak stands in a process called mesophication. Our objective was to quantify the
23 vegetation on 20 sites in an oak forest that was subject to 4 different types of
24 management at Land Between the Lakes National Recreation Area. The management
25 types we studied included (1) areas not subject to any prescribed burning or thinning
26 methods, (2) grasslands, (3) areas burned within 6 months of the study, and (4) areas
27 burned more than 6 months prior to our study.

28 **KEYWORDS** fire ecology, forest management, Land Between the Lakes, Kentucky, oak
29 forest, prescribed fire, vegetation analysis.

30 Among the variety of forest disturbances in the South, fire has been one of the largest
31 influencing factors in the Southeast (Franklin 1994, Van Lear 2004, Knapp et al. 2009).
32 Oak forests and oak savannas are maintained through periodic fire from lightning and
33 anthropogenic means. Using historical data from Land Between the Lakes National
34 Recreation Area (LBL), Franklin (1994) observed that the lightning caused fire regime in
35 the area was complemented by Native Americans groups (Cherokee, Chickasaw,
36 Choctaw, Creek, Shawnee, and Yuchi) who used periodic burning to provide space for
37 wildlife grazing and movement (USFS 2004). For thousands of years Native Americans
38 and, later, European settlers used fire to promote open woodlands with herbaceous
39 understories (Johnson and Hale 2000, Van Lear 2004). Using fire scar data, Gueyette et
40 al. (2010) observed a mean fire return interval of 5.22 years for the area that is now LBL
41 from 1709-1944. The history of an oak dominated landscape at LBL is well understood
42 through historical accounts and scientific studies (Franklin 1994, USFS 2004, Gueyette et
43 al. 2010)

44 Forest structure within Southeastern oak savannas and open oak woodlands are
45 characterized by open canopies and herbaceous understories that need to be maintained
46 by periodic burning. This forest structure is what European settlers first experienced
47 (Abrams 1992, Franklin 1994), and that provides food and habitat for native plants and
48 wildlife (May 2002). In the absence of fire, ecosystems such as oak savannas and
49 woodlands will experience increased canopy closure with an increase in shade-tolerant
50 species such as Sugar Maple (*Acer saccharum*) and American Beech (*Fagus grandifolia*),

51 a decrease in a grassy understory, and a decrease in ground fuel that is conducive to
52 periodic burning (Nowacki and Abrams 2008, Knapp 2009, Ryan et al. 2015). Some of
53 the first changes in the landscape in LBL and the surrounding area were noticed in the
54 early 1800s as the Native Americans were pushed west. At this time, burning of prairies
55 ended and small trees and shrubs took over forest understories (USFS 2004). An era of
56 fire suppression in the early 1900s began to change the forest structure in the Southeast
57 (Ryan et al. 2013). The importance of fire on certain landscapes is being re-recognized,
58 but the seasons, timing, and intensity of fires is still not enough to replicate the fire
59 regime that once occurred across the Southeast. While oaks are still currently the
60 dominant species in many forests across the Southeast (Iverson et al. 2007), the
61 regeneration of oaks is being stifled by competition from shade-tolerant and fast-growing
62 pioneer species (Van Lear 2004, Iverson et al. 2007).

63 These changes in forest structure and species composition are part of a process
64 called “mesophication” (Nowacki and Abrams 2008). According to Nowacki and Abrams
65 (2008), mesophication occurs when increasingly cool, damp, and shaded conditions
66 create a less flammable fuel bed and improve conditions for mesophytic species while
67 creating deteriorating conditions for shade-intolerant, fire-adapted species.

68 Mesophication occurs in large portions of oak forests especially on mesic sites.
69 Mesophication is projected to occur more frequently in xeric uplands that oaks have
70 traditionally dominated (USFS 2004, Van Lear 2004, Iverson 2007). These changes have
71 significant impacts on the abundance of native plants, as well as insects and wildlife that
72 rely on native plants for food and for shelter (Abrams 1992, Peterson and Reich 2001,
73 May 2002, Hutchinson et al. 2005).

74 Differences in management strategies will influence forest structure, and
75 consequently, which plant and animal species are maintained in a forest. Over the past
76 100 years the use of fire as a method for management in the Southeast has shifted from
77 suppression due to negative public opinion and lack of resources, to a growing base of
78 knowledge and technology that supports prescribed burning as a method for increasing
79 the ecological and economic value of forests (Ryan et al. 2015, Franklin 1994). The
80 Southeast was one of the first regions to begin utilizing controlled burning as method to
81 increase ecological value of forests and encourage habitats beneficial to upland game
82 species (Johnson and Hale 2000). The objectives of forest management in the Southeast
83 have developed to include increasing abundance and connectivity in oak or pine savannas
84 and woodlands (Peterson and Reich 2001).

85 The techniques most frequently used by land managers in the Southeast to
86 promote open oak forests include prescribed burning and thinning (Van Lear 2004,
87 Iverson et al. 2007, Knapp 2009). According to Iverson et al. (2007) a combination of
88 techniques is necessary to maintain open, oak-dominated stands. Even when the
89 understory is burned, mesophication may still occur because the shade caused by a closed
90 canopy will favor maple saplings over oak saplings (Van Lear 2004, Nowacki and
91 Abrams 2008, Ryan et al. 2015). On the other hand, if the forest canopy is mechanically
92 thinned, the resulting increase in light may give oaks a competitive edge over mesophytic
93 species (Iverson et al. 2007, Ryan et al. 2015). Our study area, LBL, is one of the
94 management areas in the Southeast that has adopted prescribed burning and mechanical
95 thinning as a means to combat mesophication on mesic and xeric sites and increase the
96 sustainability of oak forests.

97 In 2004, LBL wrote a land and resource management plan that included
98 objectives for increasing oak grasslands and open oak woodlands (USFS 2004). These
99 objectives address the Continuous Forest Inventory (CFI) conducted in 1996, which
100 indicated an increase in maples and poplar trees and a decrease in oaks in LBL. The
101 decrease in oaks is due in part to impaired oak regeneration even on dry uplands where
102 oaks would naturally have a competitive advantage over mesophytic species (USFS
103 2004). The age and condition of the current oak population raises concern over the
104 sustainability of oak dominated forests in the area. The desired conditions in LBL include
105 having grasslands (> 10% canopy closure), open oak woodlands on upper slopes and
106 ridges (10-60% canopy closure), and open oak forests (60-80% canopy closure)
107 throughout the landscape (USFS 2004).

108 Maintaining canopy openness, an open midstory, and an herbaceous understory
109 requires periodic fire and other methods such as mechanical thinning (Abrams 1992,
110 Hutchinson et al. 2005, Iverson 2007). LBL intends to increase the use of varying levels
111 of prescribed fire and mechanical thinning to create a heterogenic landscape with stands
112 of varying ages and canopy openness (USFS 2004). Prescribed fire will be used to open
113 the canopy and stimulate herbaceous understory growth. Tree thinning will be used in
114 dense forests to stimulate the growth of young trees to increase the diversity in age
115 structures (USFS 2004). Increasing the amount of sunlight that reaches the forest floor in
116 stands that are subject to thinning and burning will allow for an increase in an herbaceous
117 understory that is important for maintaining healthy populations of native species of
118 plants and wildlife (May 2002, USFS 2004).

119 Currently, there are some areas of LBL that are subject to prescribed burning

120 while other areas are unmanaged. In order to better understand the forest structures that
121 these contrasting management strategies create, we will study 20 sites throughout LBL
122 that have been subject to 4 different management regimes. Within each of these
123 management regimes we will study the differences in forest structure at each forest
124 stratum. By quantifying the vegetation in unmanaged areas, grasslands, areas that have
125 been burned greater than 6 months prior to the study, and areas burned less than 6 months
126 prior to the study we will be able to better understand the effect that fire has on an oak
127 forest structure.

128 **STUDY AREA**

129 Land Between the Lakes National Recreation Area has been under the jurisdiction of the
130 U.S. Forest Service since 1999. Throughout the 18th and 19th centuries our study area was
131 known as Between the Rivers and was dominated by agriculture, iron, and logging
132 industries that all led to a substantial extraction of the natural resources (Franklin 1994,
133 USFS 2004). Throughout the 20th century several government agencies managed LBL
134 and in 1964 the Tennessee Valley Authority assumed total authority of the land until it
135 was transferred to USFS in 1999.

136 LBL is a 69,000 ha peninsular land mass located between 36°36'45" and
137 37°02'45" N latitude, and 87°52'25" and 88°13'35" W longitude, all within Lyon
138 County, KY, Trigg County, KY, and Stewart County, TN. The area ranges from 6-13 km
139 wide, with Lake Barkley on the east and Kentucky Lake on the west, and is 64 km long
140 (Franklin et al. 1993). LBL receives a mean precipitation of 1,210mm annually and the
141 average temperatures are 3° C in the winter and 28° C in the summer (Franklin et al.

142 1993), with a total of approximately 195 growing days. The area lies within the
143 Mississippi Loess Valley ecoregion of Kentucky and the Western Highland Rim
144 subsection of the Interior Low Plateau Province physiographic region. According to
145 Franklin (1993), most of the area consists of highly dissected uplands, with bedrock of
146 limestone and loess (Chester 1993).

147 According to the most recent USFS management plan, LBL is 92% forested and
148 predominantly covered by mature oak forests (USFS 2004). Küchler (1964) maps the
149 potential vegetation for the area as oak-hickory. About 6% of the land cover is open land
150 consisting of cropland, wildlife plantings, hayfields, maintenance openings, ecological
151 restoration openings, old fields, and roads. Little recent data was available that detailed
152 the species composition, but Chester (1993) summarizes that ridges and upper slopes are
153 dominated by *Quercus* spp. such as scarlet, blackjack, chestnut, post, and black oaks. The
154 *Carya* spp. on these slopes include pignut, sand, and mockernut hickories. Highly mesic
155 slopes contain sugar maple, bitternut hickory, American beech, tulip tree, black gum, and
156 wild cherry. To summarize, Chester (1993) found that the major woody genera in LBL
157 are *Quercus* and *Carya*, with *Ulmus* and *Acer* “contributing significantly”.

158 **METHODS**

159 Initial data for the analysis were collected from May-August 2014. We used remote
160 sensing data to select 20 sites representing 4 vegetation types within 4 USFS
161 management overlays of LBL. We selected the sites based on vegetation from the remote
162 sensing data followed by ground truthing. We defined “unmanaged” as forest that had no
163 management, such as cutting or burning, be applied to that area. “Grasslands” were
164 defined as areas that were dominated by native species of grasses and that had little or no

165 trees on the landscape. Finally, we separated the areas being managed with prescribed
166 burning into two categories: “recently burned” referred to areas that had been burned
167 within 6 months of collecting data and “previously burned” referred to areas that had
168 been burned longer than 6 months prior to collecting data.

169 At each of the 20 locations, we collected data for the overstory, midstory,
170 understory, and the ground level at 5 points representing each cardinal direction and a
171 central point. At the overstory level, we used a densiometer to measure canopy openness.
172 We then measured the number of live stems less than 10 cm diameter at breast height
173 (DBH) in 16 m² plots at the midstory level. For the understory, we measured the number
174 of bunchgrass tussocks/m² by counting the number of bunchgrass tussocks within m²
175 quadrats. Finally, we measured the percentage of ground covered by leaf litter using
176 quadrats with 10 bands running lengthwise and across, counting the cross sections for
177 presence or absence of leaf litter.

178 After collecting data from across LBL, we wanted to see if there were differences
179 in vegetation structures subject to different management regimes. Using the forest
180 structure data, we tested the analysis of variance of a fixed effect model including the
181 four management regimes: unmanaged, grassland, recently burned, and previously
182 burned. The response variables for each included the percent canopy openness, the
183 number of living stems in the midstory, the number of bunchgrass tussocks in the
184 understory, and the coverage of leaf litter on the ground. Before running tests, we applied
185 a logistic transformation to the overstory and the ground level data since these data were
186 in percent form. We applied a logarithmic transformation to the midstory and understory
187 data (which were counts) to adjust for skew.

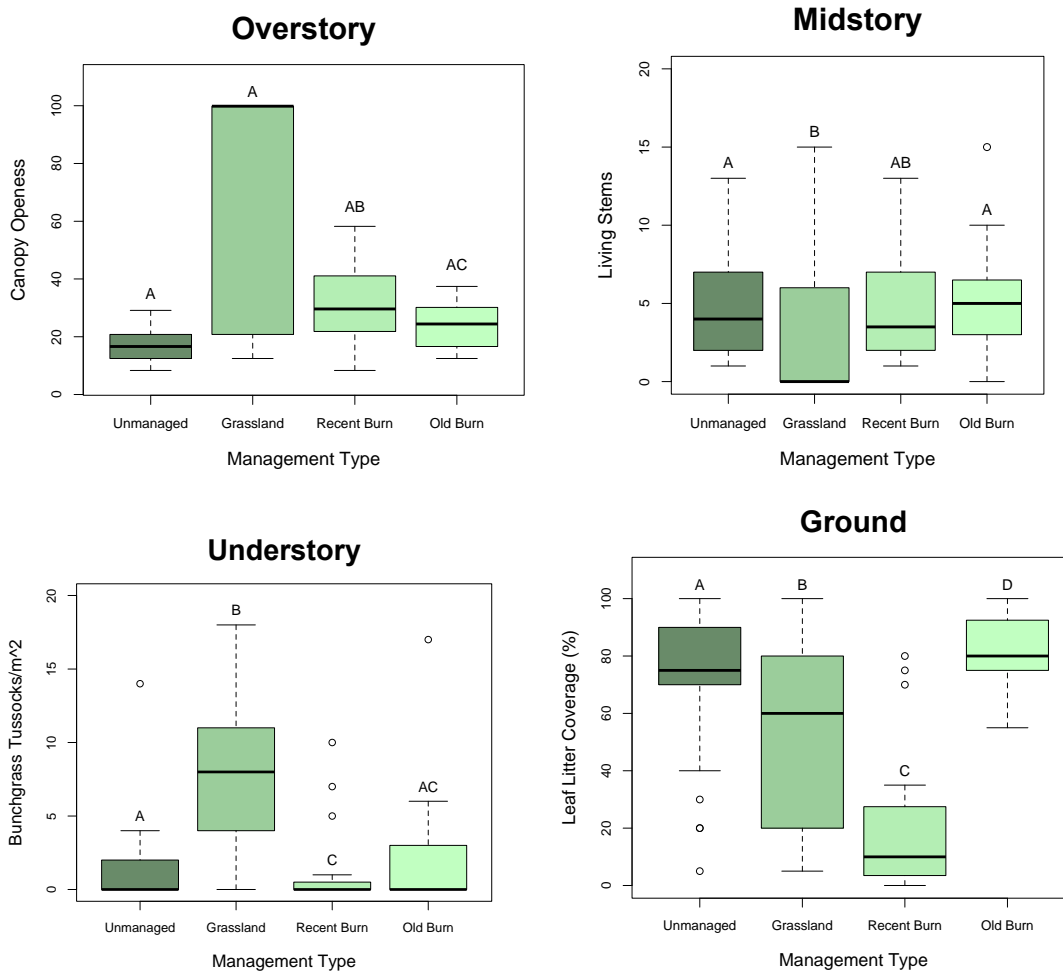
188 We first tested the data for normality using a Shapiro-Wilk test and quantile-
189 quantile plots (QQP). We then used an analysis of variance (ANOVA) for each forest
190 strata to test for any significant differences between the means of the 4 vegetation types.
191 After this, we used Tukey's post-hoc significance test to check for individual differences
192 between each of the vegetation types within forest strata. For all statistical analysis we
193 used R version 3.2.2 using the aov function in the base package and the lsmeans function
194 in the lsmeans package for the post-hoc analyses.

195 **RESULTS**

196 Overall, the least amount of variation among the management types was found in the
197 midstory, and the greatest variation was found on the ground. We also found that areas
198 that had not been burned within 6 months of the study were most similar to unmanaged
199 areas for all forest strata except the overstory.

200 Canopy openness averaged 70.6 ± 3.82 % in grasslands, 17.3 ± 0.53 % in
201 unmanaged areas, 30.55 ± 0.02 % in recently burned areas, and 23.8 ± 0.83 % in
202 previously burned areas. The average number of living stems < 10 cm DBH in the
203 midstory were 3.2 ± 0.44 in the grasslands, 4.8 ± 0.34 in unmanaged areas, 4.7 ± 0.35 in
204 recently burned areas, and 5.5 ± 0.34 in previously burned areas. We found an average of
205 7.9 ± 0.23 bunchgrass tussocks per square meter in grasslands, 1.2 ± 0.6 in unmanaged
206 areas, 2.5 ± 0.55 in recently burned areas, and 1.9 ± 0.61 in previously burned areas. On
207 the ground, we found an average of 52.8 ± 3.46 % coverage by leaf litter in grassland
208 areas, 72 ± 2.68 % in unmanaged areas, 21.4 ± 2.56 % in recently burned, and $82.4 \pm$
209 1.27 % in areas not recently burned.

210 The results from the ANOVAs revealed significant variations among sample
 211 means for the overstory, understory, and ground level. Our p-values were <.00001 for the
 212 overstory, 0.163 for the midstory, <.00001 for the understory, and <.00001 for the
 213 ground. Tukey’s post hoc revealed significant differences among many of the vegetation
 214 types at each forest strata (Figure 1).



215

216
 217 Figure 1. Boxplots showing the means and standard errors of 4 management types at each
 218 forest strata. Letters designate differences between management types according to post-
 219 hoc tests.

220
 221 **DISCUSSION**

222 Our analysis showed that burning an area may initially lead to changes in the forest floor
 223 but fire will have little lasting impact on the forest structure, especially in the midstory

224 and canopy. In the midstory, we only observed significant differences between grasslands
225 and unmanaged areas, and grasslands and previously burned areas, showing that fire has
226 little initial impact on the midstory density. Along with this, there were differences
227 between the canopy openness of all forest strata; however, the smallest difference was
228 between the unmanaged and previously burned areas. Again, this suggests that fire has
229 little initial impact on structure in the short run. The idea that few low intensity burns will
230 fail to have a lasting impact on the forest structure is not unique to our study. Several
231 other sources have documented field studies that resulted in changes in the forest
232 structure only when several years of repeated burning along with thinning methods were
233 applied to an area (Van Lear 2004, Hutchinson et al. 2005, Iverson et al. 2007, Ryan et al.
234 2013).

235 A study similar to ours conducted on the Cumberland Plateau in Kentucky looked
236 at the effect of stand structure in burned and fire excluded oak stands (Blankenship and
237 Arthur 2006). Blankenship and Arthur (2006) found that repeated burning reduced
238 midstory stem density by 91%, whereas our study showed no significant difference in the
239 average number of stems between old burns and unburned areas. Our study areas had not
240 been subjected to as many burns as other studies, showing the difference that repeated
241 burning makes for an area.

242 It is important to note than in the Blankenship and Arthur study, mesophytic
243 species such as red maple (*Acer saccharum*) resprouted vigorously after the first three
244 fires. Red maples and other shade tolerant species are capable of germinating through
245 dense leaf litter whereas most species of *Quercus* must have direct contact with mineral
246 soil. Because of this, repeated burning over several years is necessary to slowly reduce

247 the density of a mesophytic midstory. Otherwise, a moist, dense forest floor will
248 accumulate and will create undesirable conditions for oak regeneration. Iverson et al.
249 (2008) found that by year 7 in their study on an oak forest in Ohio, oak seedlings
250 numbered 3 x more in areas that were subject to thinning and burning than the control
251 sites.

252 What the Iverson et al. (2008) study and other studies have found is that repeated
253 burning in conjunction with other methods is necessary in order to maintain oak
254 dominated forests (Van Lear 2004, Hutchinson et al. 2005, Iverson et al. 2007, Ryan et
255 al. 2013). Van Lear (2004) points out that with long-term fire exclusion, the fuel bed
256 becomes increasingly wet which, coupled with colder temperatures due to a closed
257 canopy, reduces the flammability to such a degree that beginning a new fire regime
258 would be extremely difficult. Ryan et al. (2013) emphasizes that an abundance of fine,
259 dry fuels that are continuous are required for natural fires to occur in an ecosystem, and
260 that wet forests may accumulate fuel bed continuity but are rarely dry enough to burn.

261 Much of the Southeast, including our study area, has historically been a fire-
262 adapted landscape (Küchler 1964, Guyette et al. 2010, Ryan et al. 2013). Fire suppression
263 in these areas leads to mesophication: increasingly cool, damp, and shaded conditions
264 that create a less flammable fuel bed that improves conditions for mesophytic species
265 while causing deteriorating conditions for shade intolerant species. The repercussions of
266 this include a decreased fuel bed and a decrease in herbaceous species at the understory,
267 along with the implications that this decrease in plant diversity has on wildlife species
268 (May 2002, Ryan et al. 2013). While the mixed oak forest of LBL naturally exhibits
269 mesophytic characteristics in lowlands and near water sources, the encroachment of

270 mesophytic species into areas that are naturally oak dominated (ridges and east facing
271 slopes with poor soil) has been observed in many historically oak dominated areas
272 (Iverson et al. 2007, Nowacki and Abrams 2008).

273 Overall, our analysis of the vegetation at LBL exhibited patterns of mesophication
274 and showed that fire only creates initial impacts on the forest floor and understory. Our
275 findings are similar to that of other studies on oak forests in the Southeast and Midwest.
276 While LBL has objectives to increase the amount of open oak forest in their area, our
277 studies show that they will need to increase the amount of thinning and prescribed fire in
278 areas that are becoming increasingly mesophytic in order to meet these objectives.

279 **MANAGEMENT IMPLICATIONS**

280 In order to maintain oak dominated forests, forest managers need to strongly consider
281 using periodic burning accompanied by other thinning methods. Prescribed burns will
282 decrease the amount of moist leaf litter and the number of mesophytic seedlings. The
283 addition of thinning methods will ensure that shade intolerant species such as several
284 *Quercus* and *Carya* species will be able to compete in the understory. Over time, these
285 methods will reduce the density of the midstory, allowing more light to reach the
286 understory. By maintaining open oak forests, areas such as LBL could resemble the
287 historic fire-adapted landscapes of the Southeast and support greater species diversity of
288 herbaceous and woody plants along with endangered and game wildlife species.

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