DOI: 10.3195/ejejfs.958651

Research Paper – Araştırma Makalesi

Eurasian Journal of Forest Science

2021 9(3): 151-159

http://dergipark.org.tr/en/pub/ejejfs

Spatial patterns of trees in a Longleaf Pine (*Pinus palustris* Mill.) dominated stand: A case study

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Abstract

Recent studies have interested in determining optimal conditions for regeneration and restoration of longleaf pine (*Pinus palustris* Mill.). Spatial patterns of trees in stands can reveal successional status of trees which can also be used for restoration purposes. Studies regarding the spatial characteristics of trees in longleaf pine stands has been limited, thus, in this study, spatial patterns of trees were examined in a longleaf pine dominated stand in Alabama, USA. All trees larger than 5 cm in diameter at breast height (dbh) were stem-mapped, and twenty-four tree species were recorded within the study site. Point pattern analyses was conducted to monitor spatial patterns of the species. A clustered distribution pattern of trees with a short mean distance was determined. Trees represented a clumped pattern at distances smaller than 20 m, while a tendency from a clustering pattern to a random pattern was observed at distances between 26 and 65 m.

Keywords: longleaf pine, point pattern, restoration, spatial distribution

Uzun ibreli çam (*Pinus palustris* Mill.) baskın bir meşcerede ağaçların mekansal dağılımı

Özet

Uzun ibreli çamın (*Pinus palustris* Mill.) gençleştirilmesi ve restorasyonu için en uygun koşulların belirlenmesi üzerine olan ilgi son zamanlarda yapılan çalışmalarda artmıştır. Ağaçların mekansal dağılımının belirlenmesi, onların gelişme durumunu ortaya çıkarabilir, ve bu bulgular restorasyon amacıyla da kullanılabilir. Uzun ibreli çam meşcerelerinde ağaçların mekansal özellikleri ile ilgili çalışmalar sınırlı kalmıştır. Bu çalışmada, ABD Alabama'da uzun ibreli çamın baskın olduğu bir meşcerede ağaçların mekansal desenleri incelenmiştir. Göğüs yüksekliğinde çapı (dbh) 5 cm'den büyük olan olan tüm ağaçların gövde-dağılım haritası çıkartılmış ve çalışma sahasında yirmi dört ağaç türü kaydedilmiştir. Çalışma alanında ağaçlarının mekansal desenlerini izlemek için nokta desen analizleri yapılmıştır. Kısa bir ortalama mesafeye sahip olarak ağaçların kümelenmiş bir dağılım modeli gösterdiği belirlenmiştir. Ağaçların, 20 m'den daha küçük mesafelerde kümelenmiş bir düzeni temsil ettikleri, 26 ila 65 m arasındaki mesafelerde ise kümelenme düzeninden rastgele bir düzene doğru bir eğilim gösterdikleri gözlemlenmiştir.

Anahtar kelimeler: mekansal dağılım, nokta desen, restorasyon, uzun ibreli çam

1. Introduction

Development of forest ecosystems is usually associated with mortality and growth of regeneration and trees (Zanini et al., 2006). Vertical and horizontal stand structure can influence mortality and growth of individuals in forests. Tree size and competition among trees are other important variables that influence tree growth and mortality (Bhandari, 2021). Spatial patterns of trees have been useful for prediction of stand dynamics, analyzing canopy gaps, maintenance of biodiversity, examining regeneration, and interpretation on ecological mechanisms (Condit et al., 1992; Busing, 1996; Wiegand et al., 2000; Kokkila et al., 2002; Fang, 2005). This is one of the most commonly used methods to estimate role of competition between forest trees (Szwagrzyk and Czerwczak, 1993). Spatial distribution patterns vary with successional stages of a stand (Greig-Smith, 1952).

Horizontal pattern of trees has been widely used to identify stand structure. It is commonly defined by point pattern analyses (Ripley, 1977; Fortin and Dale, 2005). Tree species can be randomly distributed, clustered or regularly distributed in varying degrees. Spatial patterns of trees can be shaped due to neighboring interactions among trees, density-dependent tree mortality, as well as canopy disturbances (Szwagrzyk and Czerwczak, 1993). The neighboring interaction among trees can be both positive and negative (Liu et al., 2020). Moreover, these patterns for a given tree species may vary with site characteristics including elevation, slope, aspect etc. (Armesto et al., 1986).

Longleaf pine (*Pinus palustris* Mill.) ecosystems, which provide high biodiversity, are considered important in the southern USA because of the species' extensive natural distribution area. The exploitation of longleaf forests began in the early 1700's, and wide areas of the species were cleared (Outcalt, 2000). These insensible cuttings resulted in loss of large longleaf areas to agriculture or to dominance by other tree species such as loblolly pine (*Pinus taeda* L.). The precious longleaf pine ecosystems are currently considered ecosystems at high risk in the USA (Frost, 2006). Concern on conservation of longleaf pine ecosystems has recently increased due to its economic, ecological and social values. Consequently, there has been a growing interest in determining optimal conditions for regeneration and restoration of longleaf pine forests (Brockway and Outcalt, 2000; Avery et al., 2004).

Given the importance of longleaf pine ecosystems, a thorough understanding of stand dynamics of the species seems to be needed for its restoration. Research on the spatial patterns of trees in longleaf pine forests has been limited (Platt et al., 1988; Rathbun and Cressie 1994). Spatial patterns of trees would give many ideas on the stand dynamics of longleaf pine forests. Moreover, analysis of spatial patterns would help clarify main processes of species diversity. Thus, the main purpose of this study was to determine the horizontal distribution pattern of trees in a longleaf pine dominated stand. Mapping of all tree species was also aimed using standard procedures for stem-mapping of trees within the study stand.

2. Materials and Methods

2.1. Study Site

This study was conducted in a longleaf pine dominated stand, located in Tuskegee, AL, USA (Figure 1). The study area is mostly occupied by longleaf pine on the uplands and a mixture of hardwoods and loblolly pine in the stream bottoms. Many of the stands within the study area are overstocked, and have over-developed hardwood midstories that potentially hinder natural regeneration and diminish normal stand dynamics. Within the study site, the terrain ranges from moderately sloping to nearly level. Soils on the uplands are mostly deep, and well-drained sands. Average total annual precipitation is 135 mm. The warmest month is July (33°C), while the month with the lowest average high temperature is January 12.5°C.

Figure 1: Location of study area.

2.2. Data Collection and Analyses

A permanent rectangular study plot with an area of 3.22 ha was installed within the study stand. The stand was not treated for a prolonged time. All trees within the study plot was stem-mapped using standard procedures (Larsary et al. 2018). Within the study plot, first, a reference point was located, and its coordinates were recorded using a hand GPS (Moeur, 1993). Then, distances between the reference point and trees, which were visible from the reference point, were measured using a laser device. In addition, the azimuth degrees of trees from the reference point was also recorded using a compass (Chokkalingam and White, 2001). Next, another reference point was installed and same procedure was followed until all trees within the plot were marked. In total, twelve reference points were installed for stem-mapping. The coordinates of each tree was calculated using the coordinates of the reference points, and the distances and azimuth values from the reference points.

The dbh (cm) of all trees larger than 5 cm was measured within the plot. Tree species of all individual was also recorded (Table 1). In total, 1574 trees were measured and recorded within the plot. Basal area (BA) of the study plot was 20.2 m^2 per ha (Table 1), while the average number of trees per ha was 490 within the study plot.

Coordinates of measured trees were added to ArcMap software, and stem-mapping of trees was created and visualized. Average Nearest Neighbor analysis was used to calculate the average nearest neighbor distance of trees in ArcMap. Moreover, in order to see whether the point pattern was clustered, random or dispersed, Ripley's k-function was utilized in ArcMap. Visual assessment of the spatial distribution pattern of trees was also conducted and interpreted using ArcMap. Twenty-four tree species were examined within the plot (Table 1). However, following longleaf pine, only loblolly pine significantly contributed to the total BA within the plot since contribution of other species was negligible (Table 1).

Table 1: Tree species and their contribution to BA monitored within the study plot.

Species	Latin names	BA (m^2/ha)	% BA
American Elm	*Ulmus americana L.*	0.55	0.84
Ash	*Fraxinus spp.*	0.61	0.93
Black Cherry	*Prunus serotina*	0.01	0.02
Black Oak	*Quercus velutina)*	0.02	0.03
Black gum	*Nyssa sylvatica*	0.24	0.37
Blackjack Oak	*Quercus marilandica*	1.02	1.55
Bluejack Oak	*Quercus incana*	0.09	0.14
Bur Oak	*Quercus macrocarpa*	0.01	0.01
Dogwood	*Cornus florida*	0.38	0.58
Hickory	*Carya spp.*	0.30	0.46
Loblolly Pine	*Pinus taeda*	11.5	17.6
Longleaf Pine	*Pinus palustris*	47.4	72.1
Persimmon	*Diospyros virginiana*	0.21	0.32
Pin Oak	*Quercus palustris*	0.03	0.05
Post Oak	*Quercus stellata*	0.92	1.40
Red Maple	*Acer rubrum*	0.47	0.72
Sassafras	*Sassafras albidum*	0.01	0.02
Shortleaf Pine	*Pinus echinata*	0.08	0.12
Southern Red Oak	*Quercus falcata*	0.56	0.85
Sweetgum	*Liquidambar styraciflua*	0.42	0.64
Turkey Oak	*Quercus laevis*	0.27	0.41
Water Oak	*Quercus nigra*	0.12	0.18
White Oak	*Quercus alba*	0.22	0.33
Yellow Poplar	*Liriodendron tulipifera*	0.23	0.35
		65.7	100

Diameter distribution of main tree species (i.e., longleaf and loblolly pines) was shown in Figure 2. Loblolly trees presented a normal distribution which is typical of even-aged stands. It is possible that the loblolly trees may be from same cohort. On the other hand, the diameter pattern of longleaf pine trees was close to uneven-aged stand structure.

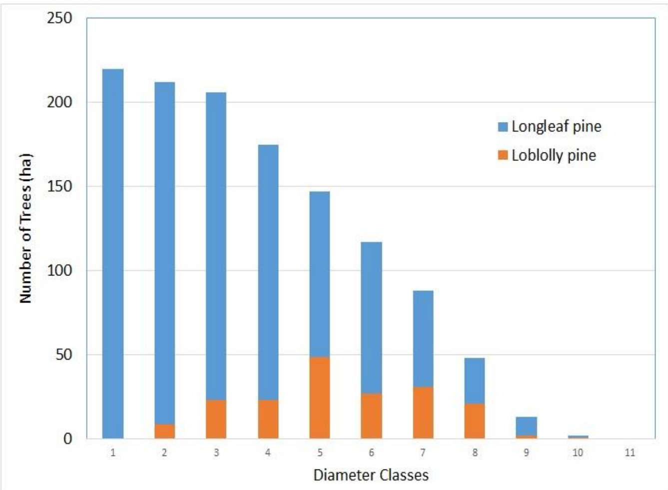

Figure 2: Tree diameter distribution of the study plot.

3. Results and Discussion

The observed mean distance, which means how far each trees is from the next on average, was 2.20 m. The expected mean distance based on a random distribution throughout the sampling area was 2.26 m between each tree. Because the nearest neighbor ratio is less than 1 (Table 2), the distribution of the trees was considered clustered. Map of point patterns attained following stem mapping indicated that there were clustering of trees within the study plot (Figure 3). Moreover, canopy openings were also apparent in stem-map.

Table 2: Average Nearest Neighbor Analysis Summary.

Parameters	Values
Observed Mean Distance (m)	2.20
Expected Mean Distance(m)	2.26
Nearest Neighbor Ratio	0.97
z-score	-1.94

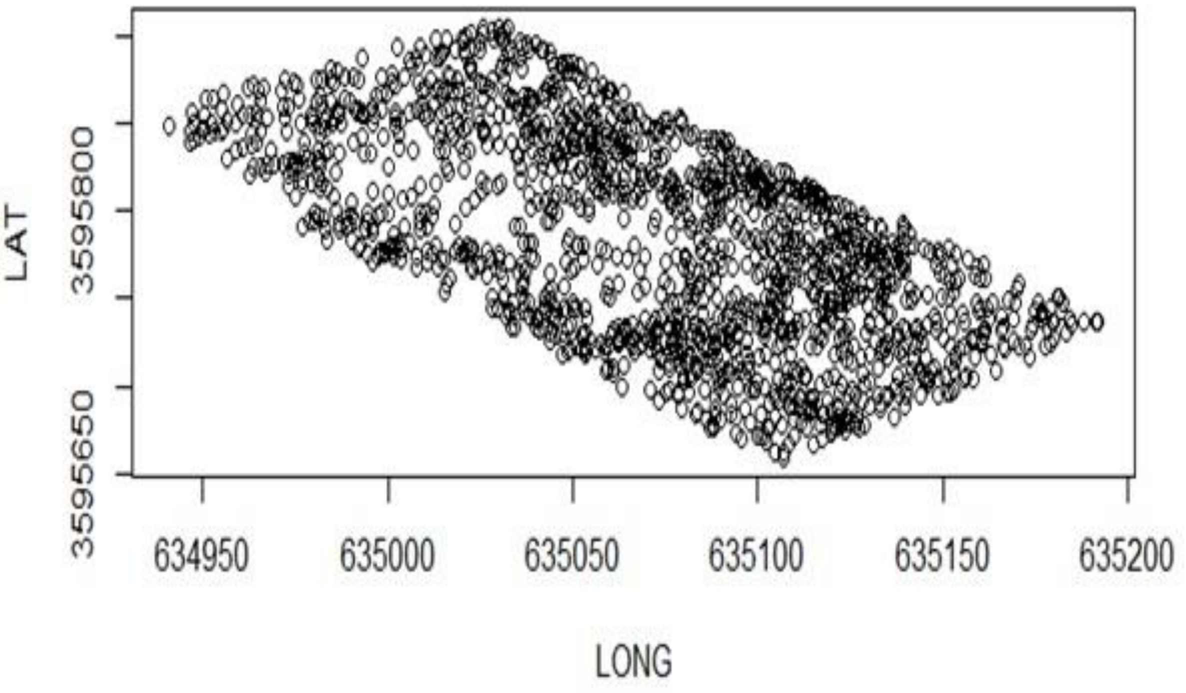

Figure 3: Map of point patterns attained following stem mapping.

The short distances among trees reveal the existence of mainly small forest gaps. Bianchi et al. (2021) examined spatial patterns of Norway spruce (*Picea abies* L.), and stated that small mean distances between trees can be associated with smaller canopy gaps. The analyses of this study indicated a tendency from a clustering pattern to a random pattern at distances greater than 26 m. Being consistent with our findings, previous researches showed that trends towards random pattern are usually common with increasing point distances (Szwagrzyk and Czerwczak, 1993).

When using Ripley's analysis, if the observed k-value is greater than the expected for a given distance, the distribution is considered more clumped than a random distribution at that distance. Thus, trees represented a clustered pattern at distances smaller than 26 m (Table 3). On the other hand, the smaller observed k-value compared to the expected k-value indicated a tendency from a clustering pattern to a random pattern at distances between 26 and 65 m (Table 3). A larger observed k-value than the upper confidence envelope value suggested that the spatial clustering for that distance was statistically significant. The observed k-value in our analysis was above the upper confidence envelope value meaning that it was not occurring based on a random chance alone (Figure 4).

Table 3: Multi-Distance Spatial Clustering k-Function Summary

Distance	L(d)	Difference	Min L(d)	Max L(d)
6,54	7,24	0,71	6,32	6,53
13,08	13,98	0,91	12,48	12,86
19,61	20,24	0,62	18,38	18,96
26,15	26,12	-0,03	24,05	24,79
32,69	31,72	-0,97	29,53	30,42
39,23	36,99	-2,24	34,71	35,84
45,77	41,97	-3,80	39,64	40,99
52,30	46,67	-5,64	44,44	45,86
58,84	51,23	-7,61	49,01	50,52
65,38	55,57	-9,81	53,30	54,97

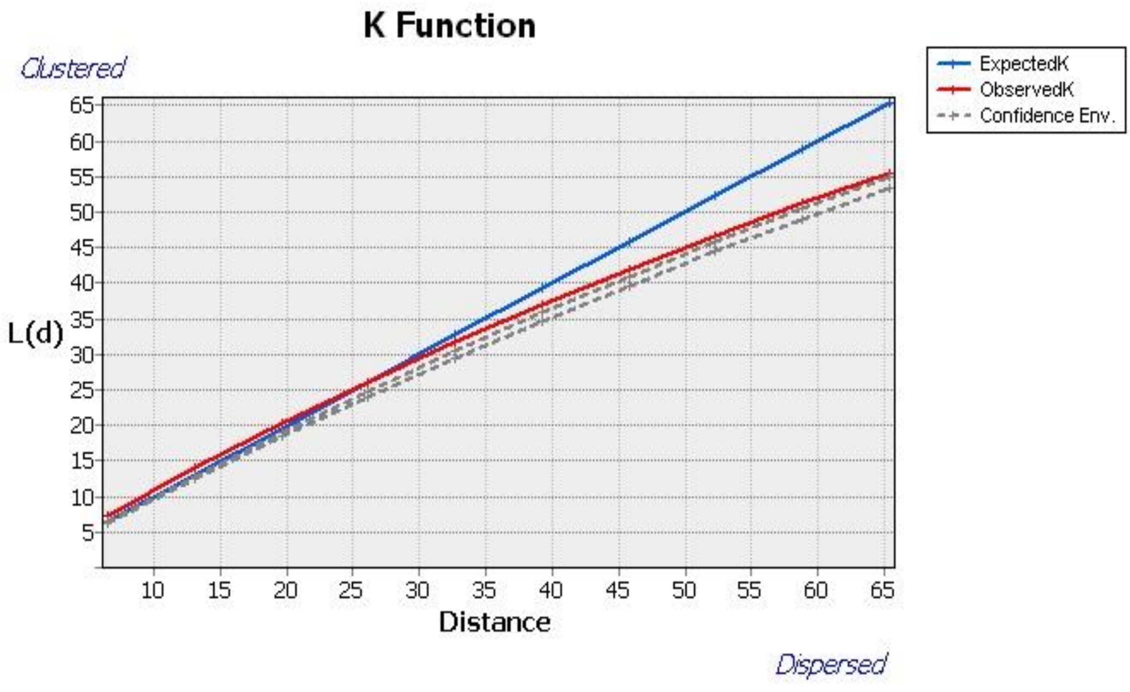

Figure 4: K-function of the point pattern analysis.

Canopy gaps can further create clustered spatial patterns of trees (Stewart, 1989). Relatively larger longleaf pine trees near and around the canopy gaps would suggest that these gaps may have formed by death of individual large trees. This type of canopy gaps are usually results of wind-throws, insect damages, diseases, lightning etc. (Engstorm et al., 2001), because longleaf pine usually exists in an environment that is subject to frequent occurrence of these disturbances (Guldin, 2006). The species can occupy growing space created after one or several mature trees are killed by lightning strike, insects,

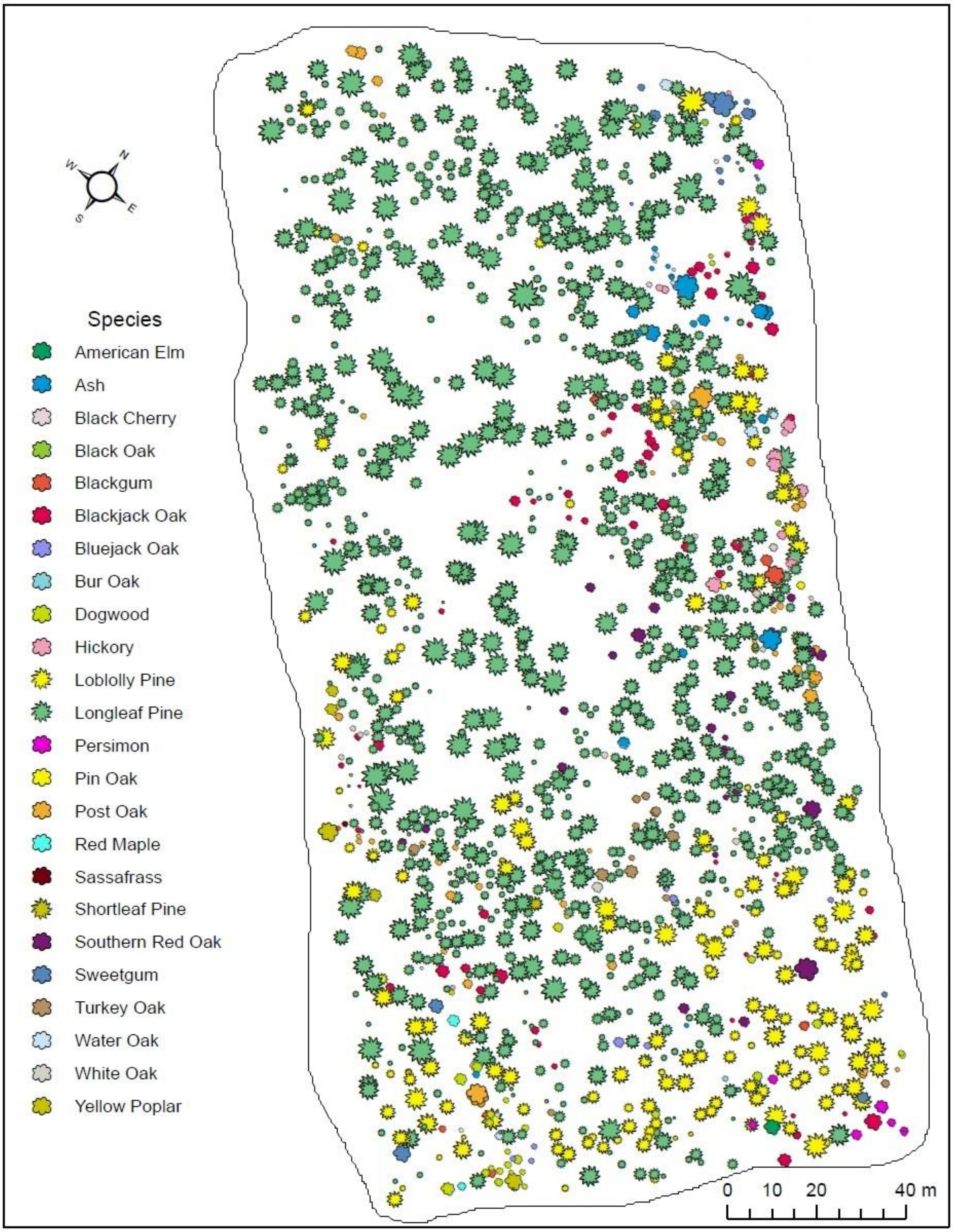

Figure 5: Stem-mapped study plot. Size of the points represent dbh of the trees.

diseases or storms (Wahlenberg 1946). Small canopy gaps can also be due to competition of large trees for belowground resources (Palik et al., 1997; Piao et al., 2013).

Figure 5 shows the spatial distribution of trees by species, and diameter size. Longleaf pine trees were clustered and occupied most of the study plot, while bottom part of the plot mostly had clustering of loblolly pine trees (Figure 5). Average dbh of longleaf pine trees was 22.7 cm ranging from 5.1 to 54.6 cm, while dbh of loblolly pine trees ranged from 7.6 to 51.1 cm with an average of 26.7 cm. Canopy openings were present where longleaf pine was dominant within the plot (Figure 5). It should be noted that, although not mapped or measured, high density of longleaf pine regeneration was monitored within the canopy gaps. Secondary species were mostly small size ranging from 5 to 39.9 cm with an average of 13.4 cm in dbh. Most of these species were more shade-tolerant than longleaf and loblolly pine, thus, they seemed to be present where tree densities were relatively higher (Figure 5). Stem-mapping also show that relatively larger longleaf pine trees were near and around the canopy gaps. Moreover, smaller size longleaf pine trees seemed to be both open-grown, as well as growing near and around the large ones (Figure 5).

Longleaf pine is known to be a shade intolerant species. Therefore, the high density of longleaf pine regeneration within canopy caps can be associated with the light and warmth requirements of longleaf pine regeneration (McGuire et al., 2001; Guldin, 2006). A new opened space is usually colonized by juveniles because competition for light and other nutrients with overstory trees is usually decreased when a canopy opening is formed (Avery et al., 2004). The colonization of longleaf pine juveniles within canopy gaps may result in clumps of trees at ensuing stages. Secondary species were mostly observed in eastern part of the plot where longleaf pine trees were mostly in small size. This can be attributed to decreasing prescribed fire intensity near small size longleaf pine trees, because the litter accumulation in close proximity to large trees is usually higher, which result in higher mortality of other species (Avery et al., 2004).

Acknowledgments: Author would like to thank Chase Seals for his help during the field work.

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Submitted: 28.06.2021 Accepted: 29.11.2021