COMPOSITION OF THE WOODY PLANT UNDERSTORY OF PLATEAU LIVE OAK (*Quercus virginiana* var. *fusiformis*) CLUSTERS IN A CENTRAL TEXAS SAVANNA

THESIS

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ABSTRACT

COMPOSITION OF THE WOODY PLANT UNDERSTORY OF PLATEAU LIVE OAK (*Quercus virginiana* var. *fusiformis*) CLUSTERS IN A CENTRAL TEXAS SAVANNA

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May 1999

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Plateau live oak is thought to act as a nurse plant to other woody species on the Edwards Plateau of central Texas; however, little is known of the nature, extent and duration of this facilitation. In this study, a comprehensive assessment of the composition and abundance of understory woody plants in oak clusters was undertaken to test the hypotheses that, 1) asymmetry exists in the woody plant understory composition and abundance around the live oak, which correspond to asymmetries in microclimate beneath oaks and, 2) Ashe juniper acts to competitively exclude other co-occurring woody plants from the cluster such that the abundance of Ashe juniper is inversely related to the abundance of other understory species. Woody species composition and abundance in the understory of twenty live oak clusters in five distinct landscapes

(pastures) at the SWT Freeman Ranch was determined in each of 4 quarters (NE, NW, SE, and SW) beneath the live oak nurse tree. The central live oaks in these clusters ranged in size from 37.4–93.7 cm dbh, 10.417.9 m in canopy diameter, 8.2–14.0 m^2 canopy area and 6.1–12.5 m maximum height. The number of woody species in the understory of these clusters ranged from 5 to 11 and the most dominant species included *Juniperus ashei*, *Celtis laevigata*, *Diospyros texana*, and *Ulmus crassifolia*. The number of individual plants ranged from 46–267 individuals/cluster. In general, there were significantly ($P < 0.05$) more woody plants in the northern half of the clusters than southern halves and densities were greatest in the northwest quarter. Plants in the north sides of clusters were also, generally, larger in size than those in the southern half of the clusters. The abundance of individual species, however, varied about the oak cluster. In particular, *J. ashei* was found to be most abundant and individuals were larger in the north side of clusters while *C. laevigata* was most abundant in the southern half of clusters. Despite their abundance and size, no inverse relationship was found between *J. ashei* abundance and that of other woody species suggesting that junipers were not competitively excluding other woody plants from these clusters. These results indicate that asymmetry in woody plant composition does exist around these live oak nurse plants though it is more subtle than the asymmetry documented for nurse-plant associations in other, drier ecosystems. This asymmetry in the woody plant understory may be due to asymmetry in microclimate effects, but woody plant competition, animal use, or fire may also play important roles.

INTRODUCTION

Both positive interactions (facilitation) and negative interactions (competition) among plants are thought to be important in influencing species coexistence and diversity, productivity, and organization of plant communities (Callaway 1995). Facilitation is a positive effect exerted by one plant, which results in the enhancement of the establishment or the growth of other plants (Fowler 1986). Nurse plant interactions represent a type of facilitation and usually involve a mature, established plant that enhances the establishment and/or growth of seedlings of other woody or herbaceous species in its immediate vicinity (Cody 1993). Initially, nurse plant associations may largely represent a one-directional species interaction, whereby one organism (the beneficiary) is benefited by the presence of the nurse (benefactor), whereas the benefactor is largely unaffected by the beneficiary (Barbour et al. 1987). Over time, the relationship between benefactor and beneficiary may shift from positive-to-neutral to mutually negative (Vandermeer 1980; McAuliffe 1984). In some cases, the beneficiary species, which was facilitated as a seedling, may eventually outlive or eliminate its benefactor and thereby persist independently for the majority of its lifespan (Callaway 1995). Thus over the long term, the net effect of some nurse plant associations may be more akin to parasitism or predation (+/-) than mutualism (+/+) or facilitation (+/0) (Cody 1993).

Nurse plants can facilitate the beneficiary in a number of ways, and the underlying nature of this facilitation may influence the long term dynamics and structure of nurse plant associations. Nurse plants can alter the microclimate in their immediate surroundings and these changes may be necessary for the successful establishment and growth of seedlings that could not otherwise colonize nearby open areas. For example, nurse trees have been found to reduce solar radiation by 60% in their understories (Tiedemann and Klemmedson 1977; Ko and Reich 1993) and this shading can then lead to reduced soil and air temperatures (Valiente-Banuet and Ezcurra 1991; Archer 1995; Fulbright et al. 1995) in the understory. With less solar radiation penetrating the subcanopy and lower temperatures, there can also be reduced evaporation from the soil and transpiration from understory plants (Valiente-Banuet and Ezcurra 1991). Moreover, effects on microclimate can vary with cardinal direction around the nurse plant due to daily and seasonal variation in solar angles (Belsky et al. 1989; Gass and Barnes 1998). Thus, in a warm desert, Franco and Nobel (1988) found soil surface temperatures lower on the northern, more shaded sides of the nurse plant than in other areas. Consequently, these directional effects on microclimate can lead to asymmetries in the establishment and growth of plants associated with the nurse plant (Franco and Nobel 1988). In addition, nurse plants have also been shown to protect young establishing plants from freezing temperatures (Nobel 1980), predation (Parker 1982) and trampling (Fowler 1986).

Nurse trees can also modify soil moisture and nutrient availability through effects on physical and chemical properties of soil. Joffre and Rambal (1993) found that more water was stored and available under tree canopies than in the open grasslands of a Mediterranean savanna. Nurse trees may also act as nutrient pumps, absorbing nutrients in soils below the rooting zone of the understory plants and eventually depositing these nutrients beneath the canopy via litterfall and throughfall (Callaway et al. 1991). The litter produced by nurse plants can further improve infiltration rates (Knight et al. 1984) and overall fertility of the subcanopy soil (Tiedemann and Klemmedson 1973; Ko and Reich 1993; Belsky 1994). The positive effects the nurse plants have on soils may still be in place, even after the nurse plant dies (Barnes and Archer 1996). However, the effect of nurse plants on soils is likely to show less of a directional effect around the nurse canopy than the effects due to microclimate.

As noted above, the positive nurse-beneficiary relationship may, in time, turn into a negative relationship, such that the understory plant begins to compete against its nurse plant. Indeed, Vandermeer (1980) pointed out that the interactions between saguaros and nurse trees (i.e., initial facilitation giving way, eventually, to competition) constitute a system that is conceptually similar to the population interactions of a classic predator-prey system. In the saguaro-paloverde system, the loss of the paloverde (nurse plant; "eventual prey") brought about by the saguaro (nursee; "eventual predator") is not instantaneous, but may occur over a span of 50–100 years (McAuliffe 1984). Yeaton (1978) described a similar outcome between *Opuntia leptocaulis* and *Larrea tridentata,* where *L. tridentata* facilitates the establishment of *O. leptocaulis*, then over time *O. leptocaulis* gradually gains more resources and causes the death of *L. tridentata*. Yeaton and Manzanares (1986) described the same pattern between *Opuntia streptacantha* and its nurse plant *Acacia shaffneri*. Franco and Nobel (1988) found that higher soil nitrogen levels and lower soil surface temperatures allowed for *Agave deserti* seedling establishment, but later competition for water and shading by the nurse plant, *Hilaria rigida*, greatly reduced the growth of the associated seedling compared with an exposed seedling. These patterns suggest that the positive effects of benefactors are strong when beneficiaries are young, but competitive interactions may predominate when the beneficiaries are older and larger (Callaway and Walker 1997).

In general, nurse plants are often found in stressful environments such as hot deserts (Franco and Nobel 1989), salt marshes (Callaway 1994), arctic tundra (Walker and Chapin 1986), and savannas (Callaway et al. 1991). Several examples of nurse plant associations are found in the grasslands and savannas of Texas. In southern Texas, honey mesquite (*Prosopis glandulosa*) establishes in open grasslands and then facilitates the invasion of a diverse group of evergreen and deciduous shrubs that establish in its understory (Archer et al. 1988). Mesquite also appears to serve as a nurse plant for red-berry juniper (*Juniperus pinchotii*) on the High Plains of northern Texas (McPherson et al. 1988), whereas post oak (*Quercus stellata*) is believed to serve as a nurse plant for eastern red cedar (*Juniperus virginiana*) in eastern Texas (Rykiel and Cook 1986).

On the Edwards Plateau of central Texas, plateau live oak appears to serve as a nurse plant for Ashe juniper (*Juniperus ashei*) and other woody species (Fowler 1988). Generally, plateau live oak grows in discrete woody clusters or "mottes" on upland sites, and these clusters contain a mixed-species understory of Texas persimmon (*Diospyros texana)*, Ashe juniper (*J. ashei)*, agarito (*Berberis trifoliolata)*, and other species (Fowler 1988). These oak mottes generally occur on 20 to 50% of the landscapes of the Edwards Plateau (Knight et al. 1984).

Although live oaks are thought to serve as nurse plants for a number of woody species, little is known of the nature of this facilitation. As pointed out earlier, live oaks may benefit understory vegetation via effects on microclimate. For example, Gass and Barnes (1998) reported significantly lower air and soil temperatures beneath the live oak canopy than in the adjacent grasslands. This decreased solar radiation along with a relatively thick (2–5 cm) litter layer beneath these oaks would further tend to slow the rate of soil drying and evaporation (Fowler 1988). In addition, Gass and Barnes (1998) also found that the north and east sides of the oaks were generally cooler than the south and west sides of clusters during warm summer/early autumn periods. However, while microclimate data showed definite asymmetry around the oak clusters, Gass and Barnes (1998) found no directionality in understory development, measured as understory height and distance from the cluster center. These authors concluded, therefore, that microclimate alteration may not be important in facilitation by oaks in mature woody clusters. However, a detailed assessment of woody understory composition was not conducted in that study. In the present study, I will further explore the nature of positive (facilitation) effects by live oak nurse by examining whether asymmetries in understory species composition and abundance exist around these trees.

One of the most common woody species thought to be "nursed" by live oaks is Ashe juniper, a woody species that is thought to be increasing in abundance in the grasslands and savannas of central Texas since Europeans settled this area. However, there is an on-going debate as to how much Ashe juniper has actually increased its geographic range and abundance in recent years (Diamond et al. 1995; Smeins et al. 1997). While oak trees are not necessary for the establishment of Ashe juniper, according to Fowler (1988) they evidently increase the likelihood that an individual will become established.

It is well known that, once established, Ashe juniper can profoundly affect ecosystem function and structure. For example, herbaceous production, diversity and seed bank composition are greatly reduced in the understory of Ashe juniper in grassland sites (Fuhlendorf et al. 1997; Ruiseco 1998). However, little is known of the effects (if any) that Ashe juniper has on co-occurring woody species in oak clusters. Observations by Gass and Barnes (1998) indicated that in clusters where Ashe juniper reached a height of >3 m, there were few other woody species in the understory and woody understories were more diverse when Ashe juniper was smaller or lower in abundance. Their observations suggest that as Ashe juniper increases in abundance in oak clusters, it may competitively exclude other woody plants from the understory.

In this study, I quantitatively describe the distribution and abundance of understory woody vegetation in live oak clusters to test the hypotheses that 1) asymmetry exists in woody understory composition and abundance around the oak that corresponds to asymmetry in microclimate beneath oaks, and 2) Ashe juniper acts to competitively exclude other co-occurring woody plants from the cluster such that the abundance of Ashe juniper is inversely related to the abundance of other understory species.

MATERIALS AND METHODS

Study Site

The study was conducted on the Southwest Texas State University (SWT) Freeman Ranch (29°56'N, 98°W; max. elevation 274 m), located 8 km west of San Marcos, Texas (Fig. 1). The Freeman Ranch is located in southern Hays County, on the eastern edge of the Balcones Escarpment, which forms the southern and eastern margins of the Edwards Plateau (Fig. 2). The Edwards Plateau region comprises an area of 51,491 km^2 in west-central Texas and the Balcones subregion is locally known as the "Texas Hill Country."

The climate of the eastern Edwards Plateau is subtropical-to-subhumid (Riskind and Diamond 1988), with a mean growing season of 254 days. The mean monthly minimum temperatures of San Marcos are lowest in January (2.2°C) and the mean monthly maximum temperature of 35°C occurs in July (Greater Austin/San Antonio Corridor Council 1997). Mean annual precipitation is 87.1 cm with peaks in May and September, however, precipitation is highly variable, and droughts and flash floods are common phenomena.

Elevation of the Edwards Plateau generally increases from the southern and eastern margins toward the northwest, and ranges from 167 m to 734 m above sea level (Riskind and Diamond 1988). The major geological formations found on the Edwards

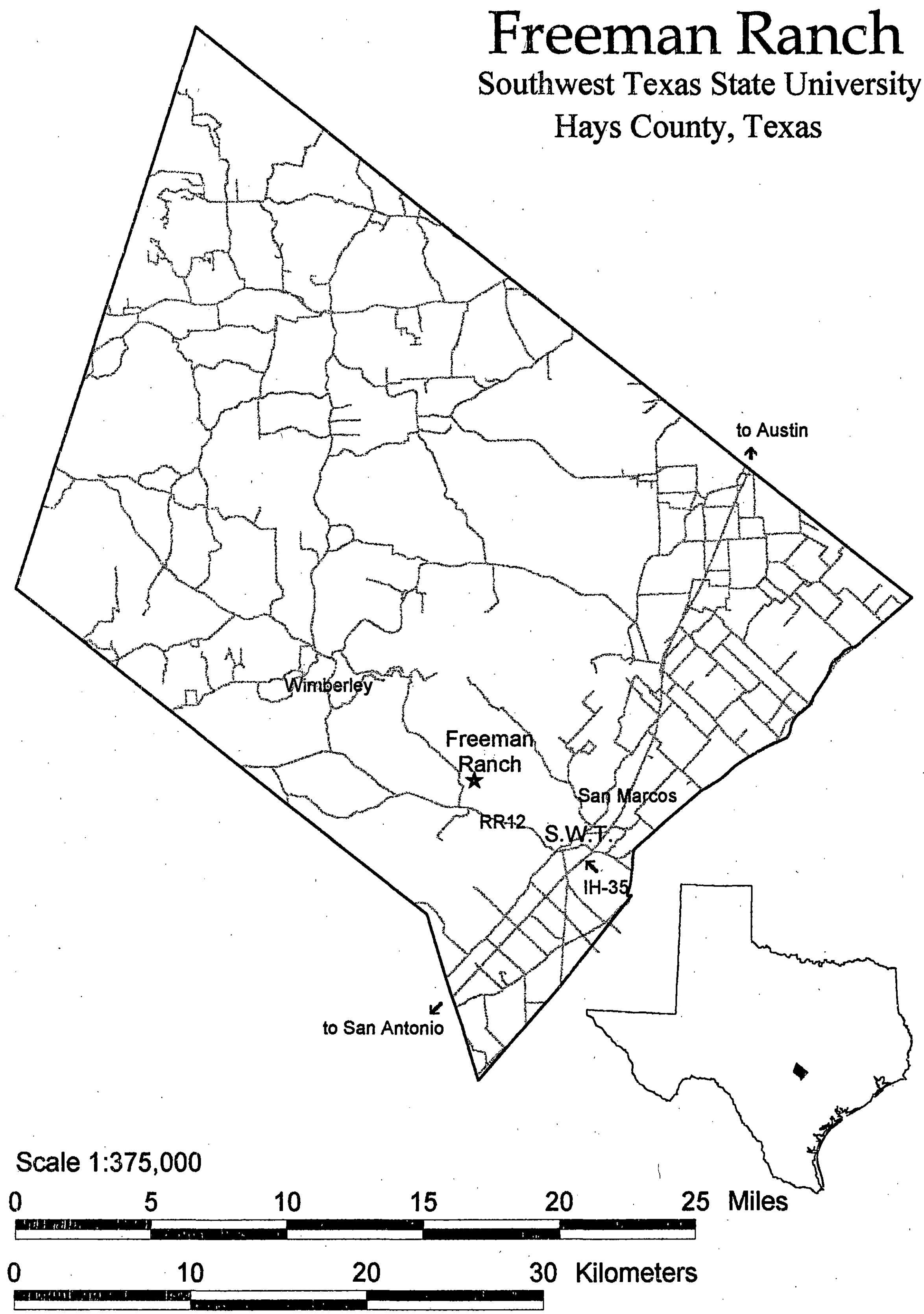


Figure 1. Geographic location of SWT Freeman Ranch in Hays County, Texas.

Natural Regions of Texas

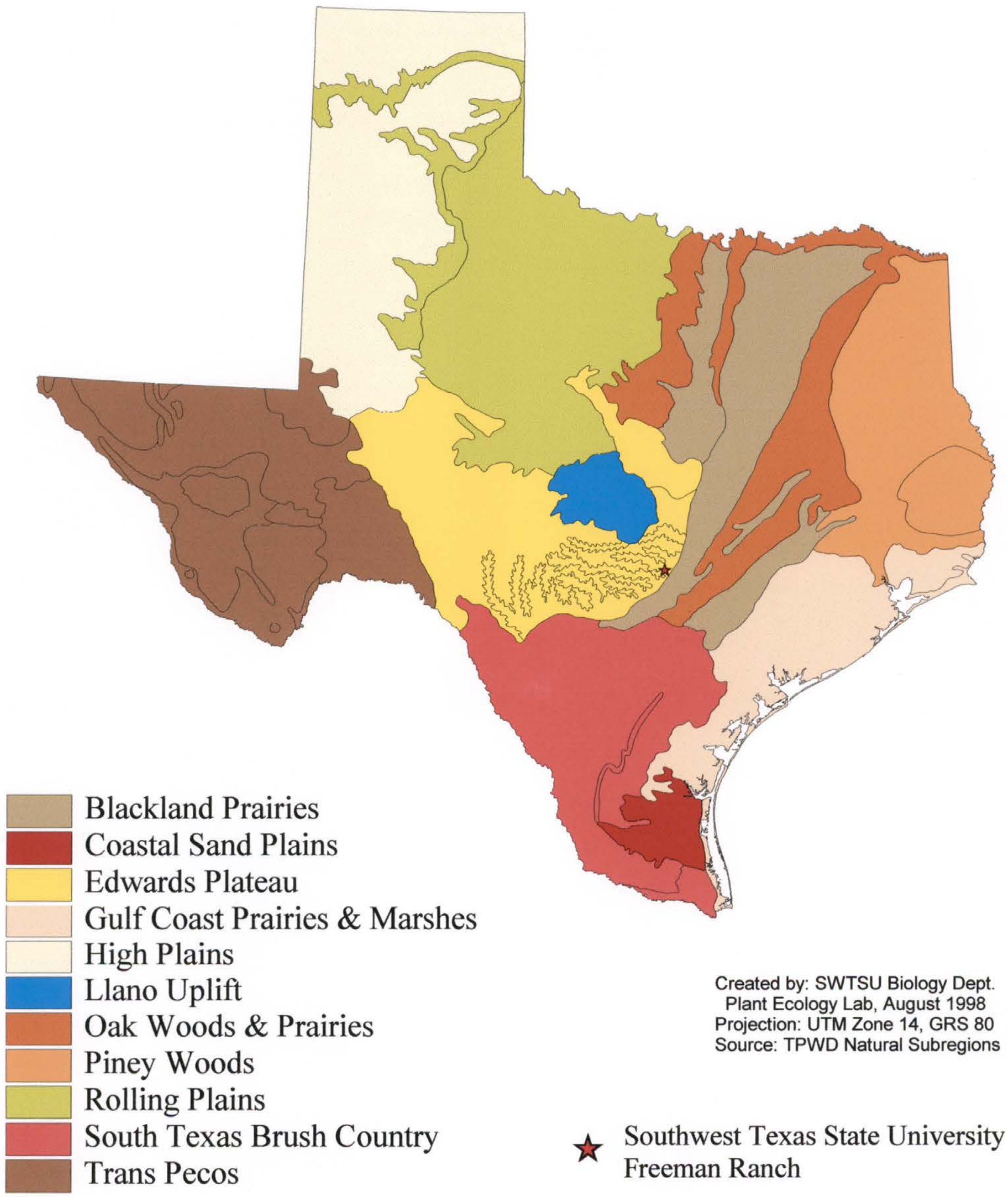


Figure 2. Natural Regions of Texas.

Plateau are the Glen Rose and Edwards formations (USDA 1984). Both of these formations are composed of limestone, which is a sedimentary rock composed primarily of calcium carbonate (Spearing 1991). Soils on the Edwards Plateau are shallow and rocky-to-gravely on slopes and hill crests, and deeper in lowlands and valleys (Riskind and Diamond 1988). The soils of eastern Hays County are classified in the Comfort-Rumple-Eckart soil series (USDA 1984). These soils are very shallow to moderately deep over indurated (hardened) limestone (USDA 1984). The live oak clusters sampled in my study occurred mainly on the Rumple-Comfort soil type.

The vegetation of the Balcones Escarpment is a mosaic consisting of grasslands and savannas on the canyon floors and woodlands and forests on the hill slopes (Van Auken 1988). Fowler (1988) characterized the upland vegetation of the Edwards Plateau as a savanna consisting of discrete clusters of live oaks and their associated woody and herbaceous understories interspersed among grasslands dominated by perennial C_4 mid- and shortgrasses.

In 1984, Southwest Texas State University and Frost Bank acquired the Freeman Ranch in the form of a trust from Joe and Harry Freeman. Prior to acquisition by SWT, it is thought that the ranch had been continuously grazed by cattle and other domestic livestock since the mid- to-late-1800s. Prior to 1984, stocking rates of animals were high, at approximately 25 animal units/acre in a four pasture system. Currently, the stocking rate is 9 au/acre in an 18 pasture rotational grazing system (B. Davis, personal communication.); this stocking rate is typical for this part of the Edwards Plateau, though it is still slightly above the Natural Resource Conservation Service recommended stocking rates for this area (i.e., 1 animal unit per 3 acres).

Sampling Methods

In this study, the understory woody vegetation was measured under large solitary Plateau live oak trees (*Quercus virginiana* P. Miller *var. fusiformis* (J.K. Small) C. Sargent) that occurred in upland savanna sites (Fig. 3) at the Freeman ranch. Four individual oak clusters were selected in each of five different pastures on the Freeman Ranch (i.e. N=20 clusters overall) (Fig. 4). To allow for tests of asymmetry in understory composition, only clusters consisting of a single live oak tree (single trunk) were sampled (i.e. multi-stemmed oak "mottes" were not sampled). In addition, clusters were selected that had woody understories that were accessible for sampling (i.e. clusters with thick tangled growth of the thorny vine *Smilax bona-nox* were avoided). Live oak clusters were also selected to represent a range of sizes across the landscape.

Each live oak cluster was divided into four quarters (northeast, northwest, southeast and southwest) based on established compass lines (Fig. 5). The diameter at breast height (1 m from the ground), maximum height, and two canopy diameter measurements to the edges of the oak cluster perpendicular to each other were taken for each oak tree.

Within each established sampling quarter, a comprehensive accounting of understory woody vegetation for each quarter in each oak tree was made. Specifically, each individual shrub or tree was identified to species and measurement of maximum shoot height (m), basal stem diameter (cm), and the largest canopy diameter (m) were determined. Species nomenclature follows Jones et al. (1997). Individual plants less than 0.5 m in height were classified as juveniles. Juveniles were tallied separately for each quarter of the oak tree. Maximum shoot height was measured using a 15 m tape or

Figure 3. Example of a solitary live oak with its associated woody plant understory that was sampled in this study.

Figure 4. Sampling site locations at the SWT Freeman Ranch. Each site is located in a different pasture and four live oak clusters were sampled at each site. All sites, except number one, experience cattle grazing over the course of this study. Site 1 has been protected from cattle grazing since 1995.


Freeman Ranch
Southwest Texas State University
N
W
E
S
4
5
1
2
3
Sites
Boundary
Created by: SWTSU Biology Dept.
Plant Ecology Lab, October 1998
Projection: UTM Zone 14, GRS 80
Source: 1m Texas DOQQ's for Wimberley
NE, SE and San Marcos N-NW, N-SW
0 0.5 1 1.5 2 2.5 Kilometers
Scale 1:35,000

Figure 4.

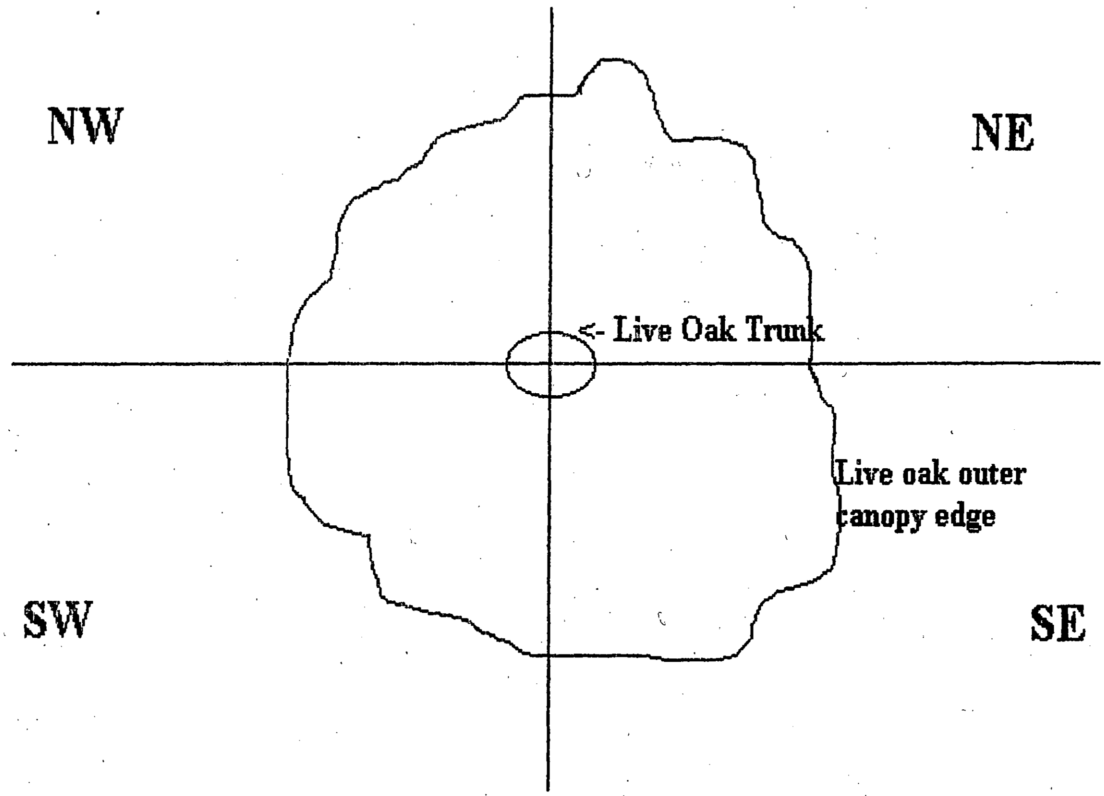


Figure 5. General layout of the four sampling quarters in a live oak cluster.

7.5 m range pole, and recorded for all plants 0.5 m tall or greater. Canopy diameters were measured using a 15 m or 50 m tape. Basal diameters were measured using a 65 cm caliper. Basal diameters at ground level were measured to alleviate potential problems associated with the shrubby branching pattern of many species in this area (Van Auken 1988). Succulents (i.e., *Opuntia engelmannii*) and woody vines (i.e., *S. bona-nox*) were not measured due to growth habits that were difficult to measure.

Measurements of photon flux density (PFD, 400–700 nm) were taken between 1100 and 1400 h CST during sunny-to-partly cloudy skies in July 1998. For each oak cluster and quarter, three ambient PFD readings were taken at random positions outside the canopy, in the open grassland, using a point quantum sensor (Model LI-190; LiCor, Inc.) equipped with a leveling base (= ambient above canopy PFD). At the same time, a 1-m line quantum sensor (Model LI-191SA; LiCor, Inc.) was used to measure PFD above and below the understory vegetation for each quarter. For each quarter, three above PFD (overstory) and three below PFD (understory) readings were taken. Therefore, for each oak tree, twelve ambient (in open grassland), overstory and understory PFD measurements were taken and recorded. The PFD measurements were averaged for every three measurements taken for each quarter. The line quantum as well as the point quantum sensors were interfaced to a portable data logger (Model LI-1000, LiCor, Inc.) for data acquisition. Data are reported as the ratio of within canopy-to-above canopy PFD (i.e., percent of incoming PFD penetrating the canopy).

Data Analysis

For statistical analyses, individual oak clusters were considered as experimental units and data were analyzed using analysis of variance (Super ANOVA for the Macintosh) for a completely randomized experimental design. Analysis of variance was also used to compare relative PFD (= proportion of above canopy PFD) with respect to quarter. Mean comparisons were made using Tukey's Comparison (Zar 1996) with differences reported as significant at $P < 0.05$, unless otherwise noted. Relationships between live oak tree size and understory plant density and biomass were analyzed using simple linear regression (Super ANOVA). Linear regression was also used to test the relationship between the number and abundance of Ashe junipers to the combined totals of all other understory species. Prior to analysis, data were examined for normality by examining frequency distributions. All variables with non-normal frequency distributions were log-transformed and frequency distributions were then re-examined. When transformations were needed to normalize data, the transformed data were analyzed with ANOVA, but means and standard errors of non-transformed data are shown in the tables and figures.

Results

Community Patterns

The twenty live oak clusters sampled varied considerably in size of the overstory and the abundance and species composition of the woody understory assemblage (Table 1). The central live oak in the sampled clusters ranged in size from 37.4–93.7 cm dbh, 10.4–17.9 m canopy diameter, 8.2–14.0 m^2 canopy area and 6.1–12.5 m maximum height. The woody understory associated with these oaks also varied greatly in total number of woody plants (46–267 individuals), densities (3.8–20.4/m^2) and species richness (5–11). A total of nineteen different woody species were identified in the understory of the clusters and ten families were represented (Table 2). Despite the variation in oak size, regression analyses showed little, if any, relationship between live oak size and the number of plants or species in the understory woody community (Figs. 6–8).

The woody understory was dominated by *Juniperus ashei, Celtis laevigata, Ulmus crassifolia, Diospyros texana*, and *Forestiera pubescens* with relative densities of 26.1, 22.7, 13.7, 11.3, and 10.8%, respectively (Fig. 9). These five species represented 85% of the total density of the woody plant understory. This same pattern of species dominance can be seen when the relative densities are calculated for each of the four quarters (Fig. 10). However, *C. laevigata* was more dominant in the two southern

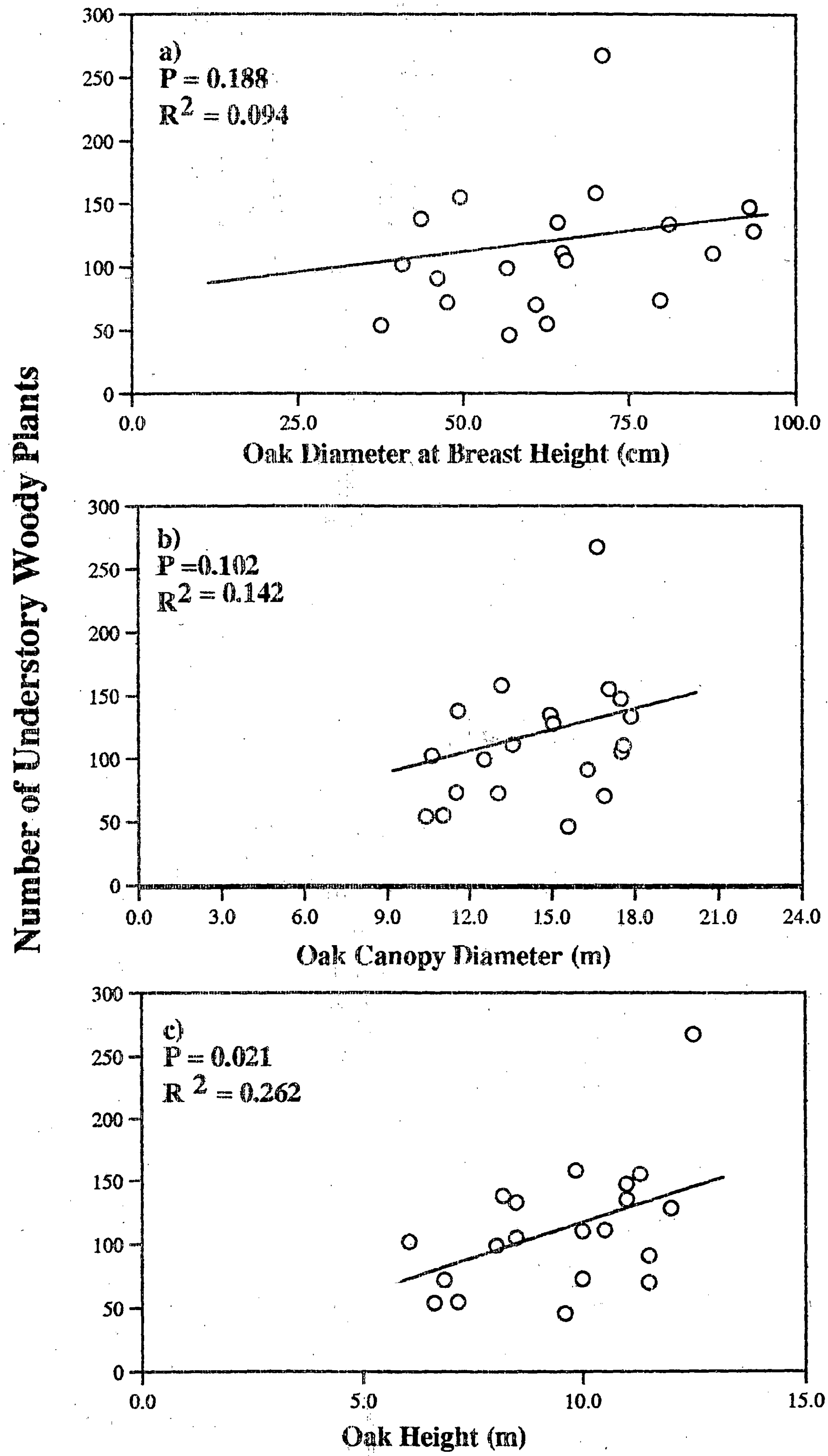
Table 1. The dimensions and woody understory abundance of the live oak clusters. Canopy dripline area ($A=\pi r^2$) was calculated using the canopy diameter assuming canopies were circles. Density was calculated by dividing the canopy dripline area into the total number of plants for each oak cluster.

Oak Cluster	DBH (cm)	Canopy Diameter (m)	Area (m^2)	Max. Canopy Height (m)	No. of Understory Woody Plants	Density(#/m^2)	No. of Species
1	40.7	10.6	8.4	6.1	99	11.85	11
2	37.4	10.4	8.2	6.6	53	6.49	7
3	56.7	12.6	9.9	8.1	99	10.05	9
4	62.7	11.0	8.7	7.2	55	6.35	6
5	65.5	17.5	13.8	8.5	105	7.64	9
6	93.1	17.5	13.7	11.0	147	10.70	9
7	79.7	11.5	9.0	10.0	73	8.07	5
8	93.7	15.1	11.8	12.0	128	10.83	9
9	49.5	17.1	13.4	11.3	155	11.56	8
10	87.5	17.6	13.8	10.0	110	7.96	9
11	46.0	16.3	12.8	11.5	91	7.11	8
12	81.0	17.9	14.0	8.5	133	9.49	8
13	61.0	16.9	13.3	11.5	70	5.28	6
14	71.0	16.7	13.1	12.5	267	20.43	8
15	65.0	13.6	10.7	10.5	111	10.40	8
16	70.0	13.2	10.4	9.9	158	15.25	10
17	47.5	13.1	10.2	6.9	72	7.03	6
18	64.3	15.0	11.7	11.0	135	11.50	9
19	43.5	11.6	9.1	8.2	138	15.15	8
20	57.0	15.6	12.3	9.6	46	3.76	7
Mean	**63.3**	**14.5**	**11.4**	**9.5**	**112**	**9.9**	**8**
SD	**16.6**	**2.6**	**2.0**	**1.9**	**50.2**	**3.9**	**1.5**

Table 2. List of all woody species encountered in the understories of live oak understories. Those with an asterisk (*) occurred only once. For growth form, D = deciduous and E = evergreen.

Species	Synonyms	Family	Growth Form	Common Name
Acacia minuata * (M.E. Jones) P. de Beauchamp	*Acacia farnesiana*	Fabaceae	Tree (D)	Huisache
Berberis trifoliolata M. Moricand		Berberidaceae	Shrub (E)	Agarito
Celtis laevigata var. *reticulata* C. von Willdenow		Ulmaceae	Tree (D)	Hackberry
Condalia hookeri * M.C. Johnston		Rhamnaceae	Shrub (D)	Brasil
Diospyros texana G. Sheele		Ebenaceae	Tree (D)	Texas Persimon
Forestiera pubescens T. Nuttall		Oleaceae	Shrub (D)	Elbowbush
Ilex decidua T. Walter		Aquifoliaceae	Shrub (D)	Possum Haw Holly
Ilex vomitoria W. Aiton		Aquifoliaceae	Shrub (E)	Yaupon Holly
Juniperus ashei J. Buchholz		Cupressaceace	Tree (E)	Ashe Juniper
Mimosa aculeaticarpa * C. Ortega	*Mimosa biuncifera*	Fabaceae	Shrub (D)	Cat's-claw Mimosa
Prosopis glandulosa J. Torrey		Fabaceae	Tree (D)	Honey Mesquite
Ptelea trifoliata * C. Linnaeus		Rutaceae	Tree (D)	Wafer Ash
Quercus buckleyi K. Nixon & L. Dorr		Fagaceae	Tree (D)	Texas Oak
Quercus virginiana P. Miller var. *fusiformis* (J.K. Small) C. Sargent	*Quercus fusiformis*	Fagaceae	Tree (E)	Plateau Live Oak
Sideroxylon lanuginosum A. Michaux	*Bumelia languinosa*	Sapotaceae	Tree (D)	Wooly Bumelia
Sophora affinis * J. Torrey & A. Gray		Fabaceae	Tree (D)	Texas Sophora
Ulmus crassifolia T. Nuttall		Ulmaceae	Tree (D)	Cedar Elm
Zanthoxylum hirsutum S. Buckley		Rutaceae	Shrub (D)	Hercules Club
Ziziphus obtusifolia * (J. Torrey & A. Gray) A. Gray		Rhamnaceae	Shrub (D)	Lotebush

Figure 6. Regression relationships of number of measured understory woody plants in relation to the size (dbh, canopy diameter, and height) of the central live oak in each cluster (N=20). Lines depict best-fit simple linear regression equations.



Number of Understory Woody Plants
a)
P = 0.188
R2 = 0.094
0 50 100 150 200 250 300
0.0 25.0 50.0 75.0 100.0
Oak Diameter at Breast Height (cm)
b)
P =0.102
R2 = 0.142
0 50 100 150 200 250 300
0.0 3.0 6.0 9.0 12.0 15.0 18.0 21.0 24.0
Oak Canopy Diameter (m)
c)
P = 0.021
R 2 = 0.262
0 50 100 150 200 250 300
0.0 5.0 10.0 15.0
Oak Height (m)

Figure 7. Regression relationships of total basal diameter (cm) of all measured woody plants in relation to the size (dbh, canopy diameter, and height) of the central live oak clusters (N=20). Lines depict best-fit simple linear regression equations.

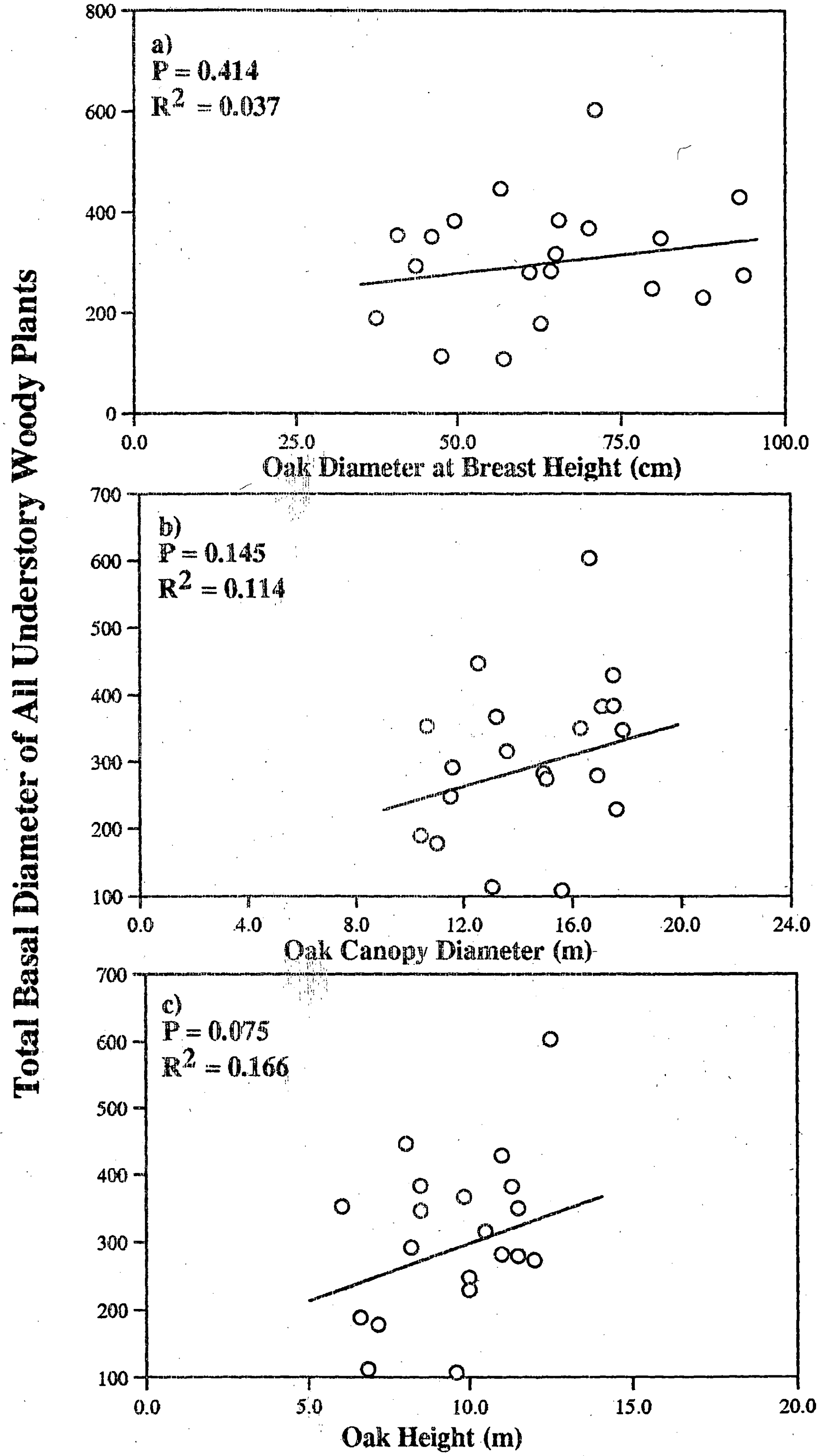
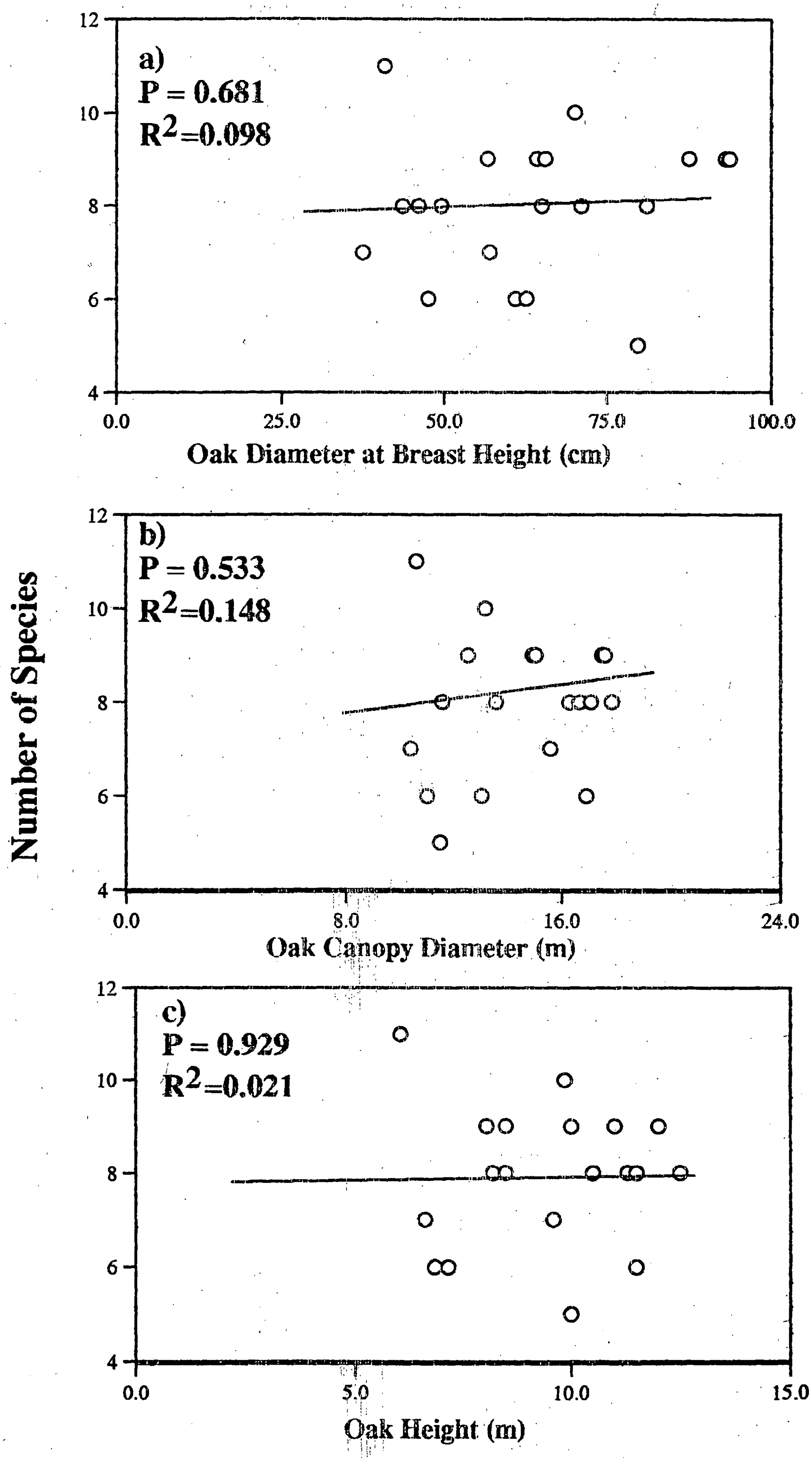

Total Basal Diameter of All Understory Woody Plants
a)
P = 0.414
R2 = 0.037
Oak Diameter at Breast Height (cm)
b)
P = 0.145
R2 = 0.114
Oak Canopy Diameter (m)
c)
P = 0.075
R2 = 0.166
Oak Height (m)

Figure 8. Regression relationships of the number of species in relation to the size (dbh, canopy diameter, and height) of the central live oak clusters (N=20). Lines depict best-fit simple linear regression equations.


Number of Species
a)
P = 0.681
R^2=0.098
12
10
8
6
4
0.0
25.0
50.0
75.0
100.0
Oak Diameter at Breast Height (cm)
b)
P = 0.533
R^2=0.148
0.0
8.0
16.0
24.0
Oak Canopy Diameter (m)
c)
P = 0.929
R^2=0.021
0.0
5.0
10.0
15.0
Oak Height (m)

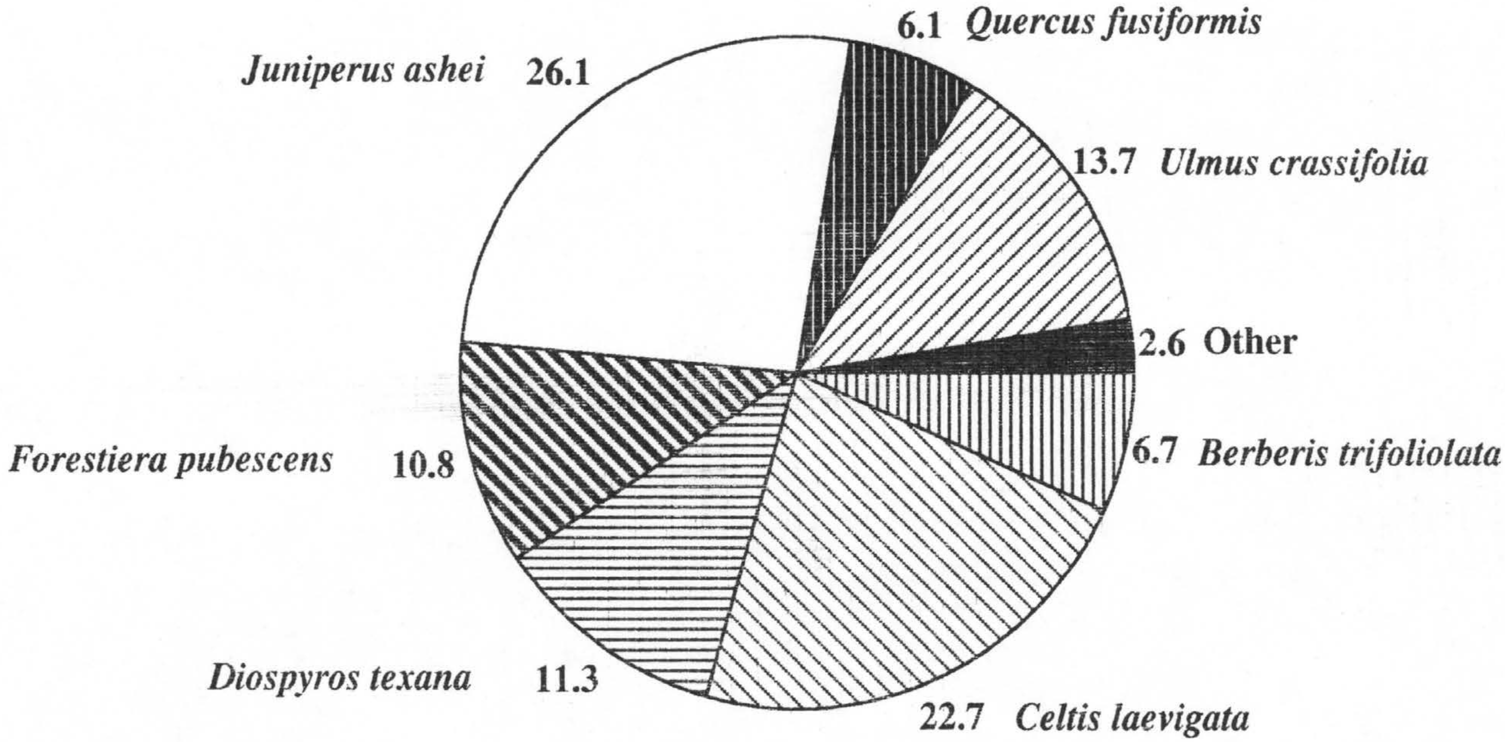
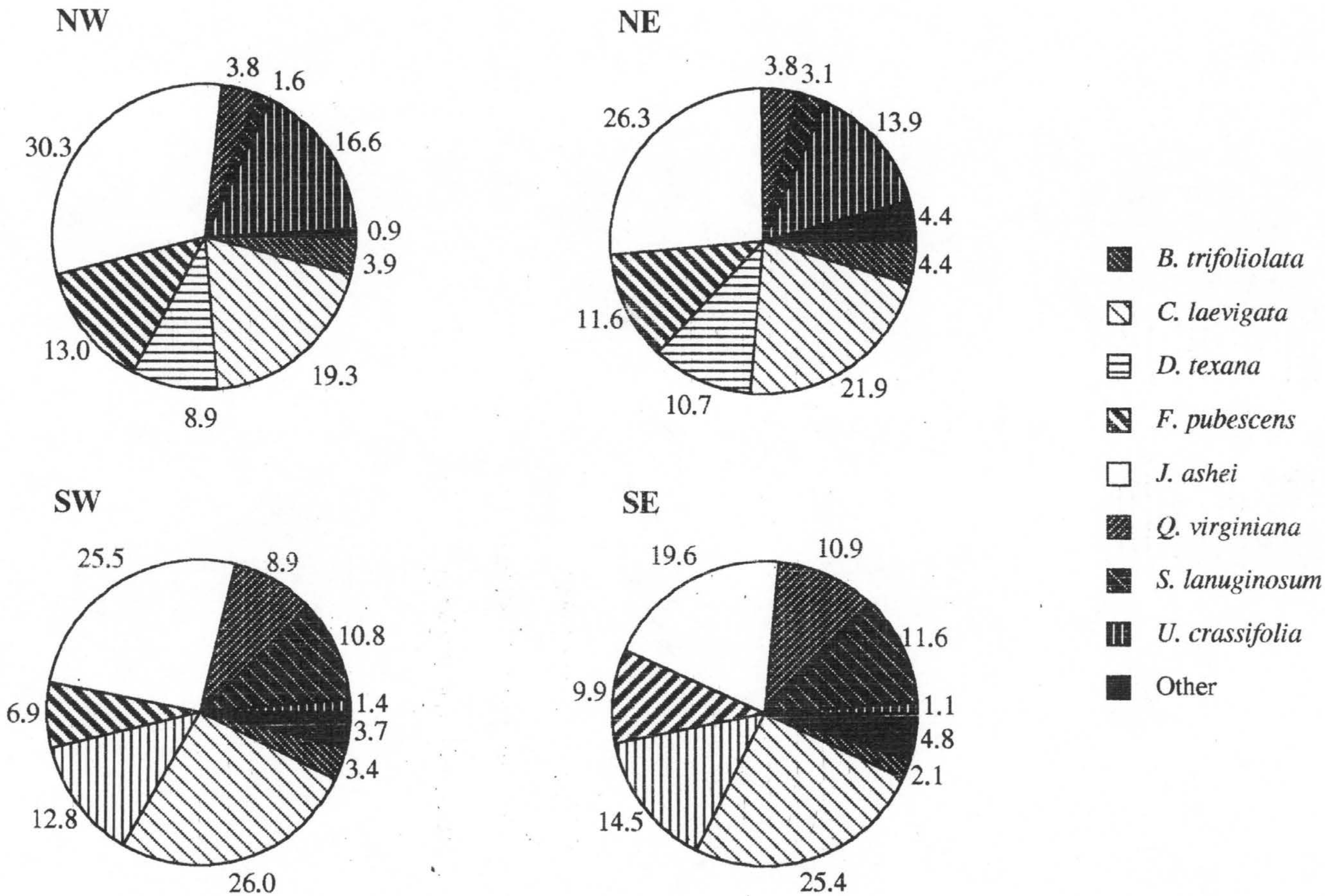


Figure 9. Relative densities (%) for dominant understory woody plants averaged over all four quarters in live oak clusters (N=20). Relative density values were calculated by dividing the total number of all individuals for all species into the number of individuals per species and multiplying by 100. Other category = all other species encountered in the understory.

Figure 10. Relative densities (%) for major understory woody plants averaged over all four quarters, of all live oak clusters (N=20). Relative density values were calculated by dividing the total number of all individuals into the number of species A and multiplying by 100. Other category = all other species encountered in the understory.


NW
3.8
1.6
16.6
0.9
3.9
19.3
8.9
13.0
30.3
NE
3.8
3.1
13.9
4.4
4.4
21.9
10.7
11.6
26.3
SW
25.5
8.9
10.8
1.4
3.7
3.4
26.0
12.8
6.9
SE
19.6
10.9
11.6
1.1
4.8
2.1
25.4
14.5
9.9
B. trifoliolata
C. laevigata
D. texana
F. pubescens
J. ashei
Q. virginiana
S. lanuginosum
U. crassifolia
Other

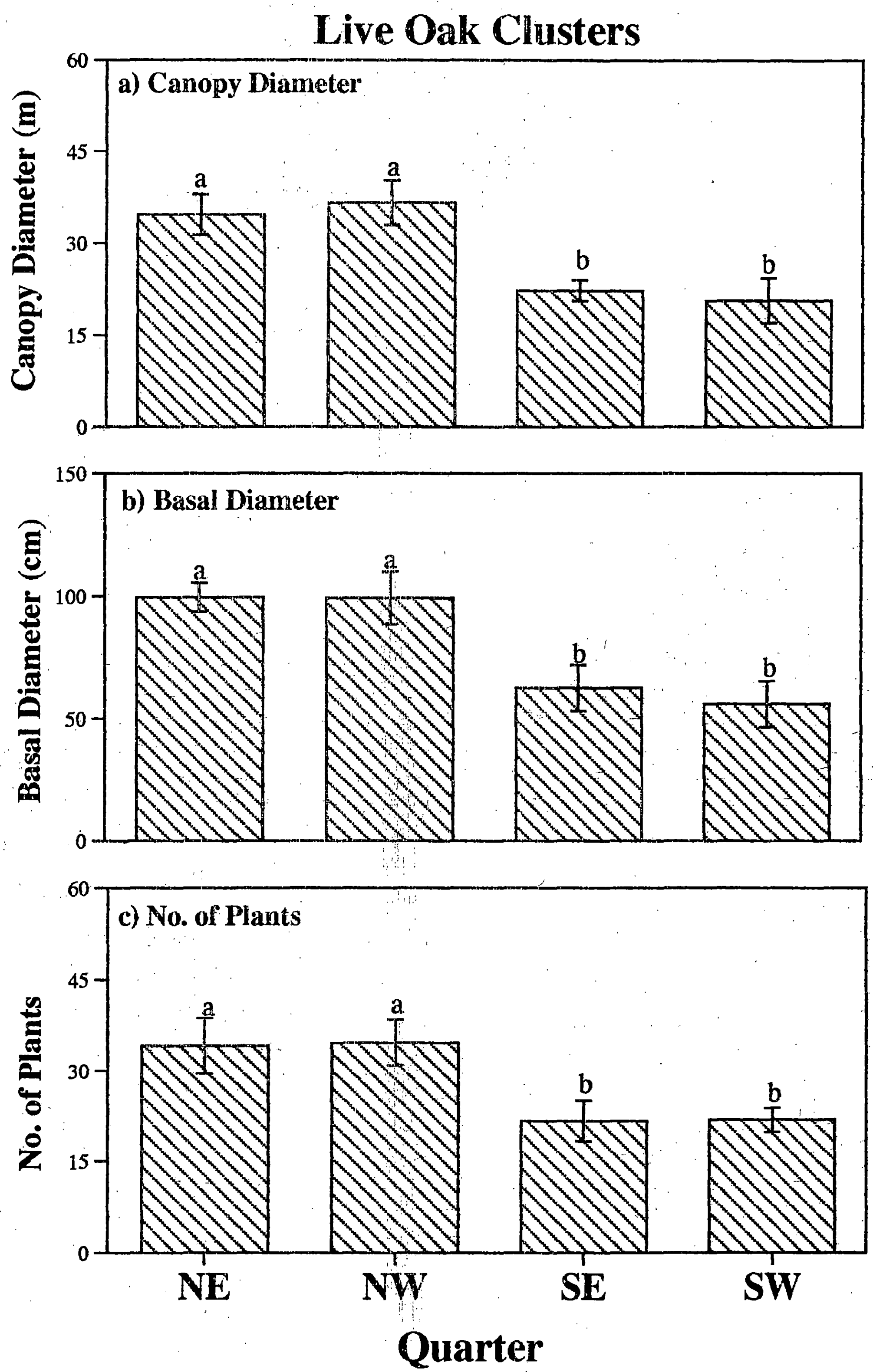
quarters, while *J. ashei* maintained its dominance in the northern aspect.

Both woody plant abundance and composition varied with cardinal direction around the live oak (Figs. 10, 11). Specifically, the northern quarters (NW and NE) had a significantly greater (P=0.008) mean number of understory woody plants (34.6 and 34.2, respectively) than the southern (SE and SW) quarters (21.7 and 21.8, respectively) (Fig. 11c). The combined northern aspect (northwest and northeast) of the oak clusters contained 61% of the total understory woody plants measured (Table 3). The same pattern was seen for basal diameter (Fig. 11b) (P=0.0010) and canopy diameter (Fig. 11a) (P=0.0004). However, directional differences were not detected for the height of understory plants (P=0.5690; data not shown).

Patterns for Individual Understory Species

Of the nineteen species encountered, eight were abundant enough to test for significant differences in abundance around the central live oak. Of these eight species, four showed statistically significant variation in abundance around the tree. *Diospyros texana* showed no detectable difference in height and canopy diameter between the individual quarters, but when data from individual quarters were pooled, this species showed greater canopy diameters (Fig. 12a; P=0.0501) and height (Fig. 12b; P=0.0458) in the northern half (NW and NE) of clusters in comparison to the southern half (SE and SW). The data for *F. pubescens* showed a pattern different than that for *D. texana*, in that canopy diameters (Fig. 13a; P=0.0355) and basal diameters (Fig. 13b; P=0.0382) were greater in the southeastern aspect of the clusters and shrubs on the eastern sides of the oaks tend to be larger than from the western sides. The averaged data for

Figure 11. Mean canopy diameter (panel a), basal diameter (panel b), and number of all measured woody plants (panel c) for each quarter for all live oak clusters (data are means ± 1 SE). Within a panel, means with the same letter are not significantly different at $P < 0.01$ ($N=20$) as determined by Tukey's test.



Live Oak Clusters
a) Canopy Diameter
Canopy Diameter (m)
60
45
30
15
0
a
a
b
b
b) Basal Diameter
Basal Diameter (cm)
150
100
50
0
a
a
b
b
c) No. of Plants
No. of Plants
60
45
30
15
0
a
a
b
b
NE
NW
SE
SW
Quarter

Table 3. Total number of understory woody plants for each quarter and oak cluster. The percentage of the total was calculated by dividing the number of woody plants found in each quarter by the total number of plants for all oak clusters.

Tree Number	NW	SW	NE	SE
1	40	13	32	14
2	10	14	18	11
3	15	14	40	30
4	12	17	15	11
5	39	24	22	20
6	43	31	53	20
7	22	16	24	11
8	34	17	42	35
9	65	19	45	26
10	28	23	37	22
11	28	19	29	15
12	38	41	21	33
13	22	17	18	13
14	60	33	102	72
15	28	37	24	22
16	47	33	57	21
17	32	17	15	8
18	71	14	39	11
19	39	28	36	35
20	19	9	15	3
Total	**692**	**436**	**684**	**433**
Mean	**34.6**	**21.8**	**34.2**	**21.7**
SD	**16.9**	**9.0**	**20.4**	**15.0**
% of Total	**30.8**	**19.4**	**30.5**	**19.3**

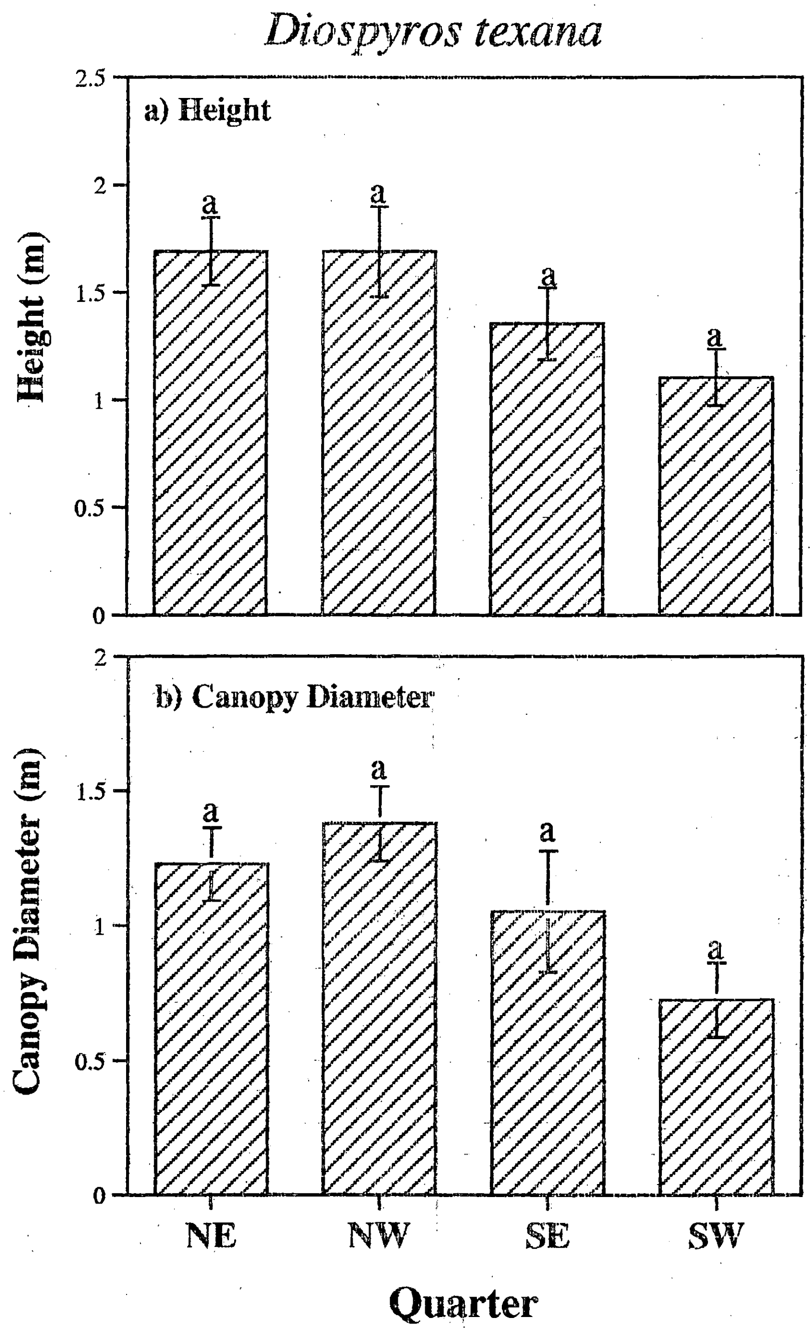


Figure 12. Mean height (panel a) and canopy diameter (panel b) of *Diospyros texana* in the four quarters for all live oak clusters. Data are means ± 1 SE (N=20) based on back-transform data. Within a panel, columns with the same letter are not significantly different as determined by Tukey's test.

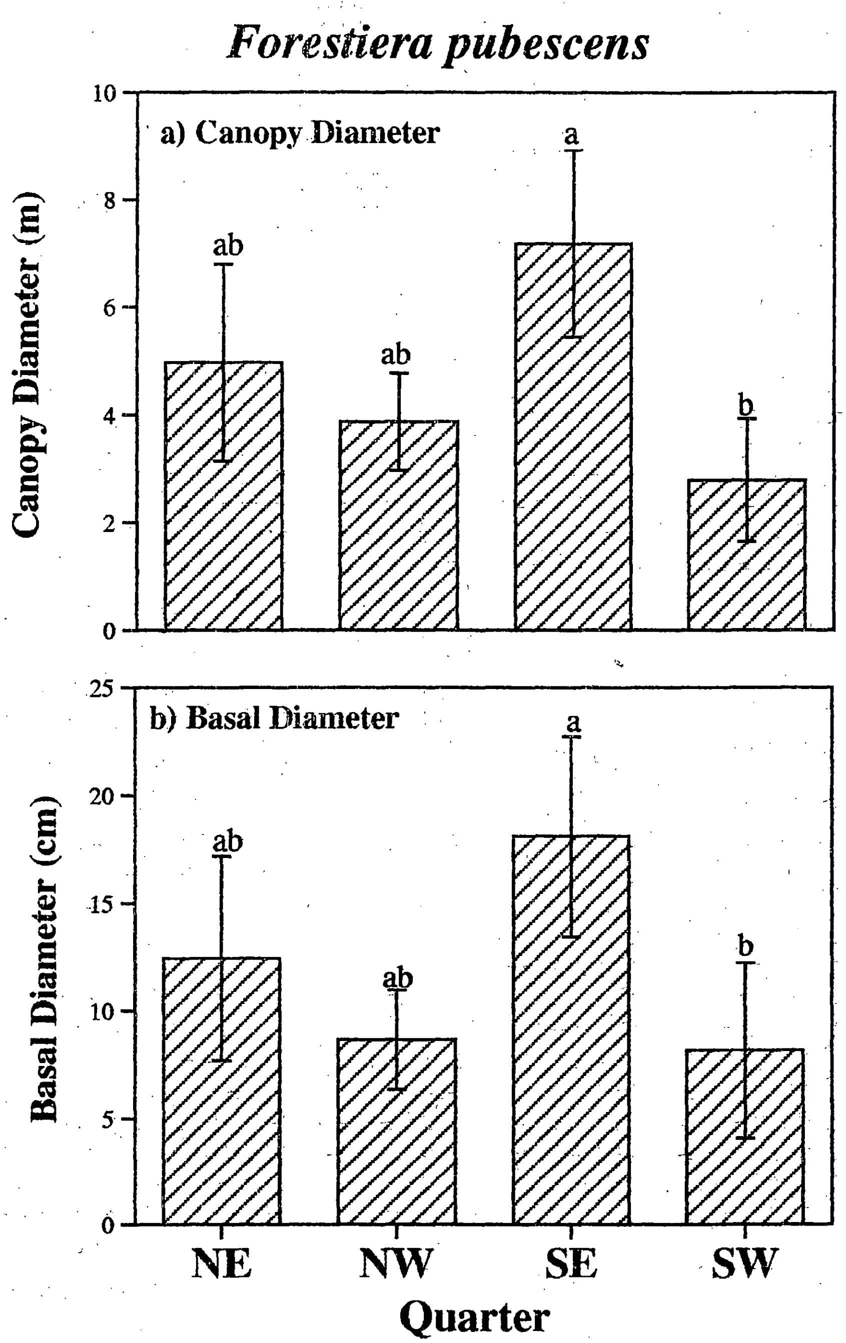


Figure 13. Mean values of canopy diameter (panel a) and basal diameter (panel b) of *Forestiera pubescens* for all live oak clusters (N=20). Data are means ± 1 SE, based on back-transformed data. Within a panel, columns with the same letter are not significantly different as determined by Tukey's test.

Q. virginiana var. fusiformis (Fig. 14; P=0.0446) indicated that the tallest individuals occurred around the northwest quarter of the clusters. *Juniperus ashei* exhibited a pattern similar to *D. texana* (i.e., abundance and growth was generally greater on the north side (P=0.024) of clusters than on the south side) (Figs.15a,b,c).

Figure 16 a, b, and c shows the frequency distributions of *J. ashei* and its measured parameters. These distributions were highly skewed to the smaller size classes, which is a pattern commonly observed in populations under rapid growth. There was no relationship between the size of the live oak tree and the number of *J. ashei* in the understory (Fig. 17). Also, no strong relationships could be found between the size of *J. ashei* and the combined size data for other woody understory species (Fig.18). In general, few significant relationships were found when comparing the parameters of *J. ashei* to all the parameters of all other understory woody species in each quarter and when significant correlation were observed they were positive rather than negative in direction (Table 4).

Recruitment of Juveniles

The above data were for individuals classified as adults (height >0.5m). In general, juveniles showed similar patterns in abundance with respect to quarter that was found in the adult plants (Table 5). Specifically, the northern half (NE and NW) had means of 27.2 and 35.9 plants/quarter, respectively, while the southern half (SW and SE) had means of 20.8 and 20.1 plants/quarter, respectively. The northern aspect contained 60% of all woody juveniles counted. No significant differences were found between the total number of juveniles and quarter (P=0.4831). However, there was a significant

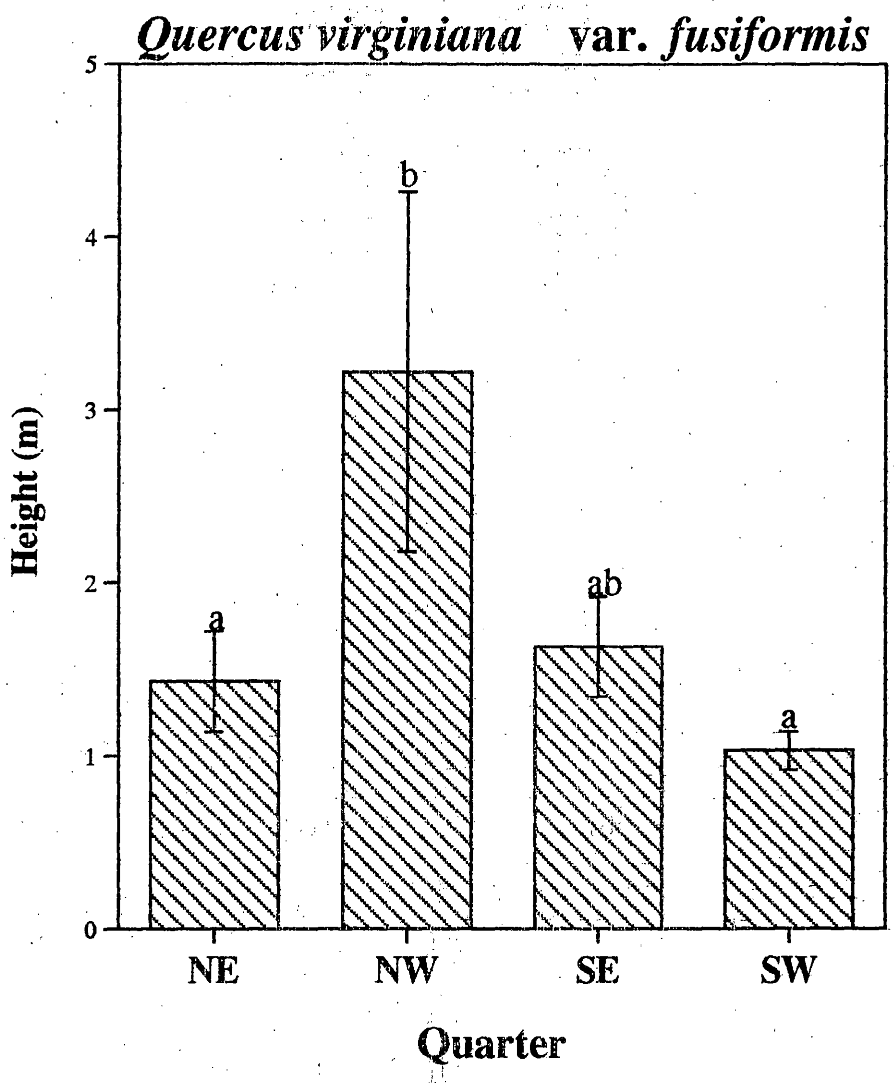
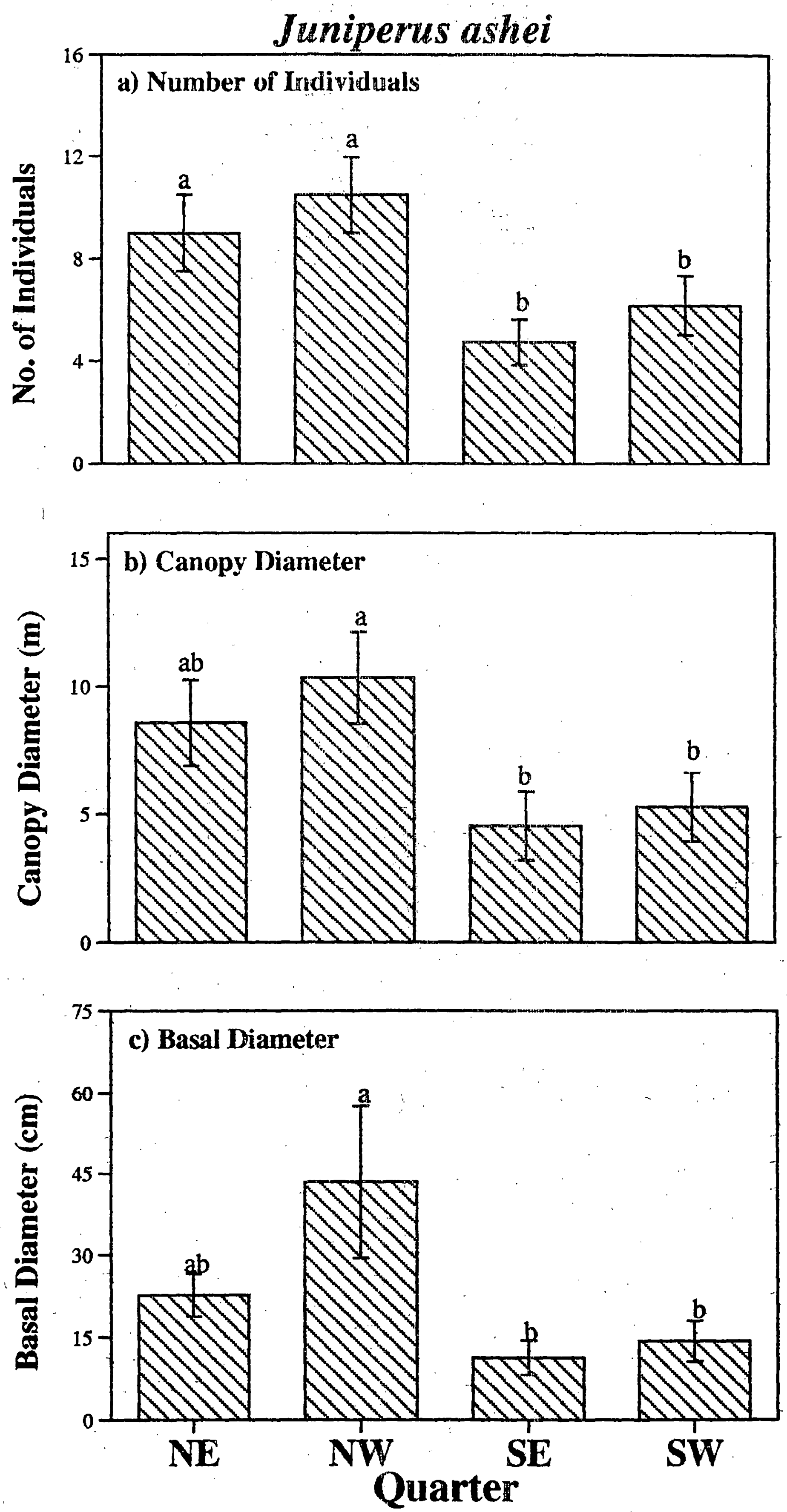


Figure 14. Mean values for averaged height (m) data for *Quercus virginiana* var. *fusiformis* found in the undestories of all live oak clusters (N=20). Data are means of averaged values ± 1 SE, based on back-transformed data. Columns with the same letter are not significantly different as determined by Tukey's test.

Figure 15. Mean number of individuals (panel a), canopy diameter (panel b) and basal diameter (panel c) for all understory Ashe juniper (*Juniperus ashei*) for each quarter for all live oak clusters (data are means ± 1 SE). Within a panel, means with the same letter are not significantly different at $P < 0.05$ (N=20) as determined by Tukey's test.



Juniperus ashei
a) Number of Individuals
No. of Individuals
0
4
8
12
16
a
a
b
b
b) Canopy Diameter
Canopy Diameter (m)
0
5
10
15
ab
a
b
b
c) Basal Diameter
Basal Diameter (cm)
0
15
30
45
60
75
ab
a
b
b
NE
NW
SE
SW
Quarter

Figure 16. Frequency distributions for all understory Ashe junipers (*Juniperus ashei*) basal diameters (panel a), canopy diameters (panel b), and height (panel c). Bars depict frequency distribution and lines depict normal curves.

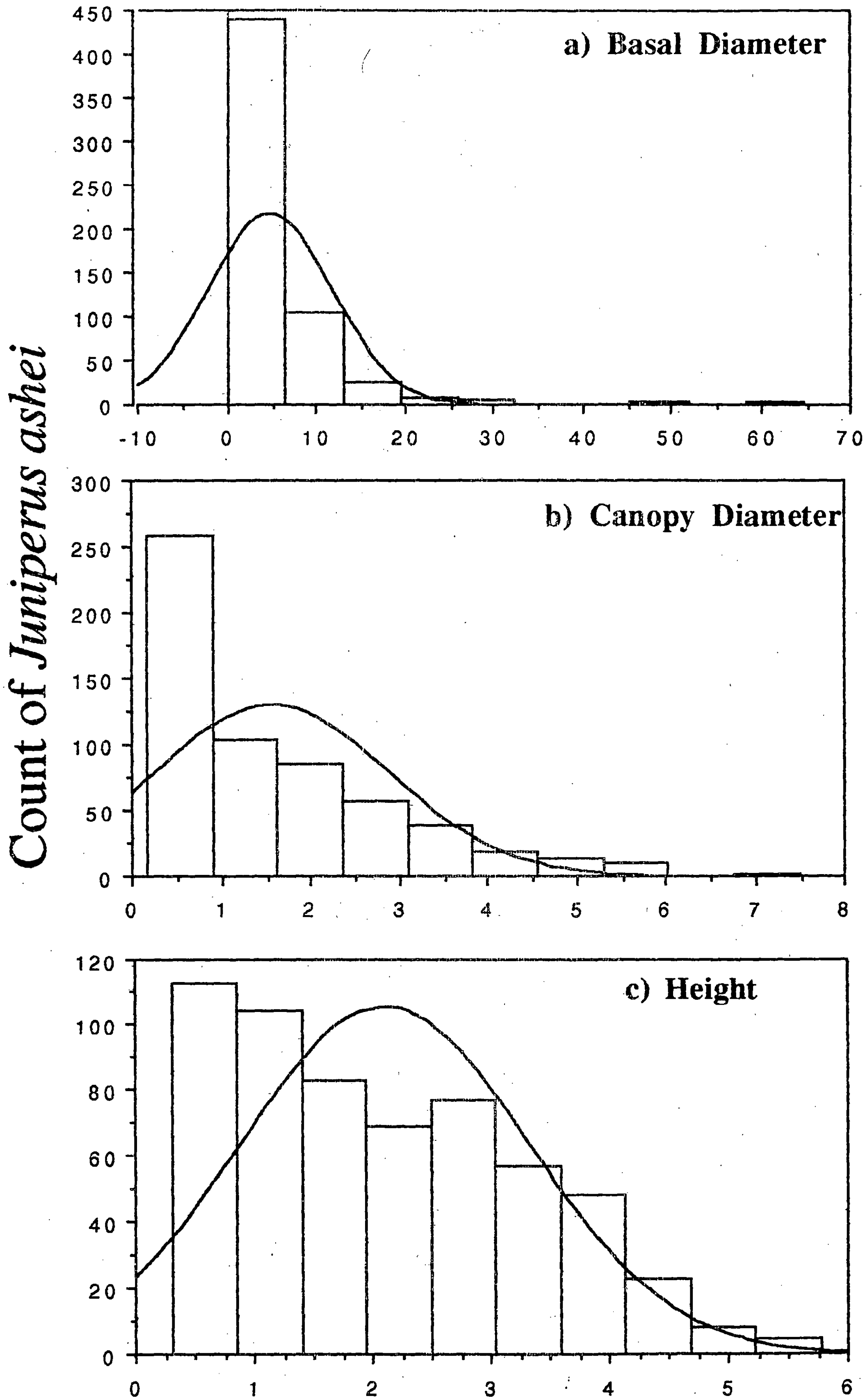

a) Basal Diameter
450
400
350
300
250
200
150
100
50
0
-10
0
10
20
30
40
50
60
70
b) Canopy Diameter
300
250
200
150
100
50
0
0
1
2
3
4
5
6
7
8
c) Height
120
100
80
60
40
20
0
0
1
2
3
4
5
6
Count of Juniperus ashei

Figure 17. Regression relationships of the number of Ashe juniper (*Juniperus ashei*) in relation to the size (dbh, canopy diameter, and height) of the central live oak clusters (N=20). Lines depict best-fit simple linear regression equations.

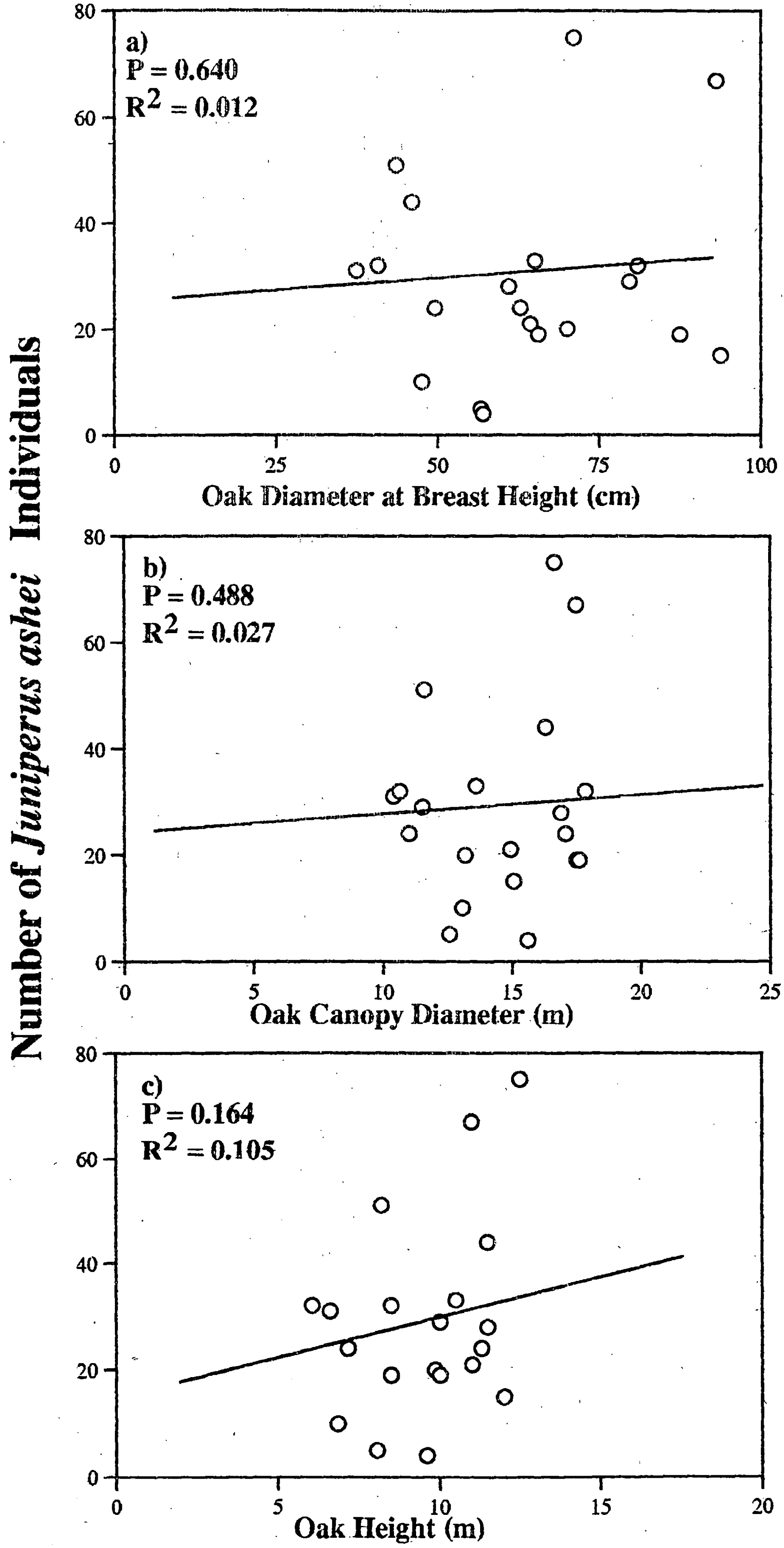
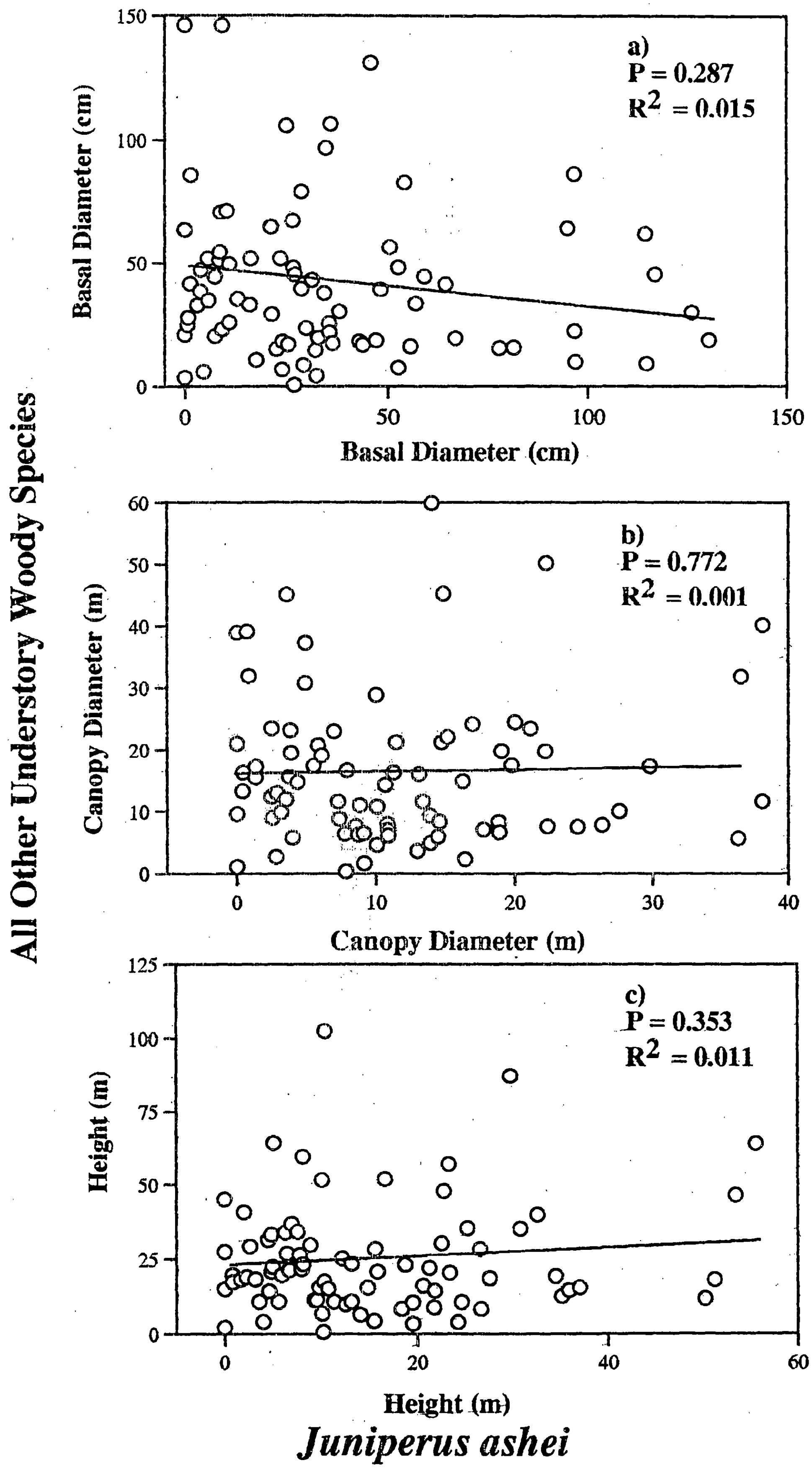

Number of *Juniperus ashei* Individuals
a)
P = 0.640
$R^2 = 0.012$
Oak Diameter at Breast Height (cm)
b)
P = 0.488
$R^2 = 0.027$
Oak Canopy Diameter (m)
c)
P = 0.164
$R^2 = 0.105$
Oak Height (m)

Figure 18. Regression relationships of the measurement values of basal diameter, canopy diameter, and height for all understory woody plants (excluding Ashe juniper) in relation to the same measurements for all Ashe junipers (*Juniperus ashei*) (N=20). Lines depict best-fit simple linear regression equations.



All Other Understory Woody Species
a)
P = 0.287
R2 = 0.015
Basal Diameter (cm)
150
100
50
0
0
50
100
150
Basal Diameter (cm)
b)
P = 0.772
R2 = 0.001
Canopy Diameter (m)
60
50
40
30
20
10
0
0
10
20
30
40
Canopy Diameter (m)
c)
P = 0.353
R2 = 0.011
Height (m)
125
100
75
50
25
0
0
20
40
60
Height (m)
Juniperus ashei

Table 4. Comparing parameters of Ashe juniper (*Juniperus ashei*) to the combined parameters of all other species for each and all quarters, using simple regressions.

Parameter	Quarter	R	R^2	p–value
Number of Individuals	All	0.278	0.077	0.0125
Number of Individuals	NE	0.28	0.078	0.2325
Number of Individuals	NW	0.19	0.00034	0.9379
Number of Individuals	SE	0.513	0.264	0.0206
Number of Individuals	SW	0.032	0.001	0.8949
Basal Diameter	All	0.121	0.015	0.2867
Basal Diameter	NE	0.291	0.085	0.2134
Basal Diameter	NW	0.245	0.06	0.2982
Basal Diameter	SE	0.104	0.011	0.6617
Basal Diameter	SW	0.015	0.00023	0.0949
Canopy Diameter	All	0.033	0.001	0.7722
Canopy Diameter	NE	0.042	0.002	0.8610
Canopy Diameter	NW	0.247	0.061	0.2937
Canopy Diameter	SE	0.156	0.024	0.5107
Canopy Diameter	SW	0.21	0.044	0.3733
Height	All	0.105	0.011	0.3527
Height	NE	0.105	0.011	0.6606
Height	NW	0.148	0.022	0.5321
Height	SE	0.411	0.169	0.0721
Height	SW	0.337	0.113	0.1468

Table 5. Total number of juveniles for each quarter for all twenty live oak clusters. The p-values are results from ANOVA.

Species	NW	SW	NE	SE	p-value
Berberis trifoliolata	23	5	15	9	**0.0869**
Celtis laevigata var. *reticulata*	79	84	88	60	**0.6188**
Diospyros texana	33	26	27	12	**0.2741**
Forestiera pubescens	111	31	62	42	**0.3939**
Ilex decidua	7	12	4	4	**No test**
Ilex vomitoria	5	0	5	3	**No test**
Juniperus ashei	53	27	32	32	**0.3144**
Mimosa aculeaticarpa	0	0	0	1	**No test**
Quercus buckleyi	2	0	0	0	**No test**
Quercus virginiana var. *fusiformis*	73	42	56	37	**0.3230**
Sideroxylon lanuginosum	3	7	13	3	**No test**
Ulmus crassifolia	77	34	51	58	**0.3654**
Zanthoxylum hirsutum	1	2	0	0	**No test**
Total	**467**	**270**	**353**	**261**	**0.4831**
Mean	**35.9**	**20.8**	**27.2**	**20.1**	
SD	**38.3**	**24.1**	**28.8**	**22.6**	

difference in juvenile abundance between the northern and southern halves (P=0.006).

The species with the greatest abundance of juveniles were *C. laevigata*, *U. crassifolia*, *F. pubescens*, *Q. virginiana* and *J. ashei*. *Celtis laevigata* and *U. crassifolia* were the most abundant and had a fairly even distribution between quarter (Table 5). By comparison, *F. pubescens* and *J. ashei* appeared to show preferential establishment in the northwest quarter of the understory but were not statistically different ($P > 0.05$; Table 5).

Photon Flux Density

There were significant differences between measured PFD and quarter for data collected near solar noon (Fig. 20). ANOVA results comparing overstory PFD to quarter were significant at $P = 0.0095$ and understory PFD to quarter were significant at $P = 0.0088$. Tukey's Comparison showed these differences were between the east and west directions. When comparing PFD means in a Students t-test (north vs. south; east vs. west), the significant difference was between east and west (overstory: $P=0.0007$; understory: $P = 0.0010$), while the results for north and south were as follows (overstory: $P = 0.8817$; understory: $P = 0.7085$). Raw data can be found in Appendix B.

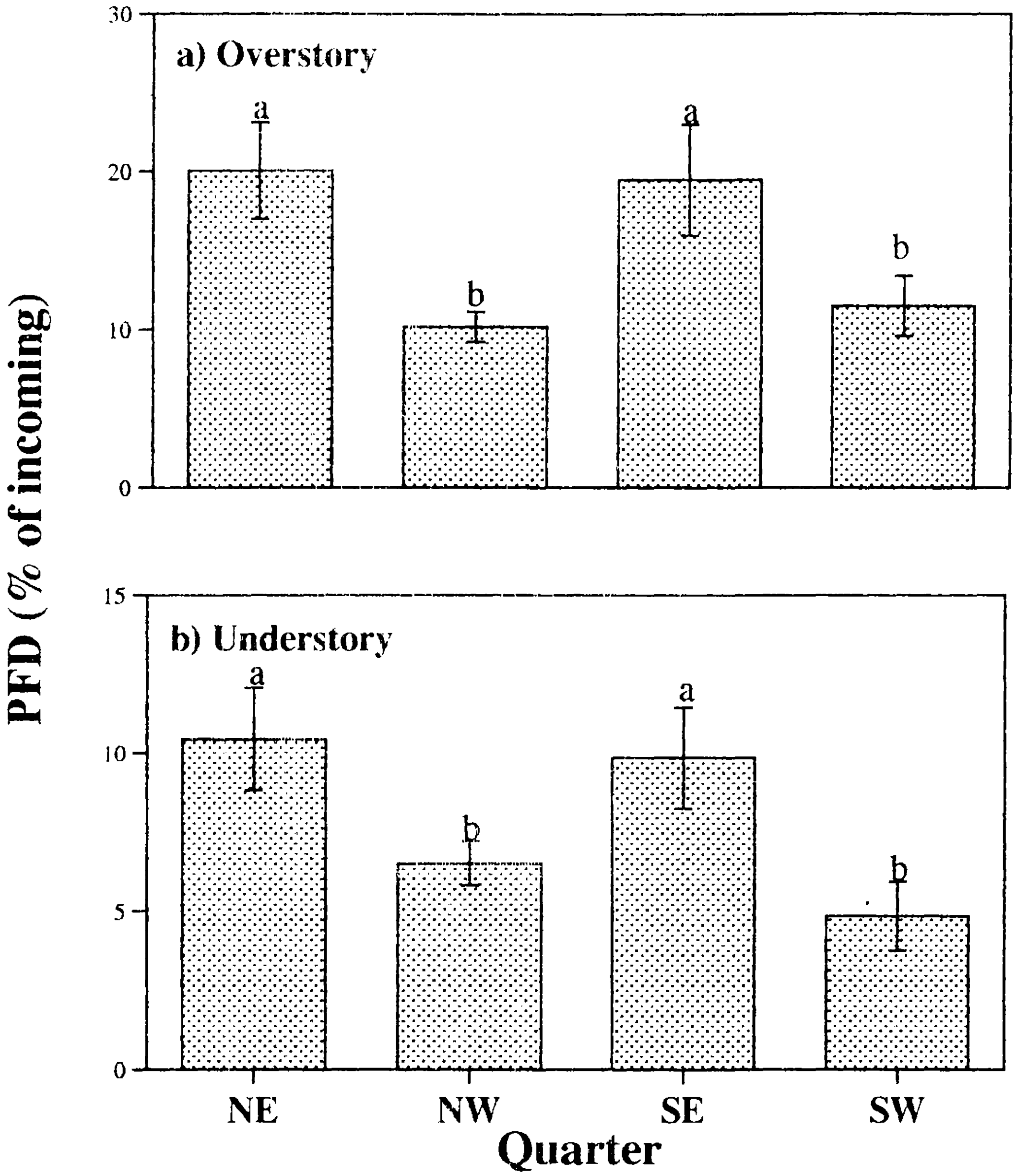


Figure 19 . Mean photo flux density (PFD; 400-700) values through the overstory (live oak canopy) and the understory (canopies of all the understory woody plants) in relation to quarter. Data were collected during daylight savingsd noon, July 1998. Data are means ± 1 SE (N=20). Within a panel, columns with the same letter are not significantly different as determined by Tukey's test.

DISCUSSION

Species Diversity of Live Oak Clusters

Woody plant clustering is a common phenomenon that has been described in a number of arid and semi-arid ecosystems (e.g., Archer et al. 1988, Vetaas 1992), however little is known of the factors that contribute to, and maintain, these woody clumps. The savannas of the Edwards Plateau of Texas are typically characterized by discrete woody clusters embedded within a matrix of herbaceous grassland. These clusters typically consist of a central live oak tree or trees and a number of woody species growing in the understory. In my study, 5 to 11 woody species were found to co-occur in these live oak clusters. However, despite the fact that I sampled clusters that varied greatly with respect to the size of the central live oak, I found no relationship between either the number of woody species or the number of individual plants, and live oak size. These findings run contrary to island biogeography theory (MacArthur and Wilson 1967) which predicts that species richness should increase with island size. Thus, even though these live oak clusters could, at one level, be considered to be islands of trees in a sea of grass, they do not appear to be governed by the same factors that influence species diversity of true islands.

My findings are also in contrast to the study by Archer et al. (1988), who found that, in southern Texas savannas, the number of woody species associated with honey mesquite (*Prosopis glandulosa*) nurse trees increased with increasing size of mesquite. However, the origin and nature of the mesquite-shrub clusters of southern Texas is fundamentally different from that of plateau live oak-shrub clusters on the Edwards Plateau. In particular, mesquite functions as an invasive, colonizing species of the grasslands of the Rio Grande plains, whereas live oaks are thought to be long-established trees in the savannas of the Edwards Plateau. Thus, the mesquite nurse is a component of woody plant succession in grasslands, whereas this appears not to be the case for the live oak system described here.

Asymmetry and Nurse Plant Facilitation

It was initially hypothesized that asymmetrical effects of live oak on microclimate (temperature and shading) would contribute to asymmetries in understory woody vegetation development around the central live oak nurse plant. Indeed, non-random distribution of plants in the understories of their nurse plants has been reported in several other studies. For example, Valiente-Banuet and Ezcurra (1991) found that five of six cactus species studied in Mexico showed preferential establishment on the northern sides of their nurse shrub. Franco and Nobel (1988) also found that *Agave* juveniles, in California, occurred in greater numbers on the northern side of the nurse plant in a warm desert. This distribution pattern was associated with reduced temperatures on the northern, more shaded sides of the nurse. In general, my findings do indicate that some degree of asymmetry exists in woody understory abundance and composition about the live oak. However, this asymmetry is more subtle than that described for nurse plant associations in deserts and is not readily apparent from casual field observations. In this respect, my finding that understory height did not vary with respect to cardinal direction is consistent with the findings of Gass and Barnes (1998) who found no evidence of asymmetry in understory height and degree of development away from the live oak trunk.

In my study, the asymmetry in the woody understory of live oak clusters was only apparent after counting and measuring woody plant canopy and basal diameters. When data from all woody species were combined, I found that the understory plants were more abundant in the northern half than in the southern half of the oak clusters. Specifically, 61% of all adult woody plants and 60% of all juveniles occurred in the northern half of the oak clusters. Individual woody plants were also larger, as indicated by greater stem and canopy diameters, on northern sides of clusters in comparison to southern sides.

While woody plants overall showed greater abundance and larger sizes on the north sides of these oak clusters, the patterns for individual woody species varied greatly. In the clusters I sampled, Ashe juniper was found to have the greatest density and abundance in relation to the other understory woody species, and these findings agree with those of Gass and Barnes (1998) who sampled at Freeman Ranch and several other sites on the eastern Edwards Plateau. The second most abundant understory plant in my study was hackberry (*C. laevigata*). Collectively, Ashe juniper and hackberry made up almost 50% of the woody plant understory in terms of relative densities. However, these two species showed very different patterns of abundance around the oak tree. Specifically, Ashe juniper dominated the woody understory in the northern half of clusters and was most important in NW quarters, whereas, hackberry was the dominant species in the southern half of these clusters. These patterns may be indicative of competition between these two species or may simply reflect differences in environmental requirements for establishment and growth.

Peaks in abundance or size in the NW sides of oak clusters as found for Ashe junipers were also evident in Texas persimmon (*D. texana*) and live oak (*Q. virginiana*). Individuals of elbowbush (*F. pubescens*) however, had both larger canopy and basal diameters on the SE sides relative to other sides of clusters. Interestingly, the juveniles of this species were most abundant in the NW quarter. Perhaps the presence of many, larger individuals of other woody species competitively exclude the growth and survival of *F. pubescens* from these locations.

It is worth noting that some plants of these woody species that were considered juveniles were likely older individuals that have experienced chronic browsing by deer or other herbivores. Indeed, many of the hackberries and cedar elms considered juveniles in this study were shorter than 0.5 m, but had relatively thick trunks. Determination of actual age in these species via tree ring analysis would provide a more definitive classification of plants as juveniles or adults. Also, it is not known whether the live oak juveniles that were counted in my study originated from acorns or were suckers developing from the roots of the mature live oak, though I suspect that most were root sprouts.

While the factors contributing to these asymmetries in understory composition and abundance are unknown, it is possible that variation in microclimate beneath the live oak could contribute, at least in part, to these patterns. It is well known that soil and air temperatures in the understories of savanna trees are considerably less than soil and air temperatures just outside their canopies (Tiedemann and Klemmedson 1977; Belsky et al. 1989; Ko and Reich 1993; Gass and Barnes 1998). In tropical savannas, these differences were greatest in the afternoon and during the summer months (Belsky et al. 1989). In live oak clusters where the woody understory had been removed, variation among cardinal directions in PFD and surface soil temperature in summer was greatest in the afternoon (Gass and Barnes 1998). Gass and Barnes (1998) also found that PFD and air and soil temperatures were lower in the northern and eastern sides of clusters than southern and western sides during late afternoon summer periods, whereas PFD levels were greatest in the western and southern sides. In my study, PFD levels were higher in the eastern half than in the western half. However, these measurements were taken just prior to solar noon and these results are therefore not unexpected given the prevailing solar azimuth angles at this time. To obtain a more comprehensive understanding of how the sun influenced the microclimate beneath the canopy, readings would have to have been taken at different times of the day (morning, noon, and evening) and year (i.e. winter and summer).

The greater abundance and growth of Ashe juniper and other shrubs in the northern halves of oak clusters suggests that these habitats provide the temperature and moisture regimes most suitable for establishment, growth and survival. Burkhardt and Tisdale (1976) reported that most juveniles of another species of juniper, *J. occidentalis,* occurred on the north sides of shrubs and trees in southeastern Idaho. Similarly, Schmidt and Stubbendieck (1993) also found that, in a Nebraska field, eastern red cedar (*J. virginiana*) juveniles preferred north-facing slopes, due to improved moisture availability.

The specific preferential establishment of seedlings of junipers in the more shaded northern half of these oak clusters may represent a compromise between water availability and light needed for photosynthesis (Smith and Huston 1989). On the Edwards Plateau of central Texas, where soils are shallow and droughts are common, transpiration demands and low water availability may be of greater importance in influencing seedling establishment. It is known that reduced light decreases plant productivity due to the light limitations of photosynthesis (Belsky et al. 1989). For plants to maintain photosynthesis and yet have suitable soil moisture availability, they might find the northern half more suitable. Thus, lower light levels in the understory on north sides may be outweighed by greater soil moisture and reduced transpiration in these areas (Callaway and Walker 1997).

In addition to microclimate effects, it is possible that other factors may contribute to the asymmetry in shrub abundance and growth around the live oak clusters. Thurow et al. (1987) found that live oak clusters on the western Edwards Plateau received or intercepted 2.4 times more rainfall, due to the nature of the soil, than the adjacent grasslands. If the oak canopy were to redistribute this intercepted moisture non-uniformly, this could lead to differential soil moisture levels in the understory. At present there are no data to indicate that this can happen.

It is also possible that differential animal activity around the oak could contribute to the patterns in shrub asymmetry observed in the present study. For example, cattle routinely use these clusters to get out of the intense summer Texas sun (personal observation). Perhaps cattle preferentially congregate and utilize the northern more shaded sides of clusters. These cattle may influence the understory composition through elimination of wastes, trampling young plants, or the consumption of plants including the central live oak. A number of other animal species also use many of the woody plants in these clusters for food and cover. For example, the fruits of Texas persimmon, agarito, and plateau live oak are known to be important food resources for birds and small mammals (Martin et al. 1951). The small fleshy cones of Ashe juniper are frequently utilized by wildlife species, such as, cedar waxwings and raccoons (Rollins and Armstrong 1997). Perhaps preferential perching or nesting by birds or mammals in different parts of the live oak canopy could lead to an increase in the accumulation of seeds through elimination.

Finally, it is also conceivable that periodic fire could influence understory growth if the effects were not uniform around the tree. Fires tend to burn at lower temperatures and with less uniformity beneath the canopies of live oaks, due to the higher moisture content in the fuel (Fonteyn et al. 1988). Perhaps the moisture content of the fuel (litter) beneath live oaks is in itself asymmetrical. Fuel in the shaded northern half of the cluster may have greater moisture content than the fuel found in the more exposed southern half, thus influencing how a fire may move beneath the canopy. Alternatively, prior fires could move through these clusters asymmetrically depending on the direction of the prevailing winds. Whether fire can influence woody plant clustering and asymmetry has been little studied, though it is know that Ashe juniper cannot resprout following a fire (Smeins et al. 1997) and is, therefore, very susceptible to periodic burning.

Influence of Ashe Juniper on Other Woody Plants

It is well known that the presence of juniper species, including Ashe juniper, decreases the production of herbaceous plants in the understory (Arnold 1964; McPherson and Wright 1990; Dye et al. 1995; Fulendorf et al. 1997). However, little is known of the effects of Ashe juniper on other co-occurring woody species. Casual observations by Gass and Barnes (1998) suggested that Ashe juniper abundance was inversely related to the abundance of other woody species in live oak clusters. These observations lead me to hypothesize that junipers, once established, competitively exclude other woody species from these understories. As an indirect test of this hypothesis, I examined whether there was any significant relationship between Ashe juniper abundance and size and the abundance/size of other understory species in these clusters. The findings from my study, however, do not indicate any negative relationship between juniper abundance and abundance of other woody plants that would be indicative of competitive exclusion. However in my study, most of the Ashe juniper individuals counted and measured had basal diameters smaller than 1 cm and thus, may have been mostly young, recently established trees (Reinecke et al. 1997). Therefore, it is possible that the competitive effects of the junipers were not fully manifested and a greater time period may be needed for competitive exclusion to occur. It is also possible that some selective clearing of junipers may have occurred in these clusters in the past as part of ranch management practices. However, there were no juniper stumps evident in these clusters and if clearing had been done, it is likely that all of the woody understory would have been removed and not just the juniper.

In conclusion, my study sought to better understand the role that plateau live oak plays in influencing woody plant clusters in a savanna ecosystem on the Edwards Plateau of central Texas. My results indicate that asymmetry in woody plant distribution and abundance does exist beneath live oaks and these patterns are consistent with the hypothesis that microclimate is an important fact of live oak facilitation of these understory species. Thus, positive interactions between woody plants may be important in structuring these woody clusters, as has been found in other plant communities (Archer et al. 1988; Callaway et al. 1991). Further study, however, is needed to elucidate the specific microclimate factors responsible for these patterns, and also to test the possibility that other factors (i.e. fire, animal activity) may be involved in influencing this asymmetry. Understanding the specific nature of this live oak, nurse-plant facilitation is needed to predict the patterns and rates of woody plant encroachment in this region, and will help contribute to the development of management plans aimed at maintaining a desired balance between woody plants and grasses in this savanna ecosystem.

Appendix A.
Summarized data for all oak clusters. No. = the number of individuals

Oak #	Quarter	Species	No.	Basal Diameter	Canopy Diameter	Height
1	NE	*Berberis*	1	8.2	1.86	1.02
1	NE	*Forestiera*	1	0.8	0.86	1.08
1	NE	*Ilex decidua*	5	9.9	5.3	10.05
1	NE	*Ilex vomitoria*	9	17.37	5.58	11.07
1	NE	*Juniperus*	10	59.1	19.8	26.6
1	NE	*Sideroxylon*	2	2.2	1.12	1.46
1	NE	*Ulmus*	4	6	2.8	3.64
1	NW	*Acacia*	1	20.4	2.2	5.8
1	NW	*Berberis*	1	0.9	0.24	0.68
1	NW	*Celtis*	2	0.6	0.86	1.4
1	NW	*Diospyros*	3	2.61	1.35	2.97
1	NW	*Forestiera*	8	10.8	7.44	8.24
1	NW	*Ilex decidua*	2	1.1	0.88	1.36
1	NW	*Ilex vomitoria*	4	7.4	2.64	4.68
1	NW	*Juniperus*	12	94.92	15.12	25.32
1	NW	*Quercus*	3	8.55	3.3	4.41
1	NW	*Sideroxylon*	1	1.3	0.57	1.2
1	NW	*Ulmus*	3	10.71	2.64	4.62
1	SE	*Berberis*	4	5.4	2.72	6.8
1	SE	*Celtis*	1	0.5	0.72	0.72
1	SE	*Ilex decidua*	1	1.1	0.76	1.1
1	SE	*Juniperus*	5	24.35	11.6	10.5
1	SE	*Ulmus*	2	1.6	0.76	1.26
1	SW	*Berberis*	1	11.45	1.96	1.04
1	SW	*Forestiera*	1	0.3	0.91	1.4
1	SW	*Ilex decidua*	1	0.5	0.33	0.39
1	SW	*Juniperus*	5	32.8	10.85	14.1
1	SW	*Ulmus*	5	7.45	2.95	3.65
2	NE	*Berberis*	1	2.1	0.4	0.73
2	NE	*Celtis*	1	0.8	0.265	0.59
2	NE	*Diospyros*	1	13.2	2.22	2.1
2	NE	*Juniperus*	14	43.05	12.93	24.23
2	NE	*Ulmus*	1	2.1	0.76	0.52
2	NW	*Juniperus*	9	26.8	7.83	10.2
2	NW	*Quercus*	1	0.6	0.32	0.67
2	SE	*Celtis*	1	1.9	1.25	2.3
2	SE	*Diospyros*	3	5	2.47	4.82
2	SE	*Juniperus*	2	3.9	2.44	3.16
2	SE	*Quercus*	3	5.51	3.30	5.48
2	SE	*Sideroxylon*	1	0.9	0.48	0.97
2	SE	*Ulmus*	1	2.7	0.67	1.65
2	SW	*Berberis*	1	1.7	0.49	0.52
2	SW	*Juniperus*	6	16	7.36	10.73
2	SW	*Quercus*	7	31.4	8.39	14.57
3	NE	*Berberis*	4	33.2	7.22	6.41
3	NE	*Celtis*	9	12.5	6.48	13.7

Appendix A. Continued

Oak #	Quarter	Species	No.	Basal Diameter	Canopy Diameter	Height
3	NE	*Diospyros*	6	55	16.63	12.82
3	NE	*Forestiera*	3	6.4	2.43	3.13
3	NE	*Juniperus*	2	9.2	3.56	5.07
3	NE	*Quercus*	1	1.1	0.52	1.06
3	NE	*Ulmus*	15	37.5	11.21	26.25
3	NW	*Berberis*	2	13.6	2.59	1.82
3	NW	*Diospyros*	4	0	0	0
3	NW	*Juniperus*	3	10.2	4.31	5.91
3	NW	*Ulmus*	6	15.6	5.34	10.07
3	SE	*Berberis*	5	0	0	0
3	SE	*Celtis*	3	5	1.5	4.19
3	SE	*Diospyros*	11	89.08	22.75	23.56
3	SE	*Forestiera*	3	13.2	4.16	3.98
3	SE	*Sideroxylon*	1	0.7	0.39	0.82
3	SE	*Ulmus*	7	9.3	3.33	8.25
3	SW	*Berberis*	1	3.6	1.07	1.08
3	SW	*Celtis*	4	12.36	7.18	10.14
3	SW	*Diospyros*	6	44.38	11.29	12.68
3	SW	*Ilex decidua*	1	0.7	0.12	1.1
3	SW	*Sideroxylon*	2	2.5	1.38	2.44
4	NE	*Celtis*	2	4.5	2.82	4.26
4	NE	*Diospyros*	4	14.4	3.76	9.37
4	NE	*Juniperus*	6	35.6	10.04	10.33
4	NE	*Sideroxylon*	3	6.6	4.19	3.86
4	NW	*Celtis*	1	1.3	0.44	1.73
4	NW	*Forestiera*	1	1.2	0.42	0.82
4	NW	*Juniperus*	8	32.4	9.14	15.52
4	NW	*Sideroxylon*	2	1.8	0.79	1.76
4	SE	*Celtis*	3	7.5	2.49	4.38
4	SE	*Diospyros*	1	4.6	2.5	3.71
4	SE	*Juniperus*	4	22.5	8.71	11.36
4	SE	*Sideroxylon*	3	3	1.22	2.64
4	SW	*Berberis*	1	7.2	1.2	0.67
4	SW	*Celtis*	4	3.8	1.72	3.08
4	SW	*Juniperus*	6	25.4	7.75	13.14
4	SW	*Sideroxylon*	6	6.1	3.5	6.91
5	NE	*Berberis*	2	13.1	2.98	1.7
5	NE	*Celtis*	5	8.7	4	7.55
5	NE	*Diospyros*	7	19.2	7.75	12.11
5	NE	*Forestiera*	1	0.5	0.2	0.55
5	NE	*Juniperus*	7	64.4	16.23	21.22
5	NW	*Berberis*	4	22.3	10.65	4.8
5	NW	*Celtis*	10	20.4	13	18.93
5	NW	*Diospyros*	9	35.4	26.86	16.49
5	NW	*Forestiera*	3	20.6	4	3.49
5	NW	*Juniperus*	7	35.9	13.99	16.64
5	NW	*Ptelea*	1	1.4	1.4	2.18

Appendix A. Continued

Oak #	Quarter	Species	No.	Basal Diameter	Canopy Diameter	Height
5	NW	*Quercus*	1	0.9	0.5	0.65
5	NW	*Sideroxylon*	3	4.9	3.1	4.63
5	NW	*Ulmus*	1	0.5	0.35	0.65
5	SE	*Berberis*	2	18.2	2.52	1.85
5	SE	*Celtis*	4	5.01	2.8	3.6
5	SE	*Diospyros*	3	10.6	6.6	8.76
5	SE	*Forestiera*	7	20.40	7.88	9.44
5	SE	*Juniperus*	2	6.44	3.32	4.26
5	SE	*Sideroxylon*	2	4.4	3.5	4.1
5	SW	*Berberis*	1	0.5	0.25	0.58
5	SW	*Celtis*	10	26.22	11.3	14.90
5	SW	*Diospyros*	9	27.44	11.58	15.09
5	SW	*Juniperus*	3	7.77	3.91	5.91
5	SW	*Sideroxylon*	1	2.1	1.5	2.75
6	NE	*Berberis*	1	12.6	1.6	1
6	NE	*Celtis*	11	11.3	7.49	16.61
6	NE	*Diospyros*	5	13.3	5.85	9.86
6	NE	*Forestiera*	6	21.1	14.39	13.52
6	NE	*Juniperusus*	24	114.2	36.15	53.4
6	NE	*Quercus*	3	1.7	1.5	2.55
6	NE	*Zanthoxylum*	3	1.9	0.94	2.9
6	NW	*Berberis*	1	4.8	1.7	1.05
6	NW	*Celtis*	10	6.7	3.78	9.12
6	NW	*Forestiera*	2	3.4	3.6	2.97
6	NW	*Ilex vomitoria*	1	0.4	0.44	0.8
6	NW	*Juniperusus*	25	130.2	38.08	51.18
6	NW	*Quercus*	4	3.4	2.14	4.08
6	SE	*Berberis*	3	23	3.57	3.06
6	SE	*Celtis*	4	2.4	2.11	3.64
6	SE	*Diospyros*	5	2.8	1.93	3.41
6	SE	*Forestiera*	2	1	0.37	1.16
6	SE	*Juniperusus*	6	21.3	10.8	9.5
6	SW	*Berberis*	2	9.9	2.06	2
6	SW	*Celtis*	3	1.6	1.09	1.91
6	SW	*Forestiera*	8	4.8	2.77	5.47
6	SW	*Juniperusus*	12	31.30	13.62	21.61
6	SW	*Quercus*	1	2.6	1.32	2.71
6	SW	*Sideroxylon*	2	1.2	0.9	1.83
6	SW	*Zanthoxylum*	3	3.5	1.2	2.12
7	NE	*Celtis*	8	9.3	5.63	10.38
7	NE	*Diospyros*	2	14.1	3.87	5.65
7	NE	*Forestiera*	5	6.9	6.56	7.12
7	NE	*Juniperusus*	9	38.2	13.03	18.72
7	NW	*Berberis*	1	11.3	2.67	1.24
7	NW	*Celtis*	6	4.1	3.17	6.94
7	NW	*Forestiera*	8	18.3	13.95	12.17
7	NW	*Juniperusus*	7	56.9	19.04	23.39

Appendix A. Continued

Oak #	Quarter	Species	No.	Basal Diameter	Canopy Diameter	Height
7	SE	*Celtis*	2	2.3	1.04	1.33
7	SE	*Diospyros*	1	5.3	1.25	2.05
7	SE	*Juniperusus*	8	52.5	16.41	19.48
7	SW	*Celtis*	6	3.9	2.35	4.42
7	SW	*Diospyros*	4	5.6	2.02	5.42
7	SW	*Forestiera*	1	1.4	1.4	1
7	SW	*Juniperusus*	5	17.6	3.95	5.6
8	NE	*Celtis*	10	12.7	5.56	9.57
8	NE	*Diospyros*	6	6.8	4.61	6.19
8	NE	*Forestiera*	15	16.1	14.18	14.48
8	NE	*Ilex vomitoria*	3	3.6	1.42	1.8
8	NE	*Juniperusus*	3	7.4	4.87	6.91
8	NE	*Sideroxylon*	4	4.6	4.11	4.47
8	NE	*Zanthoxylum*	1	0.7	0.85	0.4
8	NW	*Berberis*	1	1.7	0.72	0.62
8	NW	*Celtis*	8	6.9	3.13	81.06
8	NW	*Diospyros*	7	15.9	7.69	9.29
8	NW	*Forestiera*	5	16.6	5.94	5.87
8	NW	*Ilex decidua*	1	0.6	0.4	0.5
8	NW	*Juniperusus*	8	26.6	11.42	10.35
8	NW	*Sideroxylon*	3	4.86	3.19	3.32
8	NW	*Zanthoxylum*	1	1.6	0.5	0.9
8	SE	*Celtis*	7	10.5	4.72	5.81
8	SE	*Diospyros*	11	12.1	7.6	13.12
8	SE	*Forestiera*	11	20.6	9.702	9.61
8	SE	*Juniperusus*	4	27	8.55	8.85
8	SE	*Zanthoxylum*	2	2.1	1.89	1.28
8	SW	*Berberis*	2	27.5	3.05	2.12
8	SW	*Celtis*	5	6.8	3	5.65
8	SW	*Diospyros*	4	7.3	3.42	6.29
8	SW	*Forestiera*	2	1.6	1.57	1.36
8	SW	*Juniperusus*	4	31.4	8.84	9.8
9	NE	*Celtis*	15	16.2	9.3	17.36
9	NE	*Diospyros*	3	10.9	4.61	7.27
9	NE	*Juniperusus*	7	29.4	10.99	19.18
9	NE	*Sideroxylon*	7	6.6	3.34	10.9
9	NE	*Ulmus*	13	14.6	6.95	12.3
9	NW	*Celtis*	12	10	5.44	8.8
9	NW	*Diospyros*	2	1.95	0.99	1.67
9	NW	*Juniperusus*	13	116.6	21.14	32.55
9	NW	*Ulmus*	38	33.5	17.51	29.53
9	SE	*Berberis*	2	36.1	2.64	2.41
9	SE	*Celtis*	6	5.6	2.18	3.74
9	SE	*Diospyros*	5	16.8	6.4	7.46
9	SE	*Forestiera*	3	3.7	2.75	2.77
9	SE	*Juniperusus*	3	26.5	7.92	7.92
9	SE	*Ulmus*	7	5.2	2.74	5.18

Appendix A. Continued

Oak #	Quarter	Species	No.	Basal Diameter	Canopy Diameter	Height
9	SW	*Celtis*	10	9.5	8.11	12.31
9	SW	*Diospyros*	3	6.25	1.81	3.38
9	SW	*Juniperusus*	1	0.6	0.4	0.78
9	SW	*Quercus*	2	3.3	2.36	2
9	SW	*Ulmus*	3	6	0.97	1.85
10	NE	*Berberis*	3	4.7	3.09	2.23
10	NE	*Celtis*	10	8.8	4.4	7.67
10	NE	*Diospyros*	5	14.7	5.8	9.05
10	NE	*Forestiera*	1	2.8	1.46	1.2
10	NE	*Ilex decidua*	6	5	3.53	5.67
10	NE	*Juniperusus*	8	48.2	14.69	22.52
10	NE	*Sophora*	1	0.9	1.39	2.51
10	NE	*Ulmus*	3	2.4	1.61	1.93
10	NW	*Celtis*	11	8.8	4.16	7.55
10	NW	*Diospyros*	2	4.9	1.92	2.77
10	NW	*Ilex decidua*	3	16.6	5.15	7.72
10	NW	*Juniperusus*	5	34.3	10.64	13.15
10	NW	*Ulmus*	7	7.5	3.08	5.39
10	SE	*Celtis*	14	17.5	6.81	10.31
10	SE	*Diospyros*	2	0.6	0.61	1.13
10	SE	*Forestiera*	1	2.6	1.4	1.48
10	SE	*Juniperusus*	3	9.2	3.14	4.59
10	SE	*Ulmus*	2	2.6	1.11	1.22
10	SW	*Celtis*	13	14.6	6.1	10.43
10	SW	*Diospyros*	6	7.4	3.82	8.87
10	SW	*Juniperusus*	2	11	3.48	4.94
10	SW	*Ulmus*	1	1	0.5	0.69
10	SW	*Zanthoxylum*	1	3	1.57	2.27
11	NE	*Celtis*	6	4.1	3.02	5.59
11	NE	*Diospyros*	3	3.1	1.55	3.81
11	NE	*Juniperusus*	17	114.4	36.28	50.15
11	NE	*Quercus*	2	1.7	0.7	1.61
11	NE	*Ulmus*	1	0.4	0.32	0.56
11	NW	*Celtis*	5	3.7	2.43	5.08
11	NW	*Diospyros*	3	11.1	3.27	5.62
11	NW	*Ilex decidua*	1	0.9	0.41	1.21
11	NW	*Juniperusus*	15	66.8	24.59	35.85
11	NW	*Ulmus*	4	3.9	1.47	2.63
11	SE	*Berberis*	1	4.6	0.85	0.47
11	SE	*Celtis*	7	3.7	2.47	6.08
11	SE	*Diospyros*	1	7.3	2.7	1.61
11	SE	*Juniperusus*	6	77.9	14.43	18.36
11	SW	*Celtis*	9	6.7	3.54	10.08
11	SW	*Diospyros*	1	5.1	2.15	3.46
11	SW	*Juniperusus*	6	32.1	10.82	14.88
11	SW	*Sideroxylon*	1	1.5	0.23	0.7
11	SW	*Ulmus*	2	1.5	1.12	1.23

Appendix A. Continued

Oak #	Quarter	Species	No.	Basal Diameter	Canopy Diameter	Height
12	NE	*Berberis*	2	3.1	2.01	1.34
12	NE	*Celtis*	5	3.5	2.78	4.08
12	NE	*Diospyros*	4	1.9	1.47	2.84
12	NE	*Forestiera*	2	0.7	0.48	1.42
12	NE	*Juniperusus*	7	96.7	17.73	19.47
12	NE	*Ulmus*	1	1	0.34	0.66
12	NW	*Berberis*	1	0.9	0.44	0.61
12	NW	*Celtis*	14	14.6	6.3	12.5
12	NW	*Diospyros*	4	2.9	1.36	3.07
12	NW	*Forestiera*	1	0.7	0.22	0.75
12	NW	*Juniperusus*	14	96.6	27.61	34.48
12	NW	*Ulmus*	4	3.4	1.77	2.29
12	SE	*Berberis*	1	0.6	0.35	0.53
12	SE	*Celtis*	8	6.6	4.81	8.25
12	SE	*Diospyros*	5	20	5.55	7.17
12	SE	*Juniperusus*	6	5.7	2.48	4.51
12	SE	*Quercus*	10	21.1	10.72	12.72
12	SE	*Ulmus*	2	1.7	0.61	1.4
12	SE	*Ziziphus*	1	1.8	1.38	1.4
12	SW	*Celtis*	9	9.3	3.39	6.6
12	SW	*Diospyros*	1	9.5	1.9	2.89
12	SW	*Juniperusus*	5	8.6	3.81	6.24
12	SW	*Quercus*	22	31.1	16.58	21.93
12	SW	*Ulmus*	4	4.6	1.37	2.48
13	NE	*Celtis*	3	3	2.94	3.75
13	NE	*Diospyros*	2	7.4	2.37	3.34
13	NE	*Juniperus*	8	81.4	26.35	24.62
13	NE	*Quercus*	3	2.9	1.29	1.89
13	NE	*Ulmus*	2	2.5	1.17	1.51
13	NW	*Celtis*	2	2.2	1.22	1.72
13	NW	*Diospyros*	1	4.6	2.11	1.84
13	NW	*Juniperus*	14	43.8	18.9	21.73
13	NW	*Ulmus*	5	10	3.31	5.17
13	SE	*Celtis*	7	7.8	2.57	5.11
13	SE	*Diospyros*	3	10.5	3.89	6.2
13	SE	*Juniperus*	3	24	9.09	9.3
13	SW	*Celtis*	3	3	1	1.98
13	SW	*Diospyros*	5	58.1	10.3	19.47
13	SW	*Forestiera*	2	2.9	2.19	2.07
13	SW	*Juniperus*	3	8.8	3.74	6.42
13	SW	*Quercus*	1	0.7	0.32	0.61
13	SW	*Ulmus*	3	6	1.83	2.71
14	NE	*Berberis*	2	10.9	2.92	2.62
14	NE	*Celtis*	26	20.6	10.03	21.04
14	NE	*Diospyros*	4	4.3	1.88	3.54
14	NE	*Forestiera*	8	7.8	4.96	7.84
14	NE	*Juniperus*	27	96.5	38.12	55.56

Appendix A. Continued

Oak #	Quarter	Species	No.	Basal Diameter	Canopy Diameter	Height
14	NE	*Quercus*	11	6.8	4.38	8.79
14	NE	*Sideroxylon*	2	1.7	1.77	1.8
14	NE	*Ulmus*	22	34.4	14.21	18.36
14	NW	*Celtis*	10	11.3	5.09	7.21
14	NW	*Diospyros*	4	5	2.02	3.47
14	NW	*Forestiera*	2	3.5	2.52	3.27
14	NW	*Juniperus*	15	50.5	20.02	30.79
14	NW	*Quercus*	9	5.1	2.94	6.59
14	NW	*Ulmus*	20	31.6	11.94	14.7
14	SE	*Celtis*	15	24.6	11.22	23.44
14	SE	*Diospyros*	4	12.7	5	9.91
14	SE	*Forestiera*	9	21.5	7.03	9.68
14	SE	*Juniperus*	18	45.7	22.3	29.75
14	SE	*Quercus*	6	22.5	8.04	13.09
14	SE	*Ulmus*	20	49.8	18.98	31.16
14	SW	*Diospyros*	3	66.8	12.5	7.79
14	SW	*Forestiera*	1	0.7	0.46	0.6
14	SW	*Juniperus*	15	54.1	22.12	27.58
14	SW	*Quercus*	3	3.4	1.25	1.88
14	SW	*Ulmus*	11	11.9	5.63	8.21
15	NE	*Berberis*	2	6	1.85	1.94
15	NE	*Celtis*	6	4.3	2.15	4.79
15	NE	*Diospyros*	2	1.7	1.39	1.85
15	NE	*Forestiera*	2	1.2	0.94	2.01
15	NE	*Juniperus*	8	36.4	14.53	21.8
15	NE	*Sideroxylon*	2	1.6	1.44	2.73
15	NE	*Ulmus*	2	2.7	0.66	1.11
15	NW	*Berberis*	2	8.5	3.55	1.71
15	NW	*Celtis*	4	4.6	2.87	4.35
15	NW	*Diospyros*	2	7.3	2.99	3.16
15	NW	*Forestiera*	1	1.5	0.91	0.75
15	NW	*Juniperus*	13	125.8	29.8	37.01
15	NW	*Sideroxylon*	1	1.8	0.89	1.85
15	NW	*Ulmus*	4	4.5	5.12	2.76
15	NW	*Zanthoxylum*	1	1.65	1.05	0.91
15	SE	*Celtis*	13	13.6	6.59	13.1
15	SE	*Diospyros*	2	2.1	1.33	2.54
15	SE	*Juniperus*	2	35.7	7.25	8.1
15	SE	*Sideroxylon*	2	3.6	2.56	5.35
15	SE	*Ulmus*	3	2.6	1.18	2.23
15	SW	*Berberis*	1	3.1	0.95	0.65
15	SW	*Celtis*	17	14.3	7.92	15.61
15	SW	*Diospyros*	2	10.2	3.55	4.32
15	SW	*Juniperus*	10	13	11.23	15.6
15	SW	*Ulmus*	7	8	3.88	7.67
16	NE	*Celtis*	14	12.6	4.75	11.84
16	NE	*Condalia*	1	2.3	0.79	1.06

Appendix A. Continued

Oak #	Quarter	Species	No.	Basal Diameter	Canopy Diameter	Height
16	NE	*Diospyros*	4	23.6	7.99	10.45
16	NE	*Forestiera*	2	2.3	0.89	1.68
16	NE	*Juniperus*	6	28.6	9.99	10.09
16	NE	*Quercus*	2	3.3	1.34	2.1
16	NE	*Ulmus*	28	35	13.06	24.33
16	NW	*Berberis*	1	3.2	0.95	0.63
16	NW	*Celtis*	11	12.11	4.37	13.01
16	NW	*Diospyros*	6	13.7	5.98	9.67
16	NW	*Forestiera*	6	40.2	11.85	9.52
16	NW	*Juniperus*	2	24.9	4.9	8.08
16	NW	*Ulmus*	21	36.5	14.1	26.59
16	SE	*Celtis*	6	10.3	3.89	7.19
16	SE	*Diospyros*	3	18.8	7.27	5.61
16	SE	*Juniperus*	5	10.9	5.51	6.68
16	SE	*Prosopis*	1	7.1	3	1.4
16	SE	*Ulmus*	6	13.6	3.32	7.03
16	SW	*Berberis*	2	9.6	1.74	1.65
16	SW	*Celtis*	8	9.33	2.59	5.83
16	SW	*Diospyros*	3	7.76	1.54	2.25
16	SW	*Juniperus*	7	28.6	13.33	15.85
16	SW	*Quercus*	1	0.3	0.19	0.5
16	SW	*Sideroxylon*	1	1.8	0.35	0.7
16	SW	*Ulmus*	11	16.6	5.49	8.85
17	NE	*Celtis*	7	3.9	2.59	4.23
17	NE	*Diospyros*	2	2.2	1.35	1.47
17	NE	*Forestiera*	1	0.8	0.61	0.98
17	NE	*Juniperus*	5	23.8	10.04	10.09
17	NW	*Celtis*	6	6.4	3.89	5.41
17	NW	*Diospyros*	1	0.8	0.32	0.67
17	NW	*Forestiera*	20	28.5	32.9	20.34
17	NW	*Juniperus*	1	1.3	0.73	2.62
17	NW	*Quercus*	4	5.9	1.97	2.89
17	SE	*Celtis*	3	2.2	1.1	2.14
17	SE	*Forestiera*	1	3.3	1.23	1.4
17	SE	*Juniperus*	3	4.5	2.77	3.98
17	SE	*Quercus*	1	0.6	0.36	0.5
17	SW	*Berberis*	1	5.9	1.9	0.8
17	SW	*Celtis*	6	6.4	3.2	6.46
17	SW	*Diospyros*	2	1.2	0.65	1.31
17	SW	*Forestiera*	7	14.4	10.61	8.65
17	SW	*Juniperus*	1	0.8	0.45	0.85
18	NE	*Berberis*	4	14.7	2.95	3.23
18	NE	*Celtis*	2	7.9	3.2	4.42
18	NE	*Diospyros*	6	12.2	5.61	9.71
18	NE	*Forestiera*	22	37.4	16.09	19.24
18	NE	*Juniperus*	2	1.4	0.84	1.97
18	NE	*Prosopis*	1	11.5	3.07	2.5

Appendix A. Continued

Oak #	Quarter	Species	No.	Basal Diameter	Canopy Diameter	Height
18	NE	*Sideroxylon*	1	0.5	0.46	0.79
18	NE	*Ulmus*	1	1.7	0.54	0.75
18	NW	*Berberis*	7	24.6	7.54	6.6
18	NW	*Celtis*	17	11.2	6.35	13.91
18	NW	*Diospyros*	6	16.7	8.37	14.81
18	NW	*Forestiera*	20	27.1	14.12	16.42
18	NW	*Juniperus*	16	34.7	14.84	23.23
18	NW	*Prosopis*	1	14.3	6.3	2.75
18	NW	*Quercus*	3	1.8	2.17	1.71
18	NW	*Sideroxylon*	1	1	0.4	0.7
18	SE	*Celtis*	2	0.9	0.6	1.67
18	SE	*Diospyros*	3	4.1	2.06	4.59
18	SE	*Forestiera*	3	14.8	6	3.72
18	SE	*Juniperus*	2	7.4	2.55	3.6
18	SE	*Quercus*	1	0.5	0.34	0.7
18	SW	*Celtis*	4	3.3	1.66	3.22
18	SW	*Diospyros*	3	15.1	5.48	9.82
18	SW	*Forestiera*	4	11.7	7.55	3.85
18	SW	*Juniperus*	1	3	1.33	1.72
18	SW	*Quercus*	1	0.7	0.4	0.59
18	SW	*Sideroxylon*	1	2.1	0.49	0.65
19	NE	*Berberis*	7	43.8	5.73	6.64
19	NE	*Celtis*	5	5.5	2.85	4.9
19	NE	*Diospyros*	5	5.1	5.08	5.39
19	NE	*Forestiera*	6	4.1	2.92	3.93
19	NE	*Juniperus*	7	21.1	6.06	12.2
19	NE	*Quercus*	4	4.6	1.93	2.97
19	NE	*Ulmus*	2	1.6	0.58	1.36
19	NW	*Berberis*	5	7.3	3.18	3.19
19	NW	*Celtis*	1	1	0.42	1.11
19	NW	*Diospyros*	4	2.7	1.54	2.73
19	NW	*Forestiera*	5	2.6	1.82	3.94
19	NW	*Juniperus*	22	55.6	22.38	35.11
19	NW	*Ulmus*	2	2.7	0.64	1.64
19	SE	*Berberis*	3	6.4	1.63	2.1
19	SE	*Celtis*	1	0.8	0.62	1.5
19	SE	*Forestiera*	2	3.4	2.02	2.1
19	SE	*Juniperus*	3	16.3	5.83	7.51
19	SE	*Quercus*	26	41.4	16.45	28.39
19	SW	*Berberis*	3	8.6	3.07	3.13
19	SW	*Celtis*	1	1.3	0.55	0.6
19	SW	*Forestiera*	3	4.8	2.39	2.29
19	SW	*Juniperus*	19	47.1	18.83	26.67
19	SW	*Quercus*	1	3.5	2	1.36
19	SW	*Sideroxylon*	1	0.4	0.31	0.9
20	NE	*Berberis*	1	4	1.22	0.65
20	NE	*Celtis*	5	20.1	6.39	13.13

Appendix A. Continued

Oak #	Quarter	Species	No.	Basal Diameter	Canopy Diameter	Height
20	NE	*Diospyros*	2	5.6	2.85	3.87
20	NE	*Forestiera*	4	5.3	2.59	3.11
20	NE	*Juniperus*	3	5.8	2.85	4.83
20	NW	*Berberis*	1	2.4	0.95	0.89
20	NW	*Celtis*	4	5.4	1.02	3.11
20	NW	*Diospyros*	3	13.9	4.29	4.9
20	NW	*Forestiera*	8	7	4.32	5.69
20	NW	*Juniperus*	1	3.8	1.35	2.29
20	NW	*Prosopis*	1	8.8	4.95	3.66
20	NW	*Quercus*	1	1.2	1.75	0.65
20	SE	*Celtis*	2	2.4	0.63	1.32
20	SE	*Forestiera*	1	1.3	0.51	0.8
20	SW	*Celtis*	4	6.1	1.96	3.7
20	SW	*Diospyros*	4	14.3	6.89	10
20	SW	*Forestiera*	1	0.7	0.75	1.15

Appendix B.

Raw and percent relative density PFD data. Relative PFD was calculated by dividing the point PFD measurement into the overstory and understory values then multiplying by 100.

Tree #	Date	Time	Direction	Point	Overstory	% PFD	Understory	% PFD
1	7/26/98	11:13	NE	1752.10	342.49	19.55	564.82	32.24
1	7/26/98	11:13	SE	1804.10	424.92	18.98	337.46	18.71
1	7/26/98	11:13	SW	462.76	64.19	13.87	46.71	10.09
1	7/26/98	11:13	NW	1492.77	195.22	13.08	70.58	4.73
2	7/26/98	11:30	NE	1561.43	321.39	20.58	330.42	21.16
2	7/26/98	11:30	SE	1593.77	430.32	27.00	340.12	21.34
2	7/26/98	11:30	SW	1774.10	353.49	19.93	74.92	4.22
2	7/26/98	11:30	NW	1685.77	144.22	8.56	70.85	4.20
3	7/10/98	12:40	NE	1838.77	541.25	29.44	51.5	2.80
3	7/10/98	12:40	SE	1834.10	183.69	10.02	70.72	3.86
3	7/10/98	12:40	SW	1889.10	598.49	31.68	73.28	3.88
3	7/10/98	12:40	NW	1877.77	315.92	16.82	77.15	4.11
4	7/10/98	12:25	NE	1836.43	325.79	17.74	46.67	2.54
4	7/10/98	12:25	SE	1862.43	330.65	17.75	44.71	2.40
4	7/10/98	12:25	SW	1860.77	189.34	10.18	30.87	1.66
4	7/10/98	12:25	NW	1846.10	104.09	5.64	208.1	11.27
5	7/7/98	11:30	NE	1751.10	190.29	10.87	138.45	7.91
5	7/7/98	11:30	SE	1667.77	214.47	12.86	44.71	2.68
5	7/7/98	11:30	SW	1674.77	41.57	2.48	36.96	2.21
5	7/7/98	11:30	NW	1642.77	102.22	6.22	51.61	3.14
6	7/7/98	11:45	NE	1785.77	194.57	10.90	31.52	1.77
6	7/7/98	11:45	SE	1736.77	382.07	22.00	82.22	4.73
6	7/7/98	11:45	SW	1712.10	39.09	2.28	54.07	3.16
6	7/7/98	11:45	NW	1753.43	184.59	10.53	53.36	3.04
7	7/7/98	12:00	NE	1721.10	195.09	11.34	127.82	7.43
7	7/7/98	12:00	SE	1764.43	198.69	11.26	36.47	2.07
7	7/7/98	12:00	SW	1772.43	141.65	7.99	89.38	5.04
7	7/7/98	12:00	NW	1767.10	114.93	6.50	23.35	1.32
8	7/7/98	11:15	NE	1666.43	153.9	9.24	274.43	16.47
8	7/7/98	11:15	SE	1700.43	64.79	3.81	55.99	3.29
8	7/7/98	11:15	SW	1605.10	32.65	2.03	43.91	2.74
8	7/7/98	11:15	NW	1638.10	141.96	8.67	72.89	4.45
9	7/2/98	11:55	NE	1771.43	1261.83	71.23	184.85	10.44
9	7/2/98	11:55	SE	1836.76	521.55	28.40	360.72	19.64
9	7/2/98	11:55	SW	1809.10	139.57	7.71	167.92	9.28
9	7/2/98	11:55	NW	1790.10	184.69	10.32	37.1	2.07
10	7/2/98	11:00	NE	1639.43	414.25	25.27	122.76	7.49
10	7/2/98	11:00	SE	1630.43	145.86	8.95	141.6	8.68
10	7/2/98	11:00	SW	1651.10	71.16	4.31	54.45	3.30
10	7/2/98	11:00	NW	1653.80	61.06	3.69	43.48	2.63
11	7/2/98	11:35	NE	1668.77	326.82	19.58	120.46	7.22
11	7/2/98	11:35	SE	1679.40	335.69	19.99	131.14	7.81
11	7/2/98	11:35	SW	1715.77	201.65	11.75	95.95	5.59
11	7/2/98	11:35	NW	1706.77	152.12	8.91	33.28	1.95
12	7/2/98	12:08	NE	1843.43	485.89	26.36	227.19	12.32
12	7/2/98	12:08	SE	1837.10	867.18	47.20	455.09	24.77
12	7/2/98	12:08	SW	1818.77	504.59	27.74	161.82	8.90
12	7/2/98	12:08	NW	1815.43	122.94	6.77	49.35	2.72

Appendix B. continued

Tree #	Date	Time	Direction	Point	Overstory	% PFD	Understory	% PFD
13	7/26/98	12:10	NE	1991.77	189.85	9.53	158.75	7.97
13	7/26/98	12:10	SE	1639.10	206.29	12.59	114.57	6.99
13	7/26/98	12:10	SW	1342.43	206.23	15.36	96.77	7.21
13	7/26/98	12:10	NW	1955.43	148.72	7.61	69.07	3.53
14	7/26/98	12:38	NE	1960.43	383.29	19.55	201.15	10.26
14	7/26/98	12:38	SE	1341.87	190.19	14.17	88.79	6.62
14	7/26/98	12:38	SW	1928.77	200.22	10.38	118.76	6.16
14	7/26/98	12:38	NW	1332.44	164.22	12.32	78.97	5.93
15	7/26/98	12:25	NE	2037.77	167.49	8.22	113.78	5.58
15	7/26/98	12:25	SE	1969.77	106.34	5.40	239.89	12.18
15	7/26/98	12:25	SW	1838.43	107.58	5.85	186.55	10.15
15	7/26/98	12:25	NW	1855.43	194.85	10.50	252.25	13.60
16	7/26/98	11:55	NE	1862.77	425.59	22.85	133.45	7.16
16	7/26/98	11:55	SE	1884.77	181.05	9.61	107.56	5.71
16	7/26/98	11:55	SW	1887.10	141.24	7.48	21.97	1.16
16	7/26/98	11:55	NW	1970.10	440.15	22.34	145.93	7.41
17	7/10/98	1:10	NE	1938.43	182.69	9.42	90.36	4.66
17	7/10/98	1:10	SE	1955.10	89.44	4.57	82.35	4.21
17	7/10/98	1:10	SW	1885.10	112.27	5.96	72.86	3.87
17	7/10/98	1:10	NW	1943.77	184.39	9.49	125.5	6.46
18	7/10/98	12:33	NE	1940.43	305.99	15.77	232.64	11.99
18	7/10/98	12:33	SE	1778.10	310.42	17.46	193.03	10.86
18	7/10/98	12:33	SW	1869.10	64.42	3.45	101.08	5.41
18	7/10/98	12:33	NW	1825.77	170.89	9.36	61.94	3.39
19	7/10/98	12:15	NE	1839.10	313.65	17.05	239.09	13.00
19	7/10/98	12:15	SE	1848.43	1286.41	69.59	370.99	20.07
19	7/10/98	12:15	SW	1854.77	408.19	22.01	312.75	16.86
19	7/10/98	12:15	NW	1893.10	275.89	14.57	110.15	5.82
20	7/10/98	12.46	NE	1894.10	509.09	26.88	351.35	18.55
20	7/10/98	12.46	SE	1915.10	543.99	28.41	203.16	10.61
20	7/10/98	12.46	SW	1977.43	368.44	18.63	380.89	19.26
20	7/10/98	12.46	NW	1891.10	218.05	11.53	107.89	5.71

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