

FACTORS AFFECTING SITE PRODUCTIVITY OF LOBLOLLY PINE PLANTATIONS ACROSS THE SOUTHEASTERN UNITED STATES

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ABSTRACT

Loblolly pine (*Pinus taeda* L.) is one of the most important commercial tree species in the southeastern US. There is an underlying concept in forest management that sites further east and south within the southeastern US have greater productivity. On more southerly sites, productivity is thought to be greater because of higher temperatures year-round producing a longer growing season and greater photosynthetic rates throughout the year. Productivity is thought to be less on more westerly sites because native genetic stock have adapted over time to counter greater probabilities of drought later in the growing season by slowing growth rates and immediately halting growth at the onset of a drought. Therefore, we wanted to see if we could relate site productivity (defined to be site index at base age of 25) to site elevation and site climatic variables across the southeastern US using correlation coefficient analyses.

KEYWORDS. Genetics, *Pinus taeda*, site index.

INTRODUCTION

Loblolly pine (*Pinus taeda* L.) is one of the most important commercial tree species in the southeastern US (SE US). Loblolly pine plantation productivity depends on inherent site quality (Lantz and Kraus, 1987; Baker and Langdon, 1990; Hasenauer et al., 1994) which is a combination of factors such as elevation, slope, aspect, photoperiods, soil nutrition, soil microbes, precipitation, soil water table depths, etc.

It has long been thought that potential loblolly pine plantation volume productivity is greater the further east and south that a stand exists within the SE US, with Alabama, Florida, Georgia, and South Carolina having, on average, the highest quality sites (Wells and Lambeth, 1983; Wells, 1985; Lantz and Kraus, 1987; Schmidting, 2001). Higher productivity in these eastern areas has been partially attributed to the fact that native strains of loblolly pine in the western half of the

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SE US have genetically evolved to better withstand drought conditions. Strategies of more westerly loblolly pine sources include slowing their growth rates (Schmidting, 2001) and immediately halting growth at the onset of a drought (Grissom and Schmidting, 1997). Precipitation rates in western areas of the Southeast are generally greater or equivalent to more easterly areas from March to May (USDA Forest Service, 1969; Figure 1). However, precipitation is generally greater in more easterly areas from June to August. This is important for two reasons: 1) for any growth to occur during June to August, all growth during previous periods must be maintained, and 2) temperatures are usually greater during June to August thus increasing evapotranspiration which can result in greater water deficits. The combination of maintenance requirements and greater water deficits can greatly limit growth later in the growing season (Baker and Langdon, 1990).

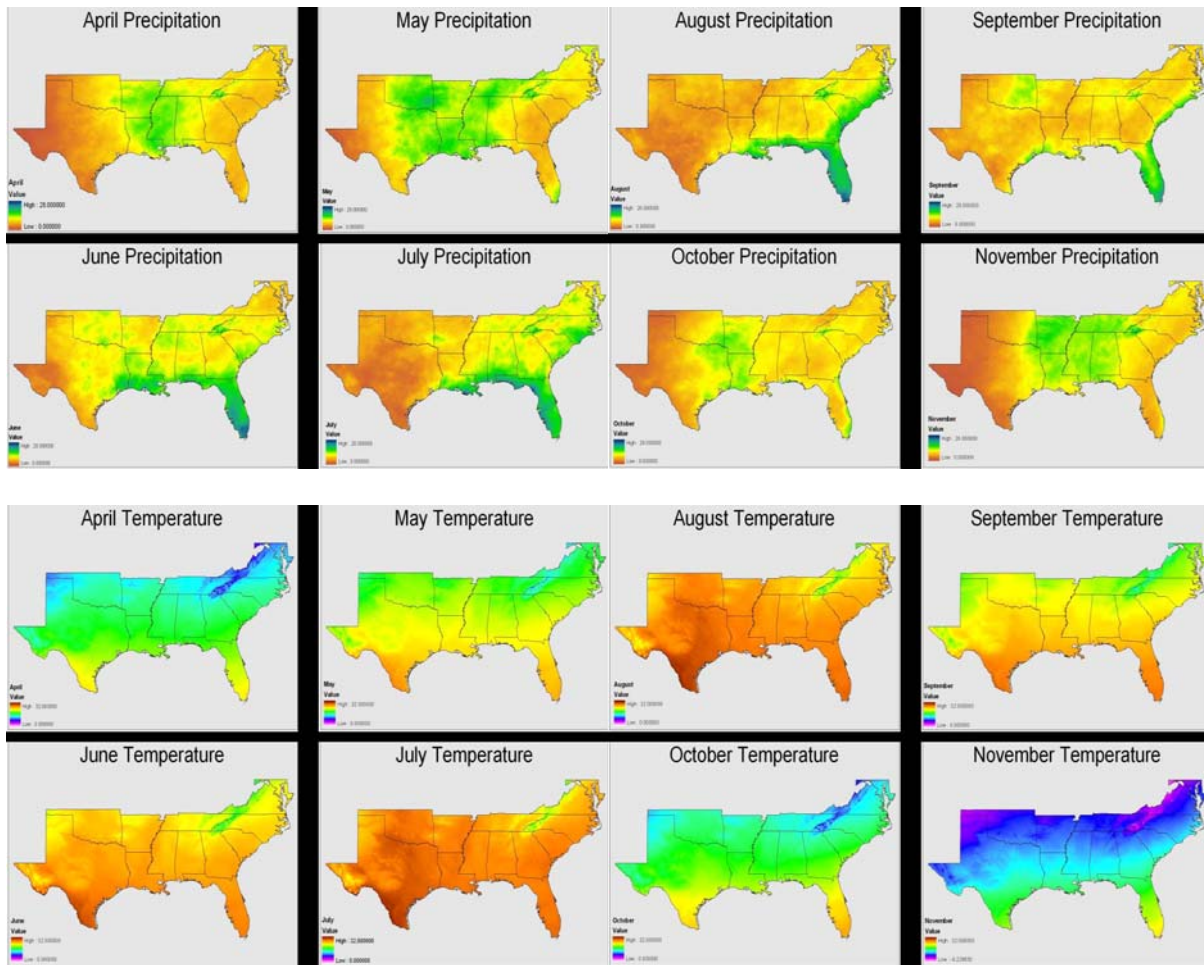


Figure 1. Average monthly total precipitation and average monthly daily temperature in the SE US for the years of 1980 to 1997. By October, loblolly pine trees are starting to go into imposed dormancy. October and November precipitation therefore is important for soil moisture recharge on more westerly sites following the droughty months of July, August, and September.

Murphy and Sternitzke (1979) and Baker and Langdon (1990) state that low precipitation rates play a role in limiting expansion of loblolly pine further west in Texas and Oklahoma. Southerly sites are thought to have greater growth rates (Baker and Langdon, 1990; Weir, 1996) because of greater precipitation (USDA Forest Service, 1969) both on an annual basis and during the growing season and because of longer growing seasons (Murphy and Sternitzke, 1979; Jayawickrama et al., 1998). More southerly sites, both in the eastern and western halves of the SE US, have longer growth periods due to greater average annual and growing season temperatures producing a longer frost-free period (USDA Forest Service, 1969; Murphy and Sternitzke, 1979; Weir, 1996; Jayawickrama et al., 1998).

The SE US can be divided into specific geographic regions; for example, Hasenauer et al., (1994) divided the region into the Atlantic Coastal Plain, Piedmont, and the Western Gulf. Other geographic divisions have also been proposed (e.g. USDA Forest Service, 1969; Schmidting, 2001). Hasenauer et al. (1994) found that loblolly pine plantations had greater maximum stand densities within the Atlantic Coastal Plain than the Piedmont, while the Western Gulf had the lowest yield capacity. Although determining whether well-defined geographic regions on average have greater productivity than other areas is valid, an analysis using GIS may provide information at a much greater detail. For instance, although the Western Gulf on average may have lower productivity than the Piedmont, certain geographic pockets within the Western Gulf may have similar or greater productivity than all stands located in the Piedmont. One such area that is widely known is Livingston Parish in Louisiana (Wells, 1985; Lantz and Kraus, 1987; Weir, 1996; Schmidting, 2001).

Loblolly pine productivity can be defined a variety of ways. For this current study, it is defined as the amount of maximum wood volume per acre produced within common economic rotation ages for this region – up to about age 40. Within the confines of this definition, greater site productivity may be observed in the Atlantic Coastal Plain because of faster growth rates (Schmidting, 2001). Loblolly pine can grow to be 200 years old (Baker and Langdon, 1990), therefore, if plantations were allowed to grow until complete decomposition, the average maximum productivity between more westerly and easterly sites may not differ.

Productivity differences between stands are largely related to inherent site characteristics (Lantz and Kraus, 1987; Hasenauer et al., 1994). In reality, we never truly know the inherent productivity of a site for a particular species. Many attempts have been made to develop measures that can represent the many complex factors that comprise inherent site productivity. One common indirect measure of site productivity for loblolly pine in the SE US is site index. Site index is defined as the average height of a given number or proportion of the tallest trees within a particular stand at a specific reference age. This measure has been shown to be correlated with maximum stand volume production; as site index increases, inherent site productivity is thought to increase. Unfortunately, site index has some shortcomings as an indirect indicator of site productivity. Silvicultural practices such as planting density, thinning, fertilization, etc., and insects, diseases, ice storms, and genetics can all affect height growth and thus estimates of site index. Despite the shortcomings of site index as a measure of inherent site productivity, it is relatively non-labor intensive, cost effective, and well known. Datasets of loblolly pine plantations were selected and manipulated to minimize a great majority of these confounding factors when using site index as an indirect measure of inherent site productivity.

The objective of this study is to relate site productivity (defined to be site index at base age of 25) to site elevation and site climatic variables across the SE US using correlation coefficient analyses.

METHODS

Data

Loblolly pine research plot data

Growth and yield information for this current study were obtained from many independent long-term studies located throughout the SE US (Table 1 and Figure 1). More specific information about the data obtained from each data source can be found in the references given below. Site index was determined for a particular research plot using the age closest to the base age of 25 years.

Table 1. Range of ages used in determining site index (SI) of individual plots within a study, and average SI values for 6 long-term loblolly pine plantation growth and yield studies in the SE US.

<i>Study name</i>	<i>Age</i>			<i>SI</i>		
	Min	Mean	Max	Min	Mean	Max
ETPPRP	10	20	26	36	69	110
FNC Regionwide 13	12	21	26	47	65	99
FNC Regionwide 7	14	19	23	51	69	92
Monticello Thinning and Pruning Study	27	27	27	58	60	64
Saucier, MS	25	25	25	38	46	62
VPI Thinning Trial	11	18	28	38	56	80

Site index was estimated for individual plots using an equation developed by Burkhardt et al. (1987):

$$\ln SI = \frac{\ln(HD)}{\left(\frac{25}{Age}\right)^{-0.02205} e^{-2.83285\left(\frac{1}{Age} - \frac{1}{25}\right)}} \quad [1]$$

Where:

SI – average height of the tallest 50% of surviving trees per hectare at the base age of 25.

HD – average height of the tallest 50% of surviving trees per hectare at the age nearest the base age of 25.

This model was developed using a subset of the data from the VPI Thinning trial data used in this current analysis. Site index was estimated on a plot basis and replications at a particular site were not averaged to get a site value.

The first source of data was obtained from a study initiated by the East Texas Pine Plantation Research Project (ETPPRP) based at Stephen F. Austin State University on existing plantations

located throughout East Texas (Lenhart et al., 1985). A total of 178 sites at a variety of plantation ages had a pair of permanent research plots established during 1982, 1983, and 1984. Planting densities ranged from 363 to 1361 seedlings per acre. These plots were remeasured on a three-year interval and all are unthinned. All seedlings were of unimproved woods-run seed sources. Most likely, the plantations were originated using seedlings of local seed sources.

A second source of data was established by the Forest Nutrition Cooperative (FNC) based at North Carolina State and Virginia Polytechnic Institute and State (VPI) universities in plantations located throughout the SE US (NCSFNC, 1995). This study (Regionwide 13) examines the impact of mid-rotation nitrogen (N) and phosphorus (P) fertilization treatments on long-term growth. Study establishment occurred in existing plantations (ages at time of establishment ranged from 10 to 19 years old) from 1984 to 1987. Initial planting densities are unknown. Only plots that received no fertilization were included in this current analysis. Genetic seed sources are unknown.

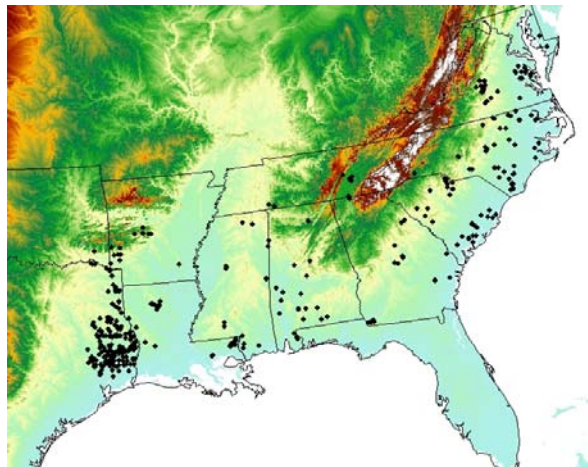


Figure 2. Study site locations and elevation across the SE US. Areas of lighter colors generally have lower elevations. Study sites are well distributed throughout the area.

Thirdly, data was obtained from another regionwide study established by the FNC (NCSFNC, 1996). This study (Regionwide 7) examines the impact of different site preparation treatments, early stand age herbicide application, and early stand age fertilization using N and P, on long-term growth. Study establishment occurred in young plantations from 1978 to 1981. All plots were planted using a 8' x 8' spacing. Only the plots receiving no fertilization were included in this current analysis. Genetic seed sources are unknown.

Another source of data are from plantations located near Monticello, Arkansas originally established in 1970 by the USDA Forest Service Southern Research Station and maintained by the University of Arkansas-Monticello since 1981 in a study called the Monticello Thinning and Pruning Study (Zeide and VanderSchaaf, 2000). This study was established in a 12-year old existing stand that was planted at a spacing of 8' by 8' with the intent of studying the impacts of different thinning and pruning treatments on loblolly pine plantation growth – therefore no unthinned plots were established in 1970. However, in 1984, unthinned plots were established in this plantation. Only the data from the unthinned plots were used in this current study. The first

measurement in the unthinned plots was conducted at age 27. Therefore, heights obtained during this initial inventory were used to calculate site index at base age 25. Although seed source is unknown, since seedlings were obtained from a state nursery located in Arkansas and they were planted in 1958 (prior to most genetic seed source transfer zones [Lantz and Kraus, 1987; Weir, 1996]), seed source is most likely local to the area (Zeide and VanderSchaaf, 2000).

The fifth source of data is from plantations established on the USDA Forest Service Harrison Experimental Forest near Saucier, Mississippi (Schmidtling, 1984). Seedlings were planted at a 10' x 10' spacing on a cutover site during 1960. Although this study involved investigation of cultivation and fertilization treatments, only the non-cultivated and non-fertilized plots were used in this current study (Treatment C). Heights of all trees within the plots were measured at age 25. Seed sources were native to southern Mississippi (Schmidtling, 1984).

A sixth source of data is from a long-term study established by the Loblolly Pine Growth and Yield Research Cooperative located at VPI. This study was initiated to examine the impacts of mid-rotation thinning treatments on long-term growth and yield. To exclude potential impacts of thinning on site index estimations, only unthinned data were used in this current study. This region-wide study is comprised of 186 sites located throughout the SE US. Planting densities, for sites where this variable is known, ranged from 500 to 1223 seedlings per acre. Study installation began in the dormant seasons of 1980-1981 and 1981-1982 in stands of different ages, site qualities, and densities on cutover, site prepared areas following protocols described by Burkhardt et al. (1985). These plots were remeasured on a three-year interval. Genetic seed are of woods-run sources. Most likely, seedlings are of local seed sources near the particular plot location.

These particular datasets were selected because they are long-term studies of loblolly pine growth. Other datasets are available for ages younger than 8; however, site index estimates when using dominant height obtained from young ages for a base age of 25 years can be greatly biased. A few long-term datasets were not used in this current study because all plots contain intensive site preparation, fertilization, or herbicide application treatments and/or they were thinned.

We have attempted to alleviate variation in site index due to fertilization, extreme herbicide treatments, and extreme site preparation treatments. Many research plots had damage from insects or diseases, particularly the southern pine beetle (*Dendroctonus frontalis* Zimmermann). In these cases, site index was determined based on the age closest to the base age of 25 that was free from disease [e.g. Fusiform rust *Cronartium quercuum* (Berk.)] or bug kills. Some plots had extreme ice storm damage, in these cases, site index was determined based on the age closest to the base age of 25 prior to the occurrence of the damage.

Site climatic attribute data

Average monthly precipitation, temperature, frost free days, and growing season degree days from 1980 to 1997 were obtained for each particular study site location from www.daymet.org (Thornton and Running, 1999; Thornton et al., 2000). Frost free days are defined as the number of days within a month where the minimum temperature was less than or equal to 0° C while growing season degree days are the number of days within a month that had average daily air

temperatures above 0° C (Thornton et al., 1997). The files were downloaded in a *.fliting format and were converted to a GIS grid coverage use ArcGIS. The grid assigns attributes to a 1 km square area by using interpolative algorithms based on nearby weather stations. Based on latitude and longitude values from each loblolly pine research plot, site climatic variables were obtained.

Site elevation attribute data

Elevation (in meters) was obtained from the GTOPO30 DEM which uses a horizontal grid spacing near 1 km. Thus, the pixels are generally 1 km². The model was completed in late 1996 by staff from the United States Geological Survey EROS Data Center. More information can be obtained at (<http://edcdaac.usgs.gov/gtopo30/hydro/>).

Potential sources of error

Bolstad and Smith (1992) stated there are two main types of error in natural resource GIS applications; one is spatial error and the second is attribute error. First, we will address potential spatial error in this analysis. Plot locations (latitude and longitudes to the nearest minute) were obtained from study coordinators for the ETPPRP, both of the FNC, and the Loblolly Pine Growth and Yield Cooperative studies. At latitudes in the study area, one minute is approximately 1.8km. Thus, errors in plot locations may easily be in the range of a few kilometers, or around two pixels of elevation and climate data. No information is available about whether plot coordinates were obtained using a GPS unit or from maps, how many GPS readings were used to determine a plot coordinate location, etc. Additionally, no implication is given whether NAD27 or NAD83 datums were used (with an average difference between the two of about 200m). Latitude and longitude coordinates for the Monticello Thinning and Pruning Study, and the study near Saucier, MS, were obtained to the nearest second from TopoZone.com (TopoZone.com, 2004). No attempt was made to obtain coordinates for each particular plot (or replication) at all general study site locations. It is assumed that microsite variation between plots on a particular study site is negligible.

The second type of error as described by Bolstad and Smith (1992) is attribute error. For this particular study, a potentially confounding factor is genetic stock. Over a long period of time, prior to any genetics programs or intentional transfer of loblolly pine genetic stock (generally around the early to mid-1960's [Lantz and Kraus, 1987; Weir, 1996]), trees on a particular site evolutionary evolved to local conditions producing great geographic variation in genetic traits (Lantz and Kraus, 1987; Weir, 1996; Schmidting, 2001). Therefore, in this current study, genetic stock would be to a great extent synonymous with inherent site quality to grow loblolly pine. Resource managers in the SE US have become very adept at planting non-site native genetic stock though (both in terms of seed transfer among geographic regions [Wells, 1985; Lantz and Kraus, 1987] and improved native site stock). Therefore, although inherent site characteristics influence productivity of a particular research plot, genetic stock also influences productivity thus potentially introducing confounding into this study that we can not account for.

Statistical Analysis

Pearson correlation coefficients were obtained for the relationships between site index and geographic, climatic, and topographic site attributes using PROC CORR of the SAS Institute.

RESULTS

Loblolly pine site index, based on correlation analysis, showed a decrease as elevation increased (Table 2 -- Dataset 1) while more southerly sites have greater site indexes but more easterly sites have lower site indexes. Our correlation coefficient of longitude shows that site productivity is greater on more westerly sites which is counter to what we expected. A potential explanation for this is the dominance of the data by the ETPPRP (Figure 2). This study was established to develop growth and yield models for loblolly pine plantations in East Texas. Thus, in order to make the model applicable to a wide range of sites, sites of varying qualities were intentionally found to get a range of site qualities in the dataset. Although on the average we expect sites on more easterly sites in the SE US to have higher productivity, there certainly are sites in E. Texas capable of producing large amounts of volume and of having high site index.

Table 2. Pearson correlation coefficients between site index and elevation, latitude, and longitude. Where: Elevation is meters above sea level, X is longitude, and Y is latitude. All three coefficients for Dataset 1 (n = 847) were significant at the p-value of <0.0001 while for Dataset 2 (n = 491) elevation and Y were significant at a p-value of 0.0041 while X was significant at the 0.3348 alpha level. Dataset 1 includes the ETPPRP data while Dataset 2 does not include the ETPPRP data.

<i>Dataset</i>	Elevation	X	Y
1	-0.22292	-0.2178	-0.2527
2	-0.26534	0.0436	-0.1292

Perhaps the purposeful location of research plots on extremely high quality sites, combined with a large number of plots located on these high quality sites for the ETPPRP dataset relative to the rest of the distribution of study plots across the SE US, may bias the correlation coefficient between site index and longitude. For example, the ETPPRP data had 70% of all plots with site index greater than 80 feet (n = 61). Site index for the ETPPRP plots may be overpredicted because we used a site index equation mainly developed using more easterly sites and a minimal amount of data from sites in E. Texas (Burkhart et al., 1987). Therefore, we decided to eliminate the ETPPRP plots to see what effect this would have on the correlation coefficient between site index and longitude (Table 2 - Dataset 2). When eliminating the ETPPRP plots, the coefficient becomes positive although it is not significant at the 0.05 alpha level. The positive coefficient between site index and longitude, without the ETPPRP data, lends credibility to the concept that more easterly sites generally have greater site productivities.

As expected there is a strong correlation between climatic variables and loblolly pine site index (Table 3). Average monthly precipitation data showed the most variability in correlation relationships with site index. Based on the expected relationship between potential drought conditions and growth of loblolly pine, significant relationships between average monthly precipitation in June, July, and September are not surprising. However, it is surprising that the average precipitation in the month of August over the period from 1980 to 1997 was not significantly positively correlated with site index and that precipitation in July was negatively correlated with site index.

Table 3. Pearson correlation coefficients between site index and climatic site factors. Where: Temp = average monthly daily temperature, Precip = average monthly total precipitation, TD = average monthly total of the number of average daily air temperatures above 0° C, TF = average monthly number of days where the minimum temperature was less than or equal to 0° C. All climate variables represent the years 1980 to 1997. Within a column, coefficients with a star were NOT significant at the p-value given at the bottom of the column. For TF, the months of April, May, Jun, and July had no days with temperatures less than 0° C across the entire Southeastern geographic region. Correlation coefficients presented in Table 3 include the ETPPRP data.

	Temp	Precip	TD	TF
Jan	0.279	0.056*	0.275	-0.292
Feb	0.272	-0.015*	0.271	-0.304
Mar	0.275	-0.163	0.274	-0.288
Apr	0.290	-0.012*	0.290	-0.287
May	0.290	0.138	0.290	-0.071
Jun	0.292	0.248	0.292	-
Jul	0.314	-0.241	0.314	-
Aug	0.304	-0.025*	0.304	-
Sept	0.303	0.089	0.303	-
Oct	0.302	0.174	0.302	-0.253
Nov	0.292	0.002*	0.292	-0.321
Dec	0.279	0.201	0.279	-0.287

*<0.0001
*0.05
*<0.0001
*0.0396

We wanted to see what impact eliminating the ETPPRP plots would have on July and August precipitation coefficients -- the correlations between July and August precipitation and site index changed. The July coefficient changed from -0.241 (Table 3) to 0.029 (not significant at the 0.51 level though) and the August coefficient changed from -0.025 to 0.228 (significant at the 0.0001). When eliminating the ETPPRP data, July and August precipitation coefficient signs agree with both the concept of more easterly sites having higher site index and the precipitation variation as seen in Figure 1. Unless specifically stated in the remainder of this paper, all results and discussion pertain to the inclusion of the ETPPRP plots in the analysis.

Table 4 presents the results of monthly climatic variables combined. As temperature increased, site index increased. Once again, precipitation showed the most variability. However, the correlation coefficient signs between site index and total precipitation from March to October, total precipitation from April to October, and total precipitation from May to October make sense biologically. Generally the period from March to October is considered the growing season for loblolly pine here in the SE US. Based on the correlation coefficient from March to October, as precipitation increases, site index increases.

DISCUSSION

Loblolly pine site index showed a strong relationship with topographic, geographic, and climatic variables (Tables 2, 3, and 4). Site index showed a negative trend as elevation increased (Table 2) which is most likely due to decreases in temperature as elevation increases resulting in shorter

Table 4. Pearson correlation coefficients between site index and climatic site factors. Where: Correlation coefficients within the Temp and Precip columns relate to the sum of the average of the Temp and Precip values over the range of 1980 to 1997 for the months listed. For the TD and TF columns, correlation coefficients apply to the summation of the average TD and TF for the months listed over the range of 1980 to 1997. Within a column, all coefficients with a star were NOT significant at the p-value given at the bottom of the column. For TF, the months of April, May, Jun, and July had no days with temperatures less than 0° C across the entire Southeastern geographic region. Correlation coefficients presented in Table 4 include the ETPPRP data.

	Temp	Precip	TD	TF
Mar, Apr, May, Jun, Jul, Aug, Sept, Oct	0.298	0.017*	0.298	-0.289
Apr, May, Jun, Jul, Aug, Sept, Oct	0.302	0.071	0.302	-0.277
May, Jun, Jul, Aug, Sept, Oct	0.304	0.081	0.304	-0.253
Jun, Jul, Aug, Sept, Oct	0.307	0.025*	0.307	-0.253
Jul, Aug, Sept, Oct	0.310	-0.068	0.310	-0.253
Aug, Sept, Oct	0.307	0.089	0.307	-0.253
Jun, Jul, Aug	0.305	-0.041*	0.305	.
Aug, Sept	0.306	0.018*	0.306	.
	<0.0001	*0.05	<0.0001	<0.0001

growing seasons (growing degree days and frost free days - Tables 3 and 4 and Figures 1 and 2) and less photosynthetic activity throughout the year reducing carbohydrate production needed for growth. For example, Baker and Langdon (1990) state that daily temperature has a dominant influence during the growing season and on the initiation of height growth in the spring. Precipitation showed the most variability of all variables in relation to site index. It is surprising that as July and August precipitation increased, the correlation showed productivity decreased (Table 3). As seen in Figure 1, more easterly sites generally have greater July and August precipitation amounts. Given the concept that more easterly sites have greater site productivity, it was expected that a positive correlation between July and August precipitation and site index would occur. However, there was a negative trend between site index and longitude (Table 2 - Dataset 1). Thus, given the inclusion of the ETPPRP data in the analysis (the ETPPRP dataset has a large proportion of the highest quality sites), negative coefficients between site index and July and August precipitation make sense. However, when removing the ETPPRP data, the correlation coefficients (July = 0.029 and August = 0.228) are in agreement with the concept of more easterly sites having greater productivity since July and August precipitation rates are higher on more easterly sites (Figure 1).

Figure 1 shows that precipitation is greater in the western half of the SE US relative to the eastern half during the months of April and May. March, April, and May is often the time of the year when loblolly pine breaks bud and starts a new growing season. Precipitation early in the growing season may produce increased growth rates on more westerly sites during these months. As seen in Figure 1 though, July, August, and to some extent September, are drier in the Western Gulf while the temperatures are the hottest of all year during this time (Figure 1). Increases in temperatures and a decrease in precipitation during these later-growing season months probably results in productivity decreases on more westerly sites relative to more easterly sites (although Dataset 1 contradicts this statement). Over several thousands of years,

genetic sources from more westerly sites have probably evolved to cope with drought later in the growing season by slowing their growth rates throughout the growing season (Schmidtling, 2001) and immediately halting growth at the onset of a drought (Grissom and Schmidtling, 1997).

Loblolly pine production is also generally thought to be greater as sites are located further south in the SE US (Murphy and Sternitzke, 1979; Weir, 1996; Jayawickrama et al., 1998). The correlation coefficient of latitude for both datasets is in agreement with this concept (Table 2). Precipitation during the early growing season, months of April and May, does not seem to differ much from north to south in this region (Figure 1). However, during June, July, and August, precipitation is generally greater on more southerly sites. During the months of June and July more southerly areas in the Western Gulf, such as those in central parts of Alabama, Louisiana, and Mississippi, have greater precipitation relative to areas in Arkansas, northern East Texas, Oklahoma, and western Tennessee and more northerly areas of Louisiana, Mississippi, and Alabama. However, temperatures during these months do not differ greatly between more northern and southern parts of the Western Gulf. Thus, increased precipitation amounts in southern areas of the states of Louisiana, Mississippi, and Alabama may result in greater loblolly pine production in these more southerly regions. Precipitation during June, July, August, and September is generally greater on more southerly and especially more southeasterly sites in the eastern half of the SE US while temperatures don't differ greatly within this area during June, July, and August except for in the Appalachians. However, as evidenced to some degree by the lack of research plots in the Appalachians (Figure 1), loblolly pine is usually not planted in these mountains. Increased precipitation on more southerly and especially southeasterly sites with little change in temperatures across the Atlantic Coastal Plain and Piedmont regions probably results in greater loblolly pine productivity on more southerly and southeasterly areas in the eastern half of the SE US. Additionally, the growing season is longer in the southern part of the SE US resulting in greater production (Baker and Langdon, 1990).

In conclusion, there are some precipitation correlation coefficients and significance levels that differ from our expectations when including the ETPPRP data. The analysis including ETPPRP data raises some interesting questions and has lead us to question whether we agree with the concept that more southeasterly sites have greater site productivities. In our opinion, within current economic rotation ages, despite the results from the analysis including the ETPPRP data, sites on more easterly and southerly sites, on the average, have greater productivity. Our continued belief in this concept is supported to some extent by our analysis using only Dataset 2 -- without the ETPPRP data (Table 2). Further analyses of these data are needed to develop a model(s) to explain variation in general trends of site index across the SE US.

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