Pederson, Neil, Kush, John S.; Meldahl, Ralph S.; Boyer, William D. 2000. Longleaf pine cone crops and climate: A possible link. In: Haywood, James D., ed. Proceedings of the tenth biennial southern silvicultural research conference; 1999 February 16-18, Shreveport, LA. Gen. Tech. Rep. SRS-30. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 255-258.

LONGLEAF PINE CONE CROPS AND CLIMATE: A POSSIBLE LINK[1]

Neil Pederson, John S. Kush, Ralph S. Meldahl, and William D. Boyer[2]

Abstract- The physiological development of long leaf pine seed extends over three calendar years. The duration of this process may explain the reason for infrequent seed crops. Infrequent crops cause problems for those interested in natural regeneration. Longleaf pine cone crops have been monitored on the Escambia Experimental Forest (EEF) in Brewton, AL since 1958. Weather data was lagged up to 4 years prior to seedfall to determine if a relationship exists between climate and cone crops. Correlation analyses indicated precipitation explained 48.6 percent of annual cone crop variation while average monthly temperatures explained 33.7 percent. With knowledge of important months for cone production, it seems likely that mangers would be able to prepare for large crops to reduce management costs. We suggest managers capture as much reproduction as possible in preparation for a reproductive drought similar to the 1969-1975 interval at EEF.

INTRODUCTION

The longleaf pine (Pinus palustris Mill.) forest covered an estimated 33-37 million hectares distributed in a broad arc from southeast Virginia to east Texas (Vance 1895, Frost 1993). This forest is now listed as critically endangered ecosystem (Noss and others 1995). Noss (1989) estimated that in pre-settlement times this ecosystem comprised 40 percent of the southern coastal plain. By 1995, the longleaf pine forest, containing one of the most species-rich understory in temperate North America (Peet and Allard 1993), occupied an estimated 1.2 million hectares or 3.2 percent of its former range (Outcalt and Sheffield 1996). Consequently, interest has escalated in the recovery and management of the longleaf pine ecosystem.

One of the major concerns in longleaf pine restoration, regeneration, and management is its sporadic seed production. Excellent mast years occur once every 4-7 years, but with wide variations geographically (Wahlenberg 1946, Boyer 1990) and interannually (Boyer 1987). Maki (1952) reported heavy seed crops might occur over much of the longleaf range once in 8 to 10 years. The minimum size of a cone crop for successful regeneration is considered 750 cones/acre or roughly, 30 cones per tree (Boyer and White 1989). From 1966-1996 in the longleaf range, five of the eight cone crops considered adequate for natural regeneration have occurred since 1990 (Boyer 1998). The 1996 cone crop was one of the largest recorded in many regions (Boyer 1998). The increase in crop size and frequency, locally and regionally, leads to the hypothesis that climate most likely plays a role in cone crop production (Boyer 1998).

To date the relationship between longleaf pine seed crops and climate remains obscure. Using a 40-year time series (1958-1997) of cone production from the Escambia Experimental Forest (EEF), located in Brewton, Alabama, the influence of temperature and precipitation on cone crops will be explored.

METHODS

Development of Longleaf Pine Cone and Seed

The visual development of long leaf pine seed extends over three calendar years. Male and female flower buds are set during the growing season before the flowers appear. Male flowers typically occur in the lower crown while females are

[1] Paper presented at the Tenth Biennial southern Silvicultural Research Conference, Shreveort, LA, February 16-18, 1999.

[2] Forestry/Dendrochronology Consultant, Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY 10964; Senior Research Associate and Assistant Professor, School of Forestry, 108 M. White Smith Hall, Auburn University, AL 36849; and Research Forest (Retired). USDA Forest Service, Southern Research Station, Devall Dr., Auburn AL 36849, respectively.

often located in the upper crown. Development of both flowers is weather dependent (Boyer 1990). Table 1 is a guideline of stages for the seed development process from Mathews (1932), Croker and Boyer (1975), and Boyer (1990) and using terminology proposed by Croker (1971).

Site Description

The study was conducted at the Escambia Experimental Forest in south central Escambia County, Alabama. The forest is maintained by the U.S. Department of Agriculture, Forest Service, Southern Research Station in cooperation with T.R. Miller Mill Company.

The climate is humid and mild with rainfall well distributed throughout the year. The warmest months are July and August with average daily minimum and maximum temperatures of 20 and 33 °C, respectively. The coldest months are December and January with average daily temperatures of 3 and 18 °C, respectively. The growing season is approximately 250 days. Annual precipitation averages 156 cm with October being the driest month.

Climate Data

Climate data were obtained from the National Climatic Data Center (NCDC) in Asheville, NC. These data were for Alabama Climatic Division 7, which is the region surrounding EEF. Regional data was used because it tends to reduce the noise of individual station data (Biasing and others 1981). This is important for the southeastern United States, since summer precipitation is characterized by convective rainstorms.

Table 1—Development of longleaf pine seed (adapted from Croker and Boyer 1971 and Boyer 1990)

Year and stage	Usual start
Bud year	
Male catkin initiation	July
Female conelet initiation	August
Male catkins appear	November—December
Flower year	
Male catkins growth begins	January
Female conelet buds appear	January—February
Pollination	Late winter—spring
Conelet, early	June
Conelet, late	October
Seed year	
Fertilization	Spring
Rapid cone growth	February—June
Cone ripens	Mid-September—mid-October
Cone opens	Late October

Seed Crop Data

All crop data from the 1950's were collected from seed traps. Cone counts from 1960-1996 were made by binocular counts and described in Boyer (1998). The number of trees sampled per year up to 1971 was 235, except for the small cone crop of 1966 when only 41 trees were sampled. After 1971, a new set of 217 trees, older than 55 years, were sampled at the EEF (Boyer 1974). No change in the number of cones per tree was observed after this shift (fig. 1). Trees from this set, which were cut or died, were not replaced. By 1996, the number of trees sampled equaled 205.

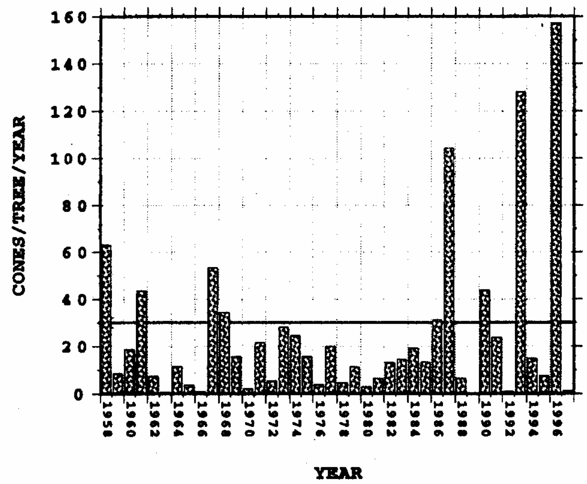

Figure 1—Average number of cones per tree per year at the Escambia Experimental Forest, AL from 1958-1997. The line at 30 cones per tree represents the level considered adequate for natural regeneration (Boyer and White, 1989).

The number of cones counted per tree was averaged to establish a time-series of cones per tree per year (CPT) for EEF.

Determining Climate Factors Important for Cone Production

Since the development of cones extends over several years, linear regression analysis was lagged four years to identify the months of influence on cone production. The CPT was compared to monthly precipitation and average temperature,

RESULTS

Cone Crop Production

On the Escambia Experimental Forest cone crops greater than one CPT were produced every year except 1963 and 1989 (fig. 1). Average CPTfor EEF from 1958-1997 was 24.7. When divided into three equal periods the number of times a crop equaled 30 or more CPT was four for 1958-71, zero for 1972-84, and five for 1985-97. Average CPT was 20.4 for 1958-71, 13.1 for 1972-84 and 41.0 for

1985-97. All of the crops larger than 100 CPT occurred between 1987 and 1996.

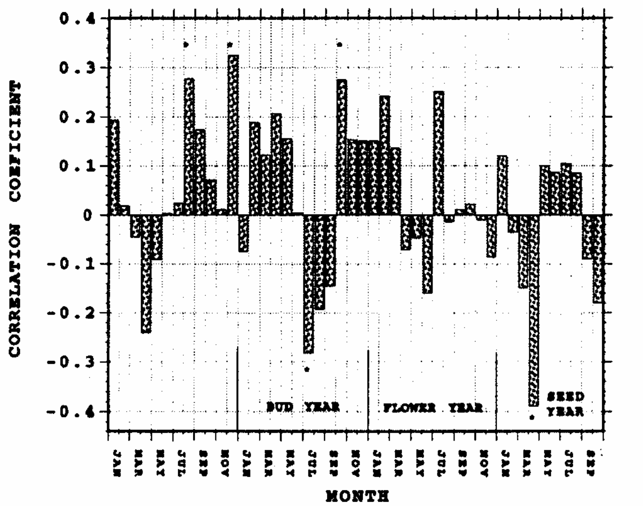

Figure 2—Correlation of monthly precipitation from AL Climate Division 7 and annual cone crops. Bud Year, Flower Year and Seed Year represent the years of development of a longleaf pine seed; * = significant correlation level p=0.10.

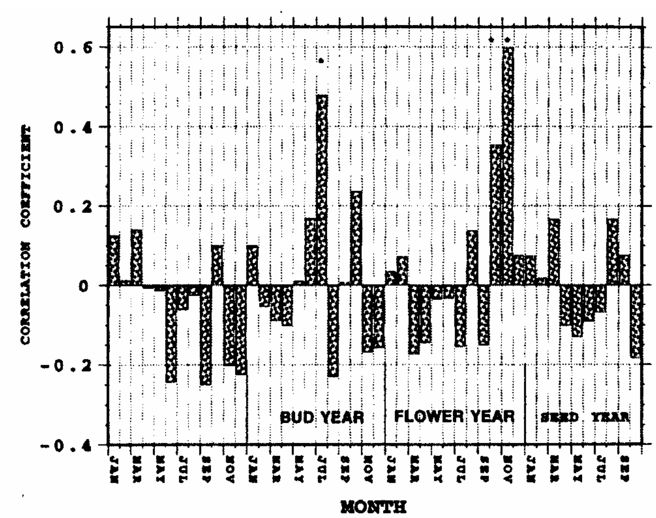

Figure 3—Correlation of monthly temperature from AL Climate Division 7 and annual cone crops. Bud Year, Flower Year and Seed Year represent the years of development of a longleaf pine seed; * = significant correlation level p=0.10.

Relation to Climate

The regional climate data were strongly related to crop production. Precipitation explained 48.6 percent of annual variation while temperature explained 33.7 percent. Several months of average temperature were significantly related to important stages of cone development (fig. 2). August and December average temperatures prior to the bud year are positively, significantly correlated with cone crops. The positive correlations continue through the winter and spring of the bud year. This is just prior to differentiation of male and female flowers. During differentiation, July temperature is significant and negatively correlated to cone crops. October temperature of the bud year is positive and significantly correlated. This is just prior to the appearance of male flowers in December. The positive correlation extends through the winter months. April temperatures of the seed year were significant and negatively correlated with cone production.

Regional monthly precipitation explained 48.6 percent of annual variation and shows important timing with crop development (fig. 3). July of the bud year is significant and positively correlated to cone crops. This marks the beginning of differentiation of male and female flowers (table 1) and is consistent with earlier findings by Shoulders (1967). Precipitation is strongly correlated with October and November of the flower year and coincides with the commencement of the late conelet stage.

DISCUSSION

Factors Influencing Cone Crop Production

This study has revealed the importance of climate and long leaf pine cone production. Many phases in the physical development of a longleaf pine cone are correlated with or preceded by significant climate variables (table 1, fig. 2 and 3). The significance of climate just before many development stages suggests that the health of the tree determine whether energy investments should be made before commencement of the next stage. Significant months at the end of the growing season (warmer August and December before the bud year, warmer October of the bud year, and a wetter October and November of the flower year) suggests that extended growing seasons are important. Extended growing seasons may allow luxuriant or non- essential nutrient uptake to improve the health of the tree, feed the cone buds and conelets, or stores extra photosynthate.

One of the largest contributions of climate was seen prior to the flower year. Flower development and pollination occurs early in the flower year. This suggests that healthy buds might be very important to cone development. A recent study found an increase in the production of female flowers plus a higher percentage of survival (Boyer 1998). Therefore, it may possible to conclude that better climatic conditions aid bud survival and health which leads to increased female flower development, survival, and pollination at EEF .

The strongest climate factor correlated to cone development at EEF is precipitation during fall of the flower year. This period is the beginning of the late conelet stage. This stage marks the end of conelet losses, is when fertilization occurs, and may be when seed viability is determined (Croker and Boyer 1975). Perhaps this late-growing season precipitation helps to provide better tree health for the large energy demand during fertilization, cone enlargement, and seed ripening the following year.

Other factors beside climate have influence on longleaf cone production. One possible reason for the increase in cone crops could be stand density. Changes in stand density would alter the competitive environment and the availability of resources like nutrients and water. For example, increased stand density reduces cone production while lower stand densities increases it (Croker 1973). However, the goal of forest management on the EEF was to maintain a constant stand density .Therefore, management does not seem to be a likely cause in the increased activity of the reproductive cycle.

Climate, Climate Change and Future Work

From the above line of reasoning, climate appears to be the primary factor in the changing cone crop production at EEF. The increased survival of female flowers (Boyer 1998) suggests that environmental conditions are improving during recent reproductive cycles. How future climate change will effect these interactions is uncertain. There is growing consensus that climate will warm in the long-term (Houghton and others 1996). The warming observed in the last century has been primarily through nighttime temperatures (T min) (Houghton and others 1996). There is no reason to expect that maximum daily temperatures (T max) have the same effect as T min (Alward and others 1999). Future work calls for understanding the effect of T min and T max on cone development and production as well as better understanding of the causes of increased survival of female flowers.

November precipitation increased 53.2 percent from 1985- 1997 when compared to 1958-1971. This change may be the primary cause for change in the reproductive cycle at EEF. The reason for the increased precipitation could be the observed changes in the Pacific Ocean. The southeastern U.S. is teleconnected to the Pacific Ocean (e.g. Ropelewski and Halpert 1986). The major 1976 step change of the Pacific (Ebbesmeyer and others 1991), recent anomalous El Nino/Southern Oscillations (ENSO) (Latif and others 1997) or the possible change of ENSO from 3-4 year mode to a decadal oscillatory mode (Zhang and others 1997, Villalba and others 1999) could provide a small, but important change in cone production. Winter is the primary season of influence of ENSO on the southeast USA (Ropelewski and Halpert 1986). Several months during the fall and winter were significantly correlated with cone production in this investigation. It is also expected that global warming will change precipitation regimes (Houghton and others 1996). Future work requires the investigation of the influence of the Pacific Ocean and precipitation indices on longleaf pine Pacific Ocean and precipitation indices on long leaf pine cone production.

SUMMARY

We have shown significant correlation between climate and longleaf pine cone production at the Escambia Experimental Forest. Several months of temperature and precipitation during different stages of the three-year cone development process contribute to total cone production. How different aspects of climate change will impact these relationships is unknown, but will be pursued in future work.

It seems reasonable than an observant manager will be able to plan for regeneration well in advance of a substantial cone crop (Boyer 1974). By observing flower development and climate variables during important months, cone crop abundance could be anticipated a year in advance. This would extend the window of opportunity for timber and fire management plans to enhance long leaf pine regeneration and reduce costs. Finally, in the face of an uncertain future climate, we suggest that managers capture as much reproduction as possible in preparation for a potential reproductive drought like 1969-1985 at EEF. The long-lived and persistent nature of long leaf pine makes this type of reproduction management possible.

REFERENCES

Alward, R.D.; Detling, J.K.; Milchunas, D.G. 1999. Grassland vegetation changes and nocturnal global warming. Science. 283(5399): 229-231.

Blasing, T .J.; Duvlck, D.N.; West, D.C. 1981. Dendroclimatic calibration and verification using regionally averaged single station precipitation data. Tree-Ring Bulletin. 41: 37-44.

Boyer, W.D. 1974. Longleaf pine cone production related to pollen density. In: Kraus, J.. ed. Proceedings of a colloquium: seed yield from southern pine seed orchards; 1974 April 2-3: Macon, GA: Georgia Forest Research Council: 8-14.

Boyer, W.D. 1987. Annual and geographic variations in cone production by long leaf pine. In: Phiilips. D.R., comp. Proceedings of the fourth biennial southern silvicultural research conference; 1986 November 4-6: Atlanta. Gen. Tech. Rep. SE-42. Asheville, NC: U.S. Department of Agriculture. Forest Service. Southeastern Forest Experiment Station: 73-76.

Boyer, W.D. 1990. Pinus palustris Mill. In: Burns, R.M.; Honkala. B.H.. tech. eds. Silvics of North America. Agric. Handb. 654. Washington. DC: U.S. Department of Agriculture. Forest Service: 405-412.

Boyer, W.D. 1998. Long-term changes in flowering and cone production by longleaf pine. In: Waldrop. T.A., ed. Proceedings of the ninth biennial southern silvicultural research conference; 1997 February 25-27; Clemson, SC. Gen. Tech. Rep. SRS-20. Asheville. NC: U.S. Department of Agriculture. Forest Service. Southern Research Station: 92-97.

Boyer, W.D.; White, J.B. 1989. Natural regeneration of longleaf pine. In: Farrar, R.M.. Jr.. ed. Proceedings of the symposium on the management of long leaf pine; 1989 April 4-6; Long Beach. MS. Gen. Tech. Rep. SO-75. New Orleans: U.S. Department of Agriculture. Forest Service, Southern Forest Experiment Station: 94-113.

Croker, T.C., Jr. 1971. Binocular counts of long leaf pine strobili. Res. Note SO-127. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 3 p.

Croker, T .C., Jr. 1973. Longleaf pine cone production in relation to site index. stand age, and stand density. Res. Note SO-156. New Orleans: U.S. Department of Agriculture. Forest Service, Southern Forest Experiment Station. 3 p.

Groker, T.G., Jr.; Boyer, W.D. 1975. Regenerating longleaf pine naturally. Res. Pap. SO-105. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 21 p.
Ebbesmeyer, G.G.; Gayan, D.R.; McLain, D.R. [and others]. 1991. 1976 step in the Pacific climate: forty environmental changes between 1968-1975 and 1976-84. In: Betancourt, J.L.; Tharp, V.L. eds. Proceedings of the seventh annual Pacific climate (PACLIM) workshop; 1990 Apri110-13; Pacific Grove, CA. Tech. Rep. 26. California Department of Water Resources. Interagency Ecological Studies Program for the Sacramento-San Joaquin Estuary: 115-126.

Frost, G.G. 1993. Four centuries of changing landscape patterns in the longleaf pine ecosystem. Tall Timbers fire ecology conference proceedings. 18: 17-43.

Houghton, J.T.; Metra Filho, L.G.; Gallander, B.A. [and others] 1996. Climate change 1995 -the science of climate change. Cambridge, MA: Cambridge University Press. 584 p.

Latif, M.; Kleeman, R.; Eckert, G. 1997. Greenhouse warming, decadal variability, or El Nino? An attempt to understand the anomalous 19905. Journal of Climate. 10: 2221-2239.

Makl,T.E. 1952. Locallongleaf seed years. Journal of Forestry. 50: 321-322.

Mathews, A.C. 1932. The seed development in Pinus palustris. Journal of Elisha Mitchell Science Society. 48: 101-118.

Noss, R.F. 1989. Longleaf pine and wiregrass: keystone components of an endangered ecosystem. Natural Areas Journal. 9(4): 211-213.

Noss, R.F.; Laroe, E.T.; Scott, J.M. 1995. Endangered ecosystems of the United States: a preliminary assessment of loss and degradation. Bioi. Rep. 28. U.S. Department of Interior, National Biological Service. 58 p.

Outcalt, K.W.; Sheffleld, R.M. 1996. The long leaf pine forest: trends and current conditions. Res. Bull. SRS-9. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 23 p.

Peet, R.K.; Allard, D.J. 1993. Longleaf pine dominated vegetation of the southern Atlantic and eastern gulf coast region, USA. Tall Timbers fire ecology conference proceedings. 18: 45-81.

Ropelewskl, C.F.; Halpert, M.S. 1986. North American precipitation and temperature patterns associated with El Nino/Southern Oscillation (ENSO). Monthly Weather Review. 114: 2342-2362.

Shoulders, E. 1967. Fertilizer application, inherent fruit-fullness, and rainfall affect flowering of longleaf pine. Forest Science. 13: 376-383.

Vance, L.J. 1895. The future of the longleaf pine belt. Garden and Forest. 8: 278-279.

Villalba, R.; D'Arrlgo, R.D.; Cook, E.R. [and others]. [In press]. Inter-decadal climate oscillations along the extra-tropical western coasts of the Americas- evidence from tree rings over the past four centuries. In: Annual meeting of The American Meteorological Society: Proceedings of the 10th symposium on global change studies; 1999 January 10-15; Dallas, TX.

Wahlenberg, W.G. 1946. Longleaf pine: Its use, ecology, regeneration, protection, and management. Washington, DC: Charles Lathrop Pack Forestry Foundation. 429 p.

Zhang, V.; Wallace, J.M.; Battlstl, D.S. 1997. ENSO-Iike interdecadal variability: 1900-93. Journal of Climate. 10: 1004-1020.