

THE PERCENTAGE OF TREES BEARING CONES AS A PREDICTOR OF ANNUAL LONGLEAF PINE CONE PRODUCTION

Thomas W. Patterson

EXTENDED ABSTRACT

Longleaf pine (*Pinus palustris*) cone production has been documented for over six decades, beginning in Escambia County, Alabama in the late 1950s and currently at 11 locations throughout the species' range (Brockway 2019, Connor and others 2014). Data from the multi-decadal study have linked cone production to variations in environmental conditions, stand dynamics, and inherent masting complexity (Chen and others 2016, 2017, 2018, 2021; Guo and others 2016; Haymes and Fox 2012; Leduc and others 2016; Loudermilk and others 2016; Pederson and others 1999). The ability to analyze complex relationships for longleaf pine cone production relates to the methodology for counting cones—providing a good estimate using a scientific protocol (Brockway 2019). Alternatively, less precise, rapid mast assessments have been proposed in the literature, and these studies have documented a close relationship between the percentage of trees bearing mast and actual mast counts (Carevic and others 2014, Greenberg 2020, Nakajima and others 2015). At present, rapid cone assessments have not been tested for longleaf pine, yet rapid assessments can help land owners estimate crop size for successful, natural regeneration. In this study, I examined the relationship between the percentage of trees bearing cones (a rapid, binary measurement) to the estimated average cone crop to understand if simple visual surveys could approximate the results of the scientifically derived dataset.

Longleaf pine cone data were obtained from the Forest Service, U.S. Department of Agriculture, Southern Research Station, which included individual tree pine-cone production from 11 locations throughout the species' range (see Brockway 2019 for information on individual sites). Some locations contained sub-compartments where cones were counted separately, and each sub compartment was treated as a separate site for a total of 18 sites in this study. Data were incomplete for numerous sites, or individual trees, and therefore approximately 20 percent of the dataset were unusable and omitted from analyses. Digitized, individual-tree data were available from 1993 to present, and all analyses were limited to the last three decades. The raw cone data were not normally distributed; therefore, I transformed these data using a natural logarithm to use statistics that assume normality. The percentage of trees bearing cones (PBC) was computed for each year at each site:

Author Information: Thomas W. Patterson, Assistant Professor, The University of Southern Mississippi, Hattiesburg, MS 39406.

Citation for proceedings: Willis, John L.; Self, Andrew B.; Siegert, Courtney M., eds. 2022. Proceedings of the 21st Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-268. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 262 p. <https://doi.org/10.2737/SRS-GTR-268>.

$$PBC = (TBC/n) \times 100 \quad (1)$$

where

PBC = percentage of trees bearing cones

TBC = number of trees bearing cones

n = number of trees

and simple linear models were assembled that examined if PBC was a statistically significant ($p < 0.05$) predictor for log-average cone production for all sites. Next, PBC was examined as it related to the Failed–Bumper cone crop classification (Brockway 2019) for average number of cones per tree: Failed 0–9, Poor 10–24, Fair 25–49, Good 50–99, and Bumper ≥ 100 . Cone crop was averaged for each of the site and year observations ($n = 314$) and performed a one-way ANOVA test with a Tukey’s HSD post-hoc analysis to examine differences in mean PBC between the Forest Service cone-crop classes. Finally, the odds of correctly identifying a Fair or better cone crop (≥ 25 cones/tree) from the threshold identified by the ANOVA analysis using a diagnostic odds test was examined.

The percentage of trees bearing cones was a statistically significant predictor for log-average cone production (table 1), and PBC model explanatory power (r^2) ranged from 58 to 94 percent variance explained for the 18 sites. The median r^2 of all models was 78 percent variance explained, with a standard deviation of 10 percent. Significant differences in mean PBC existed between the five Failed–Bumper groups ($F = 139.8$, $p < 0.001$). No difference in mean PBC existed between the Fair–Bumper groups; however, mean PBC was significantly lower ($p < 0.01$) for the Poor group and the mean PBC for the Failed group was significantly lower ($p < 0.001$) than all other groups (fig. 1). Mean PBC for the lowest of the three not-significantly different groups (Fair, ≥ 25 cones per tree) equaled 89.47, which indicates PBC values ≥ 90 corresponded with Fair or better cone crops. I performed an odds ratio to examine the efficacy of correctly identifying a Fair or better cone crop using a PBC threshold of 90, and the results of the odds ratio indicated cone-count stands in this study would be at least 18.4 (95 percent CI 10.2–33.4) times more likely to have a Fair, Good, or Bumper crop when $PBC \geq 90$ than when $PBC < 90$.

This study revealed two important findings that have implications for cone monitoring and forest regeneration. First, the percentage of trees bearing cones is a consistent and reliable predictor for log-average cone production throughout the species’ range. Models were statistically significant for all 18 sites in the study, and all models showed that PBC was a strong predictor of log-average cone production. Second, when average cone production was grouped by the Forest Service Failed–Bumper classification, there were convincing odds that a cone crop exceeding 25 cones per tree would occur when PBC was at or greater than 90. This unexpected finding has important implications for regeneration efforts, as cone crops classified as Fair or better represent good opportunities for natural regeneration (Brockway 2019). It is important to note that these results were obtained from a variety of stands throughout the longleaf pine range with data spanning the last three decades. Future studies should examine the reliability of PBC thresholds at new sites to understand how this relationship operates at different time scales, age classes, and topographic conditions.

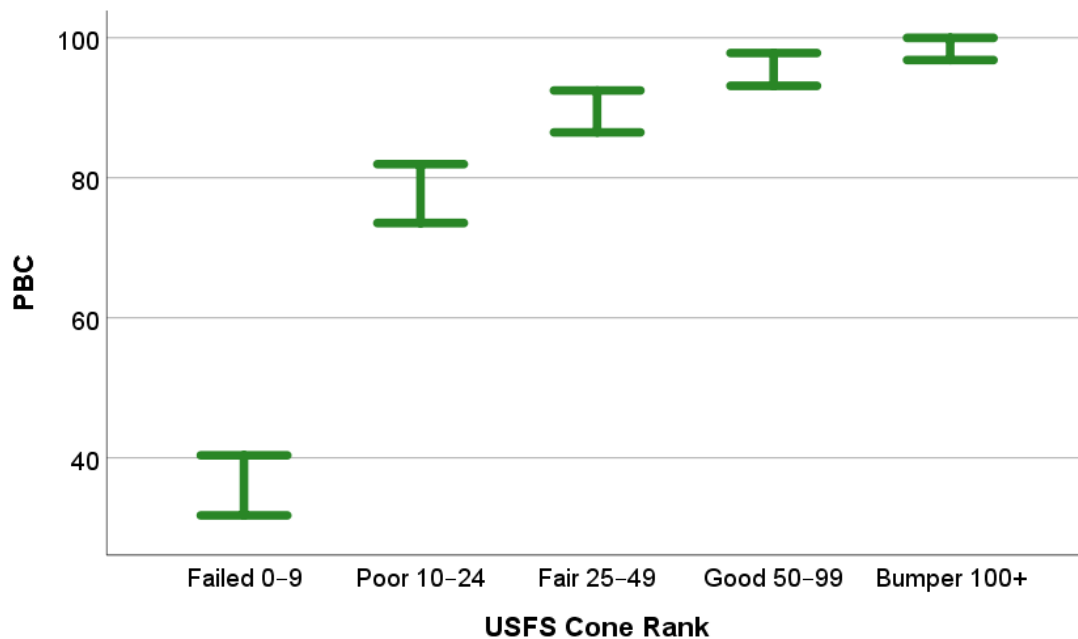


Figure 1—Error plot (i.e., 95 percent confidence intervals) from the one-way ANOVA analysis of PBC categorized by the U.S. Department of Agriculture, Forest Service cone-class ($F=139.8$, $p < 0.001$, $n=314$). Average number of cones per tree as follows: Failed=0-9, Poor=10-24, Fair=25-49, Good=50-99, and Bumper ≥ 100 .

LITERATURE CITED

- Brockway, D.G. 2019. Longleaf pine cone prospects for 2019 and 2020. Auburn, AL: U.S. Department of Agriculture Forest Service, Southern Research Station. 24 p.
- Carevic, F.S.; Alejano, R.; Fernández, M.; Martín, D. 2014. Assessment and comparison of the visual survey method for estimating acorn production in holm oak (*Quercus ilex* ssp. Ballota) open woodland of southwestern Spain. *Arid Land Research and Management*. 28(1): 102-108.
- Chen, X.; Brockway, D.G.; Guo, Q. 2021. Burstiness of seed production in longleaf pine and Chinese torrey. *Journal of Sustainable Forestry*. 40(2): 188-196.
- Chen, X.; Guo, Q.; Brockway, D.G. 2016. Analyzing the complexity of cone production in longleaf pine by multiscale entropy. *Journal of Sustainable Forestry*. 35(2): 172-182.
- Chen, X.; Guo, Q.; Brockway, D.G. 2017. Power laws in cone production of longleaf pine across its native range in the United States. *Sustainable Agriculture Research*. 6(4): 64-73.
- Chen, X.; Guo, Q.; Brockway, D.G. 2018. Characterizing the dynamics of cone production for longleaf pine forests in the Southeastern United States. *Forest Ecology and Management*. 429: 1-6.
- Connor, K.F.; Brockway, D.G.; Boyer, W.D. 2014. Restoring a legacy: longleaf pine research at the Forest Service Escambia Experimental Forest. In: Hayes, D.C.; Stout, S.L.; Crawford, R.H.; Hoover, A.P., eds. U.S. Department of Agriculture Forest Service Experimental Forests and Ranges: Research for the long term. New York: Springer: 85-101.
- Greenberg, C.H. 2020. Modelling annual Southern Appalachian acorn production using visual surveys. *Wildlife Society Bulletin*. 44(2): 292-299.
- Guo, Q.; Zarnoch, S.J.; Chen, X.; Brockway, D.G. 2016. Life cycle and masting of a recovering keystone indicator species under climate fluctuation. *Ecosystem Health and Sustainability*. 2(6): e01226.
- Haymes, K.L.; Fox, G.A. 2012. Variation among individuals in cone production in *Pinus palustris* (Pinaceae). *American Journal of Botany*. 99(4): 640-645.
- Leduc, D.J.; Sung, S.-J. S.; Brockway, D.G.; Sayer, M.A.S. 2016. Weather effects on the success of longleaf pine cone crops. In: Schweitzer, C.J.; Clatterbuck, W.K.; Oswalt, C.M., eds. Proceedings of the 18th biennial southern silvicultural research conference; 2015 March 2-5; Knoxville, TN. e-Gen. Tech. Rep. SRS-212. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 535-541.
- Loudermilk, L.E.; Hiers, K.J.; Pokswinski, S. [and others]. 2016. The path back: Oaks (*Quercus* spp.) facilitate longleaf pine (*Pinus palustris*) seedling establishment in xeric sites. *Ecosphere*. 7(6): e01361.
- Nakajima, A.; Masaki, T.; Koike, S. [and others]. 2015. Estimation of tree crop size across multiple taxa: generalization of a visual survey method. *Open Journal of Forestry*. 5(7): 651-661.
- Pederson, N.; Kush, J.S.; Meldahl, R.S.; Boyer, W.D. 1999. Longleaf pine cone crops and climate: A possible link. In: Haywood, James D., ed. Proceedings of the 10th 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.

Table 1—Site information for location (latitude, longitude), the number of trees per site, years of data per site, the average and standard deviation of cones per tree per site, model explanatory power (r^2) and significance (p), and the model parameters

Site name	Latitude	Longitude	Number of trees	Number of years	Average cones per tree	Standard deviation cones	r^2	p	Model
Apalachicola National Forest	30.36	-84.30	10	25	19.5	46.1	0.773	<0.001	$y = 2.011x - 0.345$
Blackwater River State Forest	30.84	-86.81	10	15	43.6	93.9	0.838	<0.001	$y = 2.201x - 0.381$
Bladen Lakes State Forest	34.74	-78.54	14	23	18.5	32.6	0.841	<0.001	$y = 2.247x - 0.541$
Eglin Air Force Base - Rattlesnake Road Site	30.68	-86.59	9	24	28.3	57.5	0.816	<0.001	$y = 2.157x - 0.32$
Eglin Air Force Base - Old Sandhills #1 Site	30.61	-86.54	7	21	28.3	60.1	0.869	<0.001	$y = 2.239x - 0.334$
Eglin Air Force Base - Old Sandhills #2 Site	30.56	-86.42	8	21	18	42	0.765	<0.001	$y = 0.7x + 0.127$
Eglin Air Force Base - Brown Pond Site	30.56	-86.42	10	24	19.3	35.7	0.745	<0.001	$y = 1.938x - 0.257$
Escambia Experimental Forest - Compartment 156	31.02	-87.04	10	22	26.7	52.4	0.778	<0.001	$y = 1.818x - 0.14$
Escambia Experimental Forest - Compartment 107	31.02	-87.06	10	11	48	81.2	0.701	0.001	$y = 1.913x - 0.103$
Escambia Experimental Forest - Compartment 113	31.02	-87.04	10	9	53.2	80.3	0.788	0.001	$y = 2.279x - 0.418$
Escambia Experimental Forest - Compartment 71	31.02	-87.06	7	24	31.3	53.4	0.855	<0.001	$y = 2.054x - 0.289$
Escambia Experimental Forest - Compartment 118	31.02	-87.04	10	7	26.4	37.5	0.939	<0.001	$y = 1.925x - 0.164$
Escambia Experimental Forest - Compartment 103	31.02	-87.06	20	8	37.6	57.8	0.917	<0.001	$y = 2.176x - 0.226$
Fort Benning Military Base	32.36	-84.85	50	13	39.5	90.4	0.703	<0.001	$y = 2.315x - 0.333$
Jones Ecological Research Center - Turkey Woods	31.25	-84.47	11	16	43.6	103.2	0.837	<0.001	$y = 2.934x - 0.167$
Kisatchie National Forest	31.51	-92.47	15	20	34	69.3	0.592	<0.001	$y = 1.849x - 0.359$
Sandhills State Forest	34.55	-79.97	14	21	17.2	29.5	0.694	<0.001	$y = 1.767x - 0.35$
Tall Timbers Research Station	30.67	-84.22	9	10	10.6	17.4	0.575	0.01	$y = 1.67x - 0.352$