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THE LOST COLONY AND **JAMESTOWN DROUGHTS**

Section: REPORTS

Tree-ring data from Virginia indicate that the Lost Colony of Roanoke Island disappeared during the most extreme **drought** in 800 years (1587-1589) and that the alarming mortality and the near abandonment of **Jamestown** Colony occurred during the driest 7-year episode in 770 years (1606-1612). These extraordinary droughts can now be implicated in the fate of the Lost Colony and in the appalling death rate during the early occupations at **Jamestown**, the first permanent English settlement in America.

The network of moisture-sensitive tree-ring chronologies now available for the United States has recently been used to reconstruct summer **drought** and wetness on a continent-wide basis from 1700 to 1978 A.D. (1). Much longer chronologies are available for some areas, including a network of 800-year-long baldcypress (Taxodium distichum) chronologies for the southeastern United States. These exactly dated tree-ring proxies of growing-season climate can provide unique information on environmental conditions during the early colonial history of the eastern United States. Here, we use two long baldcypress chronologies to reconstruct the Palmer hydrological **drought** index (PHDI) (2) for the Tidewater region of southeastern Virginia and northeastern North Carolina (Fig. 1) and show that extreme **drought** afflicted the first English attempts to colonize the New World at Roanoke and **Jamestown** Island.

Centuries-old baldcypress trees survive locally along the Blackwater and Nottoway rivers in southeastern Virginia (Fig. 1), and exactly dated tree-ring chronologies were developed nondestructively for each location (3). Both chronologies are directly correlated with precipitation and are inversely correlated with temperature during the growing season (April to July), in spite of the frequently flooded riparian habitat of the sample trees (4). A regional baldcypress tree-ring chronology was computed as the arithmetic mean of the Blackwater and Nottoway rivers' chronologies for the common period 1185 to 1984 A.D. (variance trend due to low sample size in the early years was removed). The regional chronology is well replicated (>26

cores from 12 trees after 1225, and 62 cores at 1600) and was used to reconstruct regionally averaged July PHDI for the Tidewater and eastern Piedmont climatic divisions of Virginia and the northern and central coastal plain divisions of North Carolina (5). This large homogeneous climatic province includes **Jamestown**, Roanoke Island, and most of the drainage basins of the Blackwater and Nottoway rivers. The PHDI is closely related to the Palmer **drought** severity index, and both are used by the National Weather Service to monitor **drought** and wetness conditions across the United States (6). The July PHDI integrates the effects of spring and summer precipitation and temperature anomalies on the soil water balance (2) and is an excellent measure of moisture availability throughout the growing season.

To calibrate the tree-ring and July PHDI data, the regional PHDI were first prewhitened with autoregressive (AR) modeling (7). July PHDI was modeled as an AR-1 process, with an AR-1 coefficient of 0.285. Regression was then used to estimate prewhitened July PHDI (y_t) from the prewhitened regional tree-ring chronology (x_t), each in year t:

(1) $y_t = -0.198 + 4.573x_t$

This model was developed for the period 1941-1984 and explains 44% of the variance in the instrumental July PHDI (Table 1 and Fig. 2). The AR coefficient of the instrumental July PHDI was then used to add the observed persistence structure back into the July PHDI estimates derived from Eq. 1. Estimated July PHDI (y_t) was compared with instrumental July PHDI available from 1896-1940 to validate the transfer function (Fig. 2). The suite of statistical tests for the 45-year verification period indicate that the tree-ring reconstruction provides a reasonable approximation of actual conditions, especially the first-differenced interannual fluctuations of July PHDI (Table 1).

Early Spanish references to Virginia climate further validate the accuracy of this tree-ring reconstruction at the opening of the colonial period. In September 1570 Father Juan Batista de Segura wrote that the Chesapeake Bay region had experienced 6 years of maize and wild-fruit shortages, famine, death, and parched soil (8). This is consistent with the reconstruction of July PHDI, which indicates a prolonged **drought** from 1562 to 1571 that was most severe from 1565 to 1569 (Fig. 3). Segura's commentary also documents the sensitivity of the native Algonquian subsistence system to prolonged **drought**, which we estimate recurred with equal or greater severity during the English settlement of Roanoke and **Jamestown**.

The full reconstruction of July PHDI extending from 1185 to 1984 A.D. (Fig. 3A) indicates that substantial interannual and decadal variance of growing-season moisture supply has been typical of the Tidewater region for at least the past 800 years. However, the tree-ring data specifically indicate that extraordinary **drought** conditions attended the settlement of both the Roanoke and **Jamestown** Colonies (Fig. 3). The Roanoke colonists were last seen by their English associates on 22 August 1587, the summer when the tree-ring data indicate the most extreme growing-season **drought** in 800 years (Fig. 3A). This **drought** persisted for 3 years, from 1587 to 1589, and is the driest 3-year episode in the entire 800-year reconstruction (Fig. 3). The tree growth anomaly map for the period 1587-1589 (Fig. 4A) indicates that the Lost Colony **drought** affected the entire southeastern United States but was particularly severe in the Tidewater region near Roanoke.

The tree-ring reconstruction also indicates that the settlers of **Jamestown** Colony had the monumental bad luck to arrive in April 1607, during the driest 7-year period in 770 years (Fig. 3). The cypress growth anomaly map for the **Jamestown drought** (1606-1612) indicates that the most severe inferred **drought** conditions occurred in the Tidewater region near **Jamestown** and that above-average growth (inferred

wetness) was recorded in the Mississippi Valley (Fig. 4B). This synoptic pattern is not unprecedented. A reasonable analogy can be drawn to the summer of 1993, when heavy precipitation brought record flooding to the Midwest, and severe **drought** occurred simultaneously over the southeastern United States (9).

The tree-ring data raise many interesting questions about early colonial history, beginning with the fate of the Lost Colony. Extreme **drought** should now be considered among the several factors responsible for the failure of the Roanoke Colony (10-13). Certainly, the native Croatan were concerned about the poor condition of their crops in 1587 (13), and the tragic shooting of friendly Croatan by the Roanoke colonists was a case of mistaken identity that arose in part from the Croatan need for food (11). The Lost Colony **drought** persisted for 3 years, and the Segura commentary (8) indicates that it would have created a major subsistence crisis for the native inhabitants. The Lost Colonists were dependent to a great degree on these native societies, and their dependence would have aggravated any food shortages.

Did **drought** contribute to the alarming mortality and near abandonment at **Jamestown** Colony? Only 38 of the 104 original settlers were still alive after the first year at **Jamestown**, and 4800 of the 6000 settlers sent to **Jamestown** between 1607 and 1625 died during this extraordinary period (10, 11). Malnutrition was a leading cause of death at **Jamestown** (10). In fact, mortality estimates for **Jamestown** Colony from 1608 to 1624 (14) as well as for the first year at Roanoke Island are significantly correlated with the tree-ring reconstructed July PHDI (Fig. 5) [1585-1586 is reconstructed as moist and only 4 of 108 people perished at Roanoke (10)]. The colonists were expected to live off the land and off trade and tribute from the Indians (11). But this subsistence system would have left the colonists extremely vulnerable during **drought**. Archival sources indicate that the native Algonquian people and the English domestic livestock also suffered during the years of heavy mortality among the colonists (10).

Poor water quality is another factor implicated in the ill health suffered at **Jamestown** (14, 15), and water quality is poorest during **drought** (16). The lower James River is a brackish estuary, and there are archival references to foul drinking water and associated illnesses among the settlers, particularly before 1613 (14). Reduced freshwater discharge during regional **drought** is associated with increased concentration of salt in the lower James River and in shallow aquifers in the vicinity of **Jamestown** (16).

The Roanoke and **Jamestown** colonists have been criticized for poor planning, poor support, and a startling indifference to their own subsistence (10-13). But the tree-ring reconstruction indicates that even the best planned and supported colony would have been supremely challenged by the climatic conditions of 1587-1589 and 1606-1612.

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Table 1.

Calibration and validation statistics (3) for the tree-ring reconstruction of July PHDI over southeastern Virginia and northeastern North Carolina [a first-differenced version (1st diff) of the reconstruction is also validated]. All results are statistically significant except the means test, where a significant difference between the observed and reconstructed means is not desirable. R^2 adj. = adjusted for loss of degrees of freedom; NS = not significant.

Legend for Chart:

B - Calibration 1941-1984
C - Validation 1896-1940
D - Validation 1896-1940 (1st diff)

	A	B	C	D
Variance explained (R^2 adj.)	0.44	0.31	0.39	
Pearson correlation		0.67(*)	0.56(*)	0.62(*)
Spearman correlation		0.67(*)	0.54(*)	0.59(*)
Means test (t)			1.46 (NS)	0.13 (N
Cross product t test		1.60(*)	0.841(A)	3.44(*)
Sign test (hit/miss)		32/12(B)	33/12(B)	29/15(A
Reduction of error		0.45	0.23	0.38
Coefficient of efficiency		0.45	0.21	0.38

(*) P < 0.0001.

(A) P < 0.05.

(B) P < 0.01.

MAP: Fig. 1. Location of Roanoke Island, **Jamestown** Colony, and the baldcypress tree-ring chronologies from Blackwater and Nottoway rivers used to reconstruct July PHDI for the Tidewater region of Virginia and North Carolina [map adapted from (13)].

GRAPH: Fig. 2. Time series of the instrumental (dashed line) (5) and tree-ring-reconstructed July PHDI (solid line) from 1896 to 1984 for the Tidewater region.

GRAPH: Fig. 3. Tree-ring-reconstructed July PHDI for the Tidewater region of Virginia and North Carolina from 1185 to 1984 (A) and for the early colonial period from 1560 to 1720 (B). The most extreme growing-season **drought** of the past 800 years was reconstructed for 1587, the year the colonists on Roanoke Island disappeared. The Lost Colony **drought** of 1587-1589 was the most extreme 3-year episode in the entire 800-year reconstruction. The prolonged **Jamestown drought** lasted from 1606 to 1612 and was the worst 7-year **drought** reconstructed for 770 years (from 1215 to 1984).

GRAPHS: Fig. 4. Spatial pattern of growing-season **drought** and wetness inferred from baldcypress tree growth in the southeastern United States during the Lost Colony **drought** of 1587-1589 (A) and the 7-year **Jamestown drought** of 1606-1612 (B). Eleven **drought**-sensitive baldcypress chronologies were restricted to the 1185-1984 common period and were used to compute all possible 3- and 7-year consecutive averages. The percentile ranking of the 1587-1589 and 1606-1612 periods at each location is mapped. The natural distribution of baldcypress is also shown (dotted line).

GRAPH: Fig. 5. Percent mortality estimates (dotted line) for **Jamestown** Colony (1608-1624) (14) and for Roanoke Colony (1585-1586) (10) are significantly correlated with reconstructed July PHDI (Pearson's r = 0.71, P < 0.001; Spearman's r = 0.69, P < 0.002). Mortality was summarized each spring from estimates of population and immigration (14), so the mortality data for 1607-1608 are compared here with July PHDI for 1607. Mortality estimates for 1614-1616 and 1618-1620 are 3-year averages.

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