Supporting Information

Hubeny et al. 10.1073/pnas.1019301108

SI Text

Assessment of Anthropogenic Influences on the Varve Signals. Because anthropogenic alterations to depositional systems can alter the preserved sedimentary record, we provide an assessment of potential influencing factors for this study. Due to the short length of the instrumental Pacific/North American (PNA) record (1949—Present), it is not possible to test the correlations of varves to the PNA pre and postanthropogenic influence. However, we present lines of evidence that support our interpretations that the varve records presented are appropriate archives for assessing past hydrologic and PNA-driven variability in the climate system.

Although the Pettaquamscutt River Estuary's watershed has never been highly developed, two specific time intervals have been identified where human influence has left a signal in the sedimentary record (1). The first, associated with Colonial agriculture, was identified between the years 1695 and 1715 A.D. and multiproxy analyses have demonstrated that this effect was a short-lived phenomenon (~20 y) that did not have a long-term influence on the sedimentary record (1). More recently, residential development has occurred since the midtwentieth century, with the largest percentage rate of growth from 1950–1959 A.D. (1, 2). Although this trend in watershed development started in the 1950s, the estuary was still lightly developed at this time, and estuarine response (as interpreted from sedimentary multiproxy data) did not occur until *ca.* 1960 A.D. (1). This lag suggests that there is a threshold level of developed land needed for the effect to be apparent in this estuary, and that this threshold level was not reached until *ca.* 1960 A.D. To test the possible impact of the noted watershed development on sedimentation, correlation coefficients were determined between decadally smoothed lamination thicknesses and regional hydrologic variables for the time periods 1899–1959 A.D. (pre1960) and 1960–1997 (post1960) (Table S1). Although the correlation coefficients change slightly from the values obtained for the entire time series (Table 1), correlations to precipitation and drought were significant both before 1960 and after 1960. These lines of evidence demonstrate that anthropogenic affects are minimal for the Pettaquamscutt River record, and that it is appropriate to utilize clastic lamination thicknesses as a proxy for moisture fluctuations in the region.

Hilfinger, et al. (3) demonstrated that anthropogenic impacts are evident in the sedimentary record of Green Lake starting in the early nineteenth century. The early influence prohibits us from conducting an analysis similar to that of the Pettaquamscutt River because the precipitation and Palmer Drought Severity Index (PDSI) records start in 1898 A.D. We argue, however, that the effects on the varve record were likely minimal based on two lines of evidence. First, Green Lake is located within a large and relatively undeveloped state park. As a result, the watershed is not prone to many of the anthropogenic forcings that can influence sedimentation and varve formation. Second, the Green Lake carbonate lamination record is statistically correlated to the Pettaquamscutt River clastic lamination record for the past millennium ($r = 0.42$, $p < 0.001$; $r = 0.62$, $p < 0.001$, annual and decadally smoothed series, respectively). If profound local anthropogenic affects were dominant in either record, then we would not expect the two records to correlate so well over the length of the record.

PNA Teleconnection to SSTs. Correlation analyses were conducted with the PNA instrumental record and the Pettaquamscutt River/Green Lake (PRGL) Index against gridded sea surface temperatures (SST) data (Fig. S1). SST data were from the National Oceanic and Atmospheric Administration's National Climate Data Center's Extended Reconstruction SST (ERSST) data on a two-degree grid. Analyses were conducted during the period of instrumental overlap (1948–2001) for winter/spring data (December–May).

Significant positive correlations were observed with SSTs along the eastern margin of the Pacific Ocean as well as in the eastern tropical Pacific Ocean for both records. Significant negative correlations were observed for the midlatitude Pacific Ocean and North Atlantic Ocean SSTs as compared to the two time series. These results demonstrate that during negative PNA (low PRGL) years, the eastern tropical Pacific Ocean experiences negative SST anomalies, whereas the North Atlantic experiences positive SST anomalies. This spatial pattern of SST has been identified in association with continental "megadroughts" (15).

Details on Spectral Analysis of the PRGL Record. Spectral analysis of the PRGL time series was performed in order to test for correlation to the PNA in the frequency domain. Spectral analyses of instrumental PNA records reveal significant periodicities between 3.2 and 3.5 y (4, 5). The PRGL series contains a highly significant spectral peak at 3.4 y (Fig. S2), which is consistent with a strong PNA influence. An 8.2 y peak is likely associated with the Northern Annular Mode (NAM), as this teleconnection pattern has been shown to have such a spectral signature (6).

Spectral analysis was performed using the multitaper method with three tapers. The analyses were performed after resampling the time series at 1-y, and applying a log transformation to ensure a normal distribution of the data. Significant peaks were identified with respect to a first order serially autocorrelated process (7).

Details on the Continental Drought Synthesis. A literature review (8–14) revealed at least nine continental-scale droughts over the last millennium (Table S2, Fig. S3). We have assembled these data along with associated dates to compile the timing of continental drought events and analyze the PRGL Index in light of these events. In the case of multiple cited dates, we were conservative and selected the dates that are inclusive for the entire range. The majority of droughts reported were reconstructed from Western or Southwestern regions of the US.

In addition to the continental-scale droughts, there are two large droughts (D13 and D11) reported from Chesapeake Bay (14). These events, dated at 1510–1555 A.D. and 1625–1655 A.D., were not observed in any of the reconstructions from the Western US, and are therefore interpreted as being localized to the midAtlantic or Atlantic regions.

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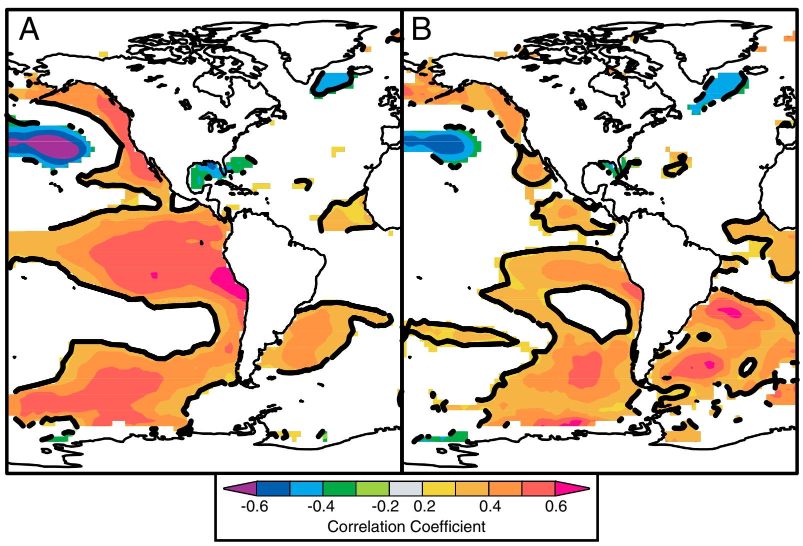

Fig. S1 Geospatial correlations between gridded SSTs and (*A*). PNA index (EOF2) and (*B*). PRGL Index over the period 1948–2001. Color scale indicates correlation coefficient (*r*), and thick contour shows $p = 0.05$. Note the significant correlations calculated for both series in relation to the eastern tropical Pacific Ocean SSTs (positive) as well as the North Atlantic Ocean SSTs (negative).

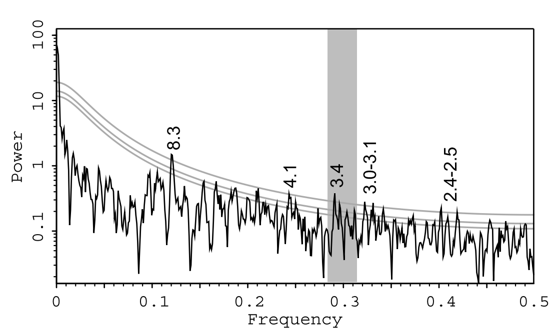

Fig. S2 Multitaper spectral analysis of PRGL Index time series. Gray lines represent the 90%, 95%, and 99% confidence levels with respect to a first-order autoregressive [(AR) (1)] red noise background. The PNA frequency band that equates to periodicities of 3.2–3.5a is shown with gray box. All periodicities significant above 99% are labeled.

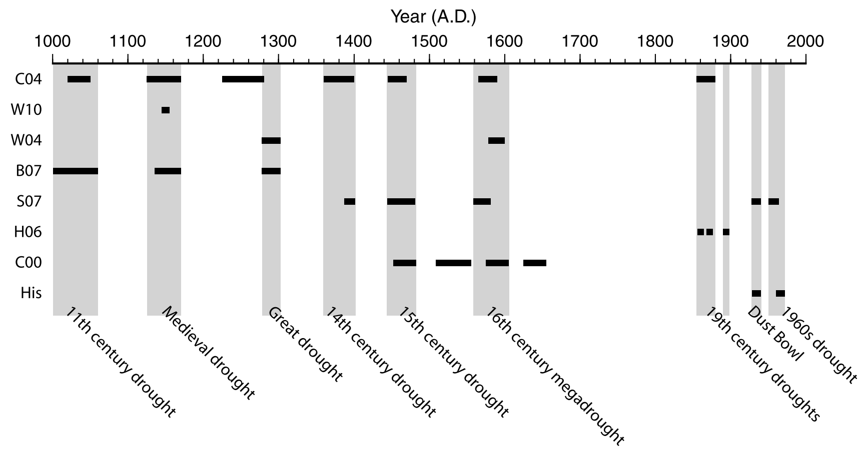

Fig. S3 Timing of significant droughts in North America during the last millennium as reported from previous studies (black rectangles). Continental-scale droughts are illustrated with gray boxes, and age ranges are inclusive of all reported records. C04 (8) from Western US; W10 (9) from American Southwest; W04 (10) from Western US; B07 (11) from Western US; S07 (12) from North America and/or Western US; H06 (13) from North America; C00 (14) from Chesapeake Bay; His from historical record. The early 16th and early 17th century Chesapeake Bay droughts (14) have not been observed in the Western US, and are therefore likely events restricted to the midAtlantic or perhaps Atlantic regions.

Table S1. Correlation analysis between decadally smoothed PR compaction-corrected clastic lamination thicknesses and regional climate variables, before (1899–1959 A.D.) and after (1960–1997 A.D.) anthropogenic impact in the watershed (1)

Climate index	Correlation coefficient (*r*)	Significance (*p*)	Degree of Freedom (DOF)
Rhode Island precipitation (pre1960)	0.57	0.0265	13
Rhode Island precipitation (post1960)	0.83	0.0030	8
Palmer Drought Severity Index (pre1960)	0.76	0.0010	13
Palmer Drought Severity Index (post1960)	0.68	0.0305	8

Table S2. North American continental-scale droughts of the past millennium reconstructed from cited literature

Drought name	Inclusive time period (A.D.)
11th century drought (8, 11)	990–1060
Medieval drought (8, 9, 11)	1125–1170
Great drought (10, 11)	1276–1299
**Cook, et al. (8) anomalous age range	**(1225–1280) (8)
14th century drought (8, 12)	1360–1400
15th century drought (8, 12, 14)	1444–1481
16th century megadrought (8, 10, 12, 14)	1559–1605
19th Century droughts (two periods) (8, 13)	1856–1880
	1890–1896
Dust Bowl (12)	1929–1940
1960s drought (12)	1951–1970