A dendroclimatological analysis of the Stebbin's Gulch ring-width chronology from Holden Arboretum, Kirtland, OH

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Abstract

Stebbin's Gulch, containing one of Ohio's oldest forests, is a valuable research site for dendroclimatologists. Cores were obtained from 29 chestnut oak (*Quercus montana)* trees in Stebbin's Gulch and analyzed in the College of Wooster Tree Ring Lab. Ring widths at this site increased over time and experienced a rapid increase from about 1840 to about 1915. This increase is also seen in cores from other sites in northeast Ohio, but occurs at different times depending on where the site is located; southern sites had an earlier increase and northern sites had a later increase. We suggest that settlers entering Ohio from the south initially increased the productivity of trees in Stebbin's Gulch by logging, thereby decreasing competition. Ring widths continue to increase because of various climatic and land use changes.

Introduction

Stebbin's Gulch, located within Holden Arboretum, is a deep ravine around which one of Ohio's oldest forests grows. Holden Arboretum is based in Kirtland, Ohio, approximately 35 kilometers northeast from Cleveland as the crow flies. Precipitation in this area tends to be fairly high year-round, in part due to lake-effect precipitation (Figure 1). The temperatures in this area can range from an average of 25°F in the winter to 75°F in the summer (Figure 1).

Stebbin's Gulch was designated a National Natural Landmark by the National Park Service, so access to the site is limited for both visitors and researchers. For this reason, Stebbin's Gulch is one of Ohio's most coveted old-growth forests for researchers. However, since access to the area is so limited, research permits are hard to come by. This lab has been lucky enough to acquire one and visit the site for samples. The last chronology made of the Stebbin's Gulch forest was done in 1983 by Dr. Ed Cook of the Lamont-Doherty Tree Ring Lab, so an update to it is much overdue. Additionally, ring-width data and climate analyses obtained from this research will help us see the effects of anthropogenic climate change on old growth forests like the one at Stebbin's Gulch.

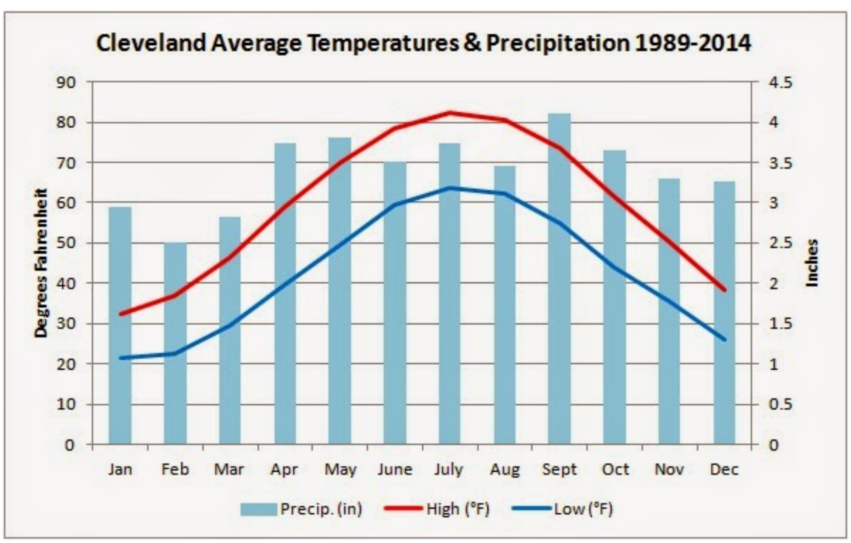

Figure 1. Climograph for Cleveland, Ohio. Precipitation tends to peak twice, before and after summer months during September and May. Temperature peaks in July. (http://clevelandclimate.blogspot.com/p/climate-controls.html)

Methods

Field Methods

Cores were obtained using standard 5mm increment hand borers of varying lengths. Old *Quercus montana* trees were targeted, but some younger, fast-growing trees were cored as well. Fifty-three cores were taken from 29 trees. We also measured the diameter at breast height (DBH) of most trees we sampled, but were unable to get some due to dangerous slope conditions. The GPS location of each tree was also recorded to the nearest 0.1 second (Figure 2).

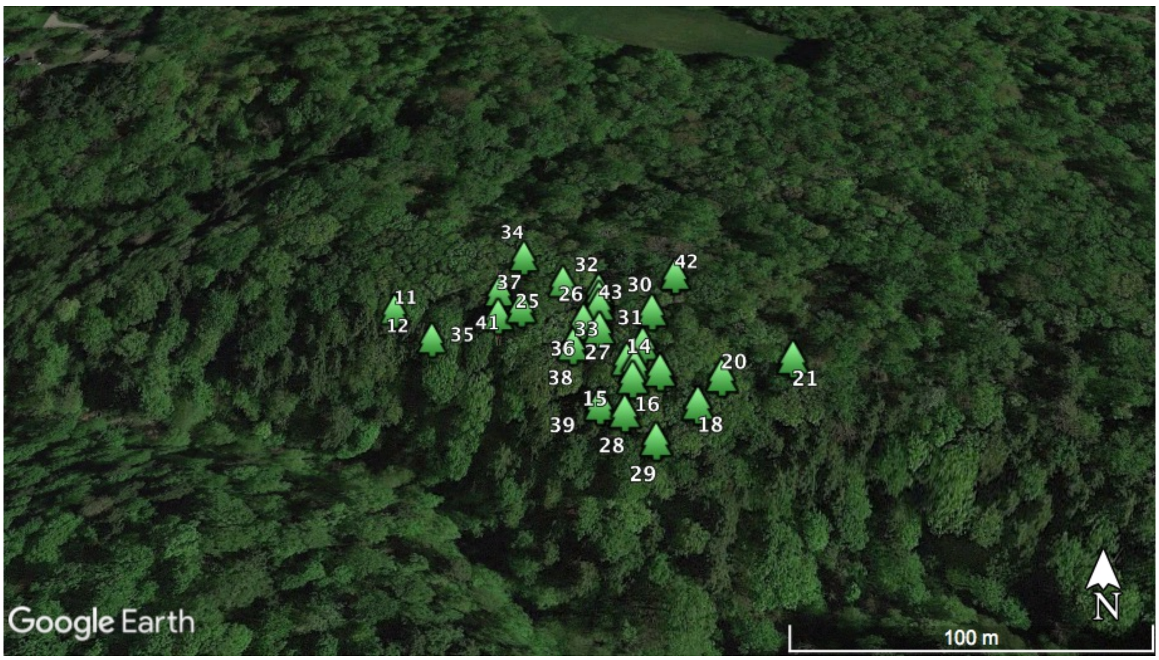

Figure 2. Map of locations of trees sampled.

Lab Methods

Cores were left out to dry before being glued into wooden mounts. After being mounted, the cores were sanded on a belt sander, and then finer hand sanding was done to polish the surface of the cores so individual cells of the rings could be seen. Ring widths were measured to the nearest 0.001mm using a Velmex measuring table and the values were recorded in the program MeasureJ2X. Since we had access to Dr. Cook's existing chronology of Stebbin's Gulch, our cores were then cross-dated with this chronology in the program COFECHA to look for flags in the data, correct errors, and improve correlations. COFECHA removes low-frequency, long term trends in the data to emphasize high-frequency year-to-year variability in the cores, which tend to be more important for crossdating (Grissino-Mayer, 2001). The program serves as a quality control check by detecting outlying ring measurements and suggesting a shift in correlation for certain sections of the core. This is helpful in recognizing missing or extra rings as well as their possible placement in the core (Grissino-Mayer, 2001).

After refining the ring width data, we compiled a master chronology of the data from our most highly correlated cores along with the data from Dr. Cook's cores. From our 53 cores, 49 were included in the master. The crossdated ring width measurements were then processed in ARSTAN to standardize the data in a variety of ways for further analysis (Cook, 1985). Next, we plotted the raw ring widths in KaleidaGraph (Figure 3). We also present standardized data using negative exponentials, linear equations, and the Hugershoff growth curve (Figure 4), as well as data standardized by using a horizontal line through the arithmetic mean (Figure 5). Using local station data from KNMI Climate Explorer, we compared our ring width data to temperature at the Cleveland station and precipitation records from a regional average of stations located within 40°E to 42°E and 80°W to 82°W (Trouet and van Oldenborgh, 2013).

Results

After measuring the rings, we assigned the innermost and outmost rings of each core a year (Table 1). In most cases, especially in cores with preserved bark, the outermost year was 2017, since that was the last full year of growth. In other cores, like SG32, the bark was sometimes lost in the field during coring along with a few of the most recent rings. The number of rings in each core and the diameter at breast height (DBH) were also recorded.

Table 1. Trees sampled. First year is the first year of growth, last year is the last full ring in the core, and DBH is the diameter of the tree at breast height.

Tree ID	First Year	Last Year	# of Rings	DBH
SG11	1643	2017	375	N/A
SG12	1821	2017	197	86
SG14	1791	2017	227	70
SG15	1632	2017	386	84
SG16	1930	2017	88	77
SG17	1728	2017	290	88
SG18	1830	2017	188	88.5
SG20	1840	2015	176	75
SG21	1806	2017	212	101
SG25	1858	2017	160	80
SG26	1682	2017	336	105
SG27	1659	2017	359	87
SG28	1945	2017	73	79
SG29	1861	2016	156	N/A
SG30	1850	2017	168	N/A
SG31	1857	2017	161	129
SG32	1876	2015	140	72
SG33	1809	2017	209	87
SG34	1885	2017	133	84
SG35	1722	2017	296	82
SG36	1685	2017	333	92
SG37	1687	2017	331	75.5
SG38	1752	2017	266	69
SG39	1608	2017	410	79
SG41	1912	2017	106	92
SG42	1873	2017	145	100
SG43	1729	2017	289	90
STEB01	1920	2017	98	N/A
STEB02	1730	2012	283	N/A

We plotted the raw ring widths versus year in KaleidaGraph to see what overall trends the data showed before they were taken out (Figure 3). We can see a rapid increase in ring widths starting in about 1840. Ring width is almost doubled by 1900, and continues to rise after that (Figure 3). For the individually standardized series (Figure 4), the rise can still be seen, but the overall trend levels out after about 1920. The mean-standardized ring widths (Figure 5) show the rapid increase, then a sustained doubling of ring widths after the disturbance. We also plotted the DBH of each tree against the number of rings in that tree's core to see if there was a visible relationship between DBH and age (Figure 6). We see no apparent relationship between the two.

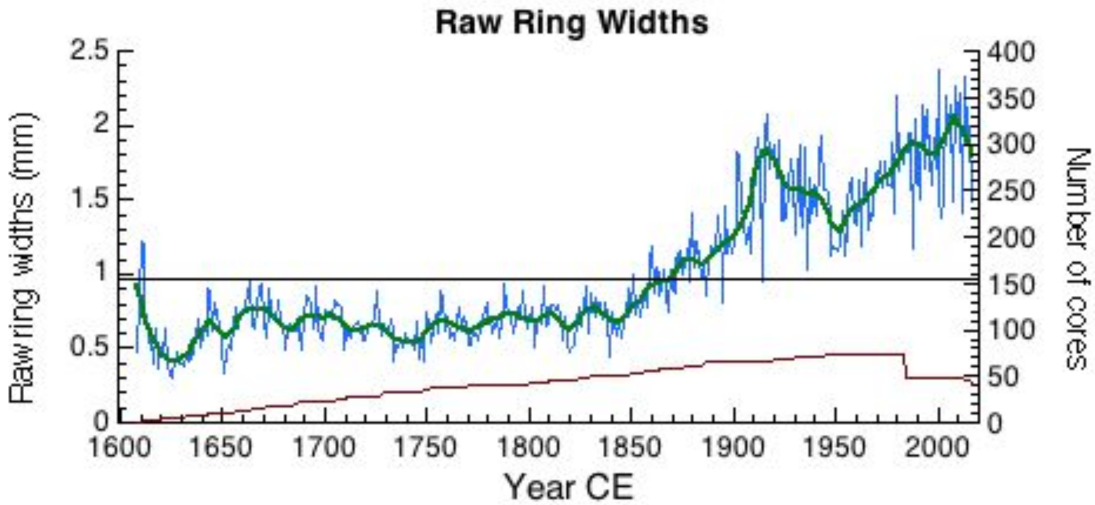

Figure 3. Raw ring widths plotted against year, with a 4% weighted curve fitted to the curve and the number of cores containing each year shown at the bottom. Horizontal line is shown through the mean, at about 0.98mm.

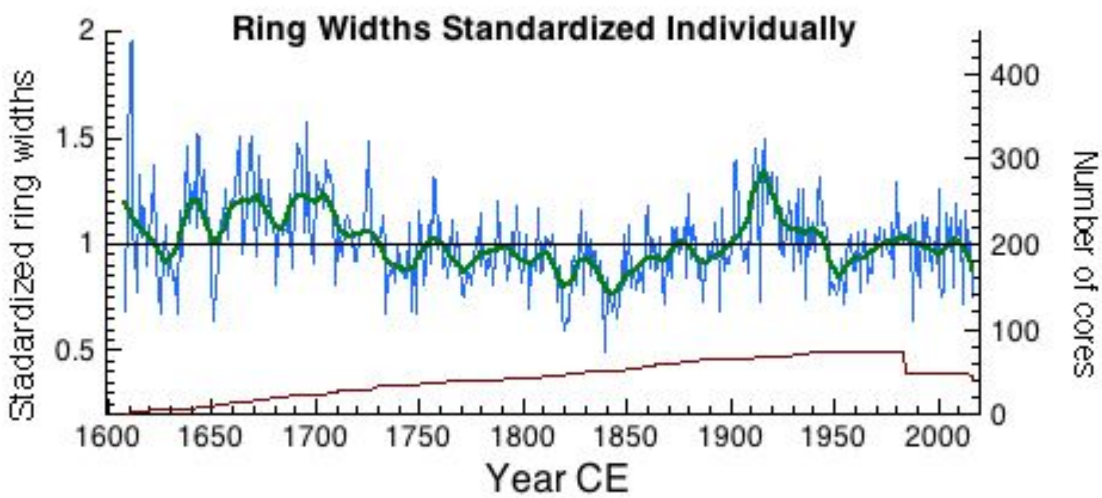

Figure 4. Plot showing how individually standardized ring widths change with time, with a 4% weighted curve fitted to the points to emphasize trends and with the number of cores containing each year shown at the bottom.

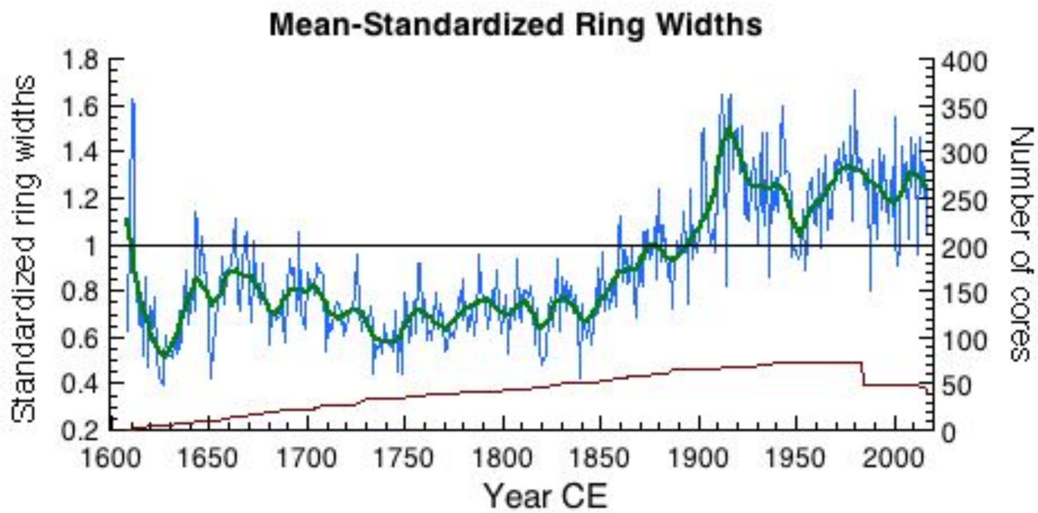

Figure 5. Plot showing how mean-standardized ring widths change with time, with a 4% weighted curve fitted to the points to emphasize trends and with the number of cores containing each year shown at the bottom.

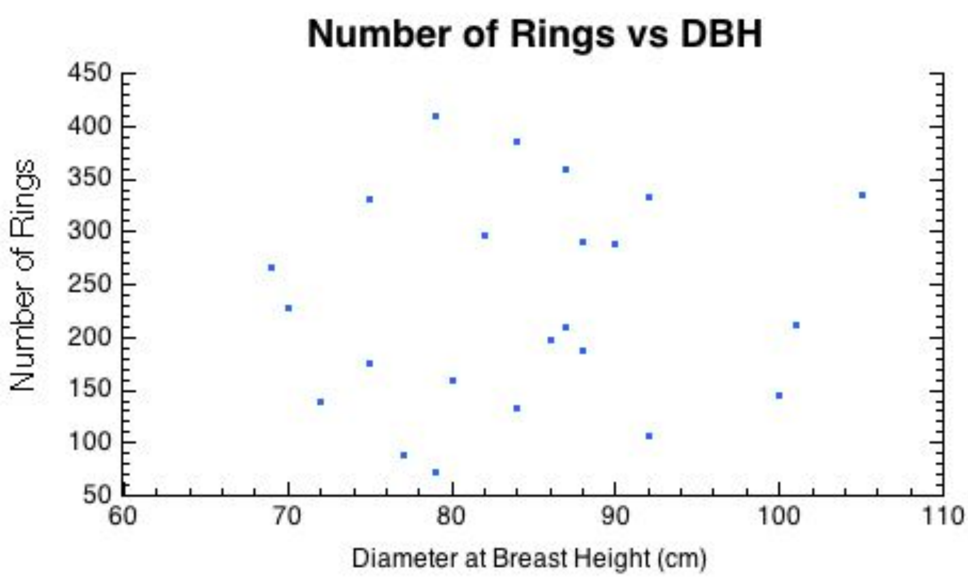

Figure 6. Plot showing the number of rings for each tree versus that tree's diameter at breast height, or DBH.

Next, we correlated our data with precipitation and temperature in KNMI Climate Explorer (Trouet and van Oldenborgh, 2013). A single station's data, the Cleveland station, gave the best correlations for temperature (n=65 years). For precipitation, better correlations were obtained when the average of a range of stations was used (n=112 years). Precipitation data from a larger area is more relevant than that of a single station because of the spatial variability of precipitation. The correlations were then graphed (Figures 7 and 8). Individually standardized cores tended to give better correlations for temperature, while mean-standardized cores tended to give better correlations for precipitation. June seemed to be the most influential month for both of these factors, followed by July, then by August.

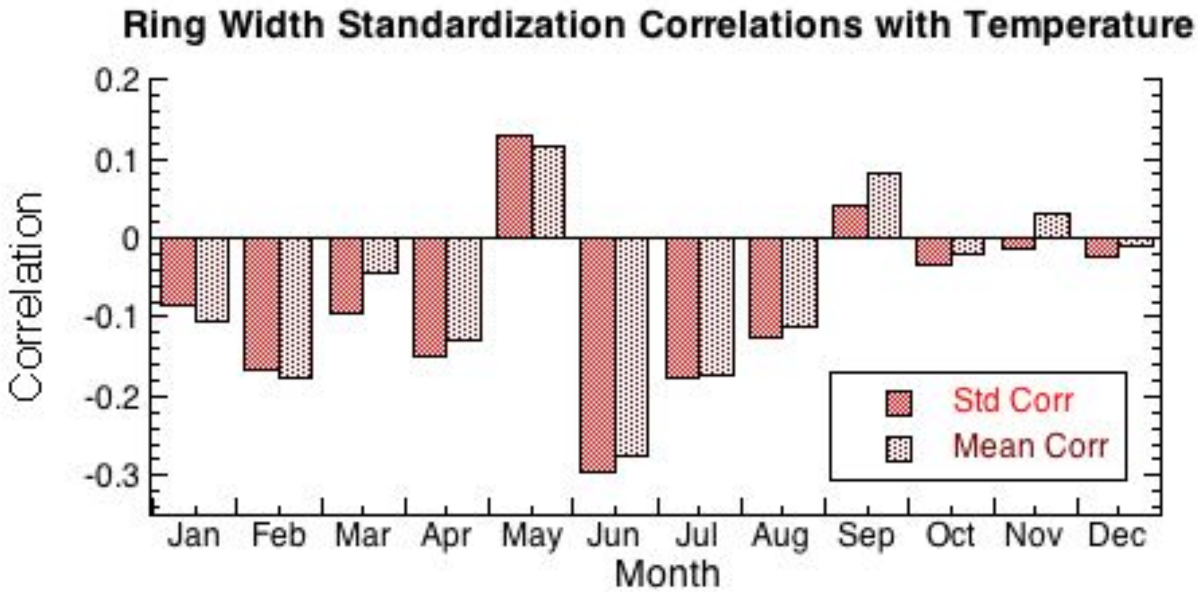

Figure 7. Histogram of standardized ring widths correlated with temperatures recorded at Cleveland station. Temperature records of Cleveland station go back to 1947, and include 65 years of data. Full red bars are ring widths standardized individually to maximize year-to-year variability and dotted white bars are ring widths standardized by a horizontal line through the arithmetic mean. Correlations are significant in June, which lies above the 95% confidence level.

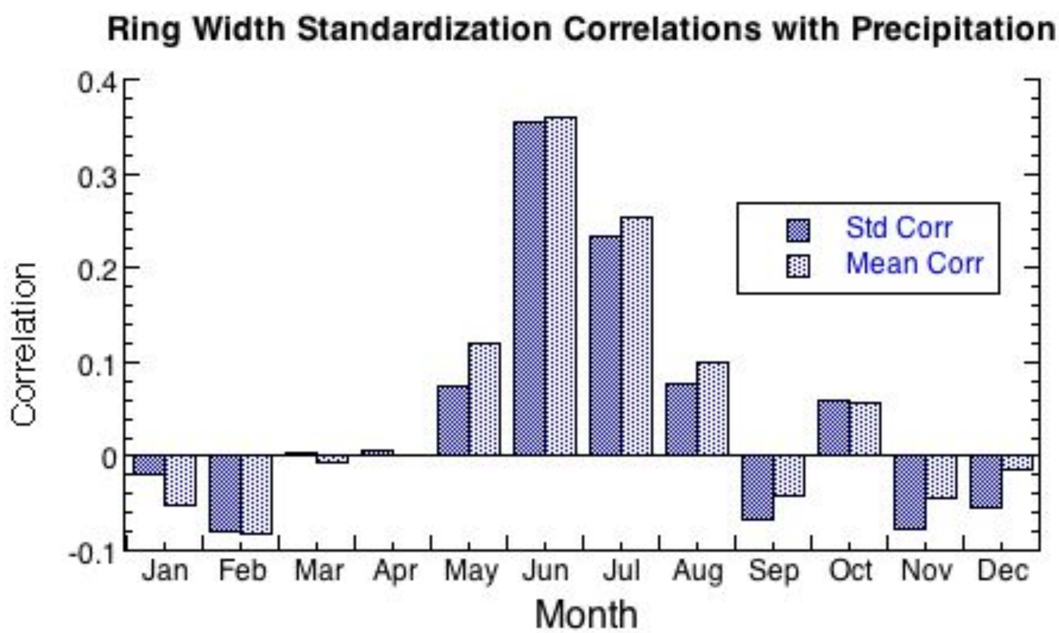

Figure 8. Histogram of standardized ring widths correlated with averaged precipitation amounts recorded at stations within 40°E to 42°E and 80°W to 82°W. Precipitation records of dataset go back to 1901, and include 112 years of data. Full blue bars are ring widths standardized individually to maximize year-to-year variability and dotted white bars are ring widths standardized by a horizontal line through the arithmetic mean. Correlations are significant in June and July, which lie above the 95% confidence level.

Discussion

Over time, trees at Stebbin's Gulch have undergone a release, growing wider rings after 1837 (Figure 3). This is contrary to expected growth trends, where ring widths typically decrease over time as the circumference of the tree increases (Cook, 1987). In Stebbin's Gulch, we can see that there is little to no apparent relationship between the diameter and age of the trees, so this typical trend is definitively defied (Figure 6).

In Figures 3, 4, and 5, we can consistently see this release as a relatively rapid rise in the graphs from about 1840 to 1915. Raw ring widths in Figure 3 continue to rise, but the overall rising trend was taken out with standardization in Figures 4 and 5. The spike appears in all three figures, however, indicating that it happened with sufficient speed to be recorded as a high frequency trend in most cores. Figure 10 shows this increase as it is seen in the cores. Ring widths almost double between rings 1837 and 1838 (Figure 10). Abrupt increases in ring width like this may indicate a change in competition and canopy cover, allowing light to penetrate the undergrowth and encourage recruitment (Cook, 1987; Pederson et al., 2014). We see this recruitment reflected in our cores as an influx of new trees around 1920. We suggest that more widespread land use and deforestation from settlement led to decreased competition, windblown nutrient-rich sediment from farms, and local hydrological disturbances (Figure 11).

Figure 10. Photomicrograph of core SG38E. Sudden increase in ring width is shown between rings 1837 and 1838.

Evidence of this release appears in other chronologies around Ohio as well, including those of Brown's Lake Bog in southern Wayne County, Sigrist Woods at The Wilderness Center in Wilmot, and Johnson Woods in Wayne County. In all four chronologies, a significant increase in ring width occurs in the early 1800s, indicating that whatever change in the environment that caused this increase must have been widespread across most of northeast Ohio. However, it occurs in different areas at different times. Generally, the further south the site is, the earlier the spike appears. For example, the spike at Brown's Lake Bog begins around the 1820s, while the spike at Stebbin's Gulch occurs at 1840. This supports our hypothesis of settlement driving this sudden increase in ring width. Settlers generally came up into Ohio from the Ohio River, founding southern settlements like Marietta and Cincinnati before moving north to populate Columbus, and then finally Cleveland (Collins, 1980; Galbreath, 1925). Cincinnati and Marietta both were founded in 1788, while Cleveland was founded a few years later in 1796 (Collins, 1980). Cleveland was finally chartered as a city in 1836, just before we see a significant increase in ring widths (Galbreath, 1925).

The increased ring widths persist, however, continuing to defy traditional growing trends up until this day. After recruitment and protection through identification as a nature preserve, however, competition at Stebbin's Gulch should increase again. So, other factors must be playing a role. Industrialization of Ohio occurred not long after settlement, when coal production and use became much more commonplace (Collins, 1980). This coal was first burned in steamboats, then in factories and trains, pumping CO_2 into the atmosphere (Deshpande and Mishra, 2007). The addition of other fossil fuels to the market only added more. CO_2 is necessary for tree growth, and therefore may have a positive effect on tree productivity. In addition, we see a relatively high positive correlation between summer precipitation and ring width, indicating that summer precipitation has a significant effect on tree ring width (Figure 8). We also see a moderate negative correlation between summer temperatures and ring width (Figure 7), since increased temperatures lead to increased evapotranspiration. In northeast Ohio, both increased temperature and increased precipitation are to be expected from global warming (Trenberth, 2011). So, it follows that contemporary climate change and increases in precipitation are a factor in the increased productivity of trees at Stebbin's Gulch.

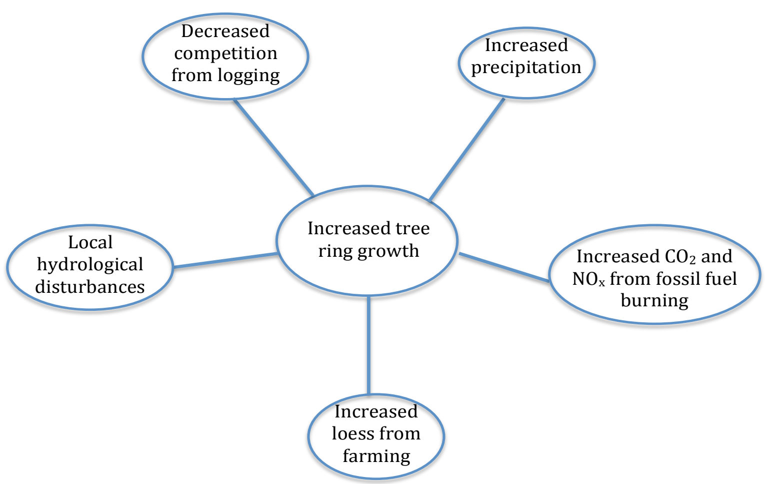

Figure 11. Possible causes of increased tree ring growth at Stebbin's Gulch beginning in 1840.

Uses for tree ring chronologies

Chronologies like these are crucial in understanding past drought and comprise a database of information called the North American Drought Atlas (NADA) (Cook, 2004). Data provided by this study will be entered in NADA to be used by climatologists, ecologists, and water managers to understand the development of drought and pluvials.

In addition to providing information about past climate, tree ring dating is one of the most accurate ways to date structures and is commonly used in archaeology to date houses and cabins. Living chronologies like the one at Stebbin's Gulch form a characteristic pattern of ring widths for the range over which the trees cored have lived, which can then be compared with undated cores. The undated cores match up with specific sections of the dated cores, and so dates may be assigned to the undated cores based on how they match up. Recently, this method was used with data from this lab to date a sunken ship pulled up from the Boston Harbor (Creasman et al., 2015).

Conclusions

Increasing ring widths at Stebbin's Gulch were likely caused by a reduction in competition from logging as well as other factors associated with land use changes and climate change. The story told by the trees in Ohio mirrors the story of settlement and records a unique interaction between trees and anthropogenic change. This creates a new opportunity to study how specifically these trees were affected by human settlement. Additionally, the trees themselves can then be used as a proxy for land use records to map out settlement.

Acknowledgements

Special thanks to Dr. Ed Cook for graciously providing tree ring data from Stebbin's Gulch. Many thanks to those who provided funding for this project, including the Sherman Fairchild Foundation, the College of Wooster Earth Sciences department, and the AMRE program. A big thanks to my advisor, Dr. Greg Wiles of The College of Wooster. Thank you to all in the College of Wooster Tree Ring Lab: Kendra Devereux, Juwan Shabazz, Nick Wiesenberg, Victoria Race, and Josh Charlton. Much thanks to David Burke and others at Holden Arboretum for permitting the coring of trees in the Arboretum.

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Supplementary Data

COFECHA output- Part 5, correlations

PART 5: CORRELATION OF SERIES BY SEGMENTS: 16:55 Wed 13 Jun 2018 Page

Correlations of 50-year dated segments, lagged 25 years
Flags: A = correlation under 0.3281 but highest as dated; B = correlation higher at other than dated position

Seq	Series	Time_span	1600 1649	1625 1674	1650 1699	1675 1724	1700 1749	1725 1774	1750 1799	1775 1824	1800 1849	1825 1874	1850 1899	1875 1924	1900 1949	1925 1974	1950 1999	1975 2024
1	113031	1618 1983	.63	.60	.62	.61	.45	.46	.58	.55	.63	.70	.68	.70	.64	.51	.64	
2	113032	1671 1983			.68	.67	.73	.79	.77	.73	.73	.70	.68	.70	.66	.67	.68	
3	113041	1704 1983					.77	.82	.78	.78	.82	.79	.53	.46	.66	.77	.75	
4	113042	1687 1983				.76	.73	.83	.71	.73	.78	.63	.33	.46	.75	.68	.67	
5	113051	1615 1983	.37	.49	.42	.44	.49	.64	.70	.74	.81	.77	.75	.76	.79	.75	.71	
6	113052	1620 1983	.24B	.21B	.43	.62	.58	.62	.64	.65	.73	.73	.73	.77	.78	.68	.65	
7	113061	1686 1983				.62	.64	.82	.66	.70	.80	.74	.55	.64	.76	.64	.68	
8	113062	1670 1983			.54	.53	.58	.72	.68	.77	.85	.78	.57	.64	.83	.73	.53	
9	112071	1742 1983						.33	.35	.45	.69	.57	.30A	.51	.70	.55	.55	
10	113091	1763 1983							.67	.71	.81	.87	.82	.84	.84	.74	.76	
11	113111	1752 1983							.19B	.77	.85	.85	.81	.86	.83	.79	.80	
12	113121	1612 1983	.46	.66	.82	.66	.56	.63	.70	.85	.70	.47	.60	.75	.59	.40	.40	
13	113122	1642 1983		.67	.74	.61	.64	.75	.80	.85	.67	.45	.57	.73	.69	.52	.49	
14	113131	1664 1983			.64	.62	.66	.75	.73	.68	.63	.75	.81	.74	.75	.74	.74	
15	113132	1652 1983			.55	.56	.63	.65	.52	.46	.54	.63	.66	.76	.78	.64	.65	
16	113171	1748 1983						.66	.69	.67	.77	.74	.70	.58	.59	.60	.51	
17	113172	1751 1983							.69	.72	.84	.83	.78	.74	.58	.53	.52	
18	113181	1678 1983				.58	.37	.49	.24A	.28A	.69	.79	.78	.76	.78	.74	.76	
19	113182	1706 1983					.64	.66	.61	.66	.76	.76	.77	.72	.71	.79	.86	
20	113191	1656 1983			.52	.44	.67	.76	.68	.74	.70	.54	.56	.66	.72	.53	.51	
21	113201	1728 1983						.29A	.26A	.53	.67	.64	.64	.68	.70	.65	.60	
22	113211	1711 1983					.70	.78	.78	.72	.70	.74	.80	.80	.68	.63	.63	
23	113231	1626 1983		.43	.53	.59	.69	.72	.72	.75	.77	.72	.65	.70	.81	.72	.75	
24	113232	1642 1983		.36	.39	.60	.71	.69	.67	.78	.79	.77	.72	.68	.68	.59	.62	
25	SG11E	1643 2017		.70	.74	.50	.37	.38	.27B	.32A	.33	.37	.59	.74	.58	.42	.45	.56
26	SG11S	1707 2017					.42B	.44	.24B	.17B	.46	.66	.74	.69	.49	.39	.47	.49
27	SG12N	1924 2017													.49	.50	.53	.60
28	SG12S	1821 2017									.64	.59	.64	.67	.66	.74	.76	.75
29	SG14E	1810 2017									.12B	.23B	.39	.60	.67	.58	.54	.80

30	SG14NE	1850	2017											.54	.56	.70	.55	.54	.77
31	SG14S	1791	2017								.63	.72	.60	.49	.51	.70	.60	.55	.77
32	SG15N	1815	2017									.71	.70	.59	.60	.77	.71	.65	.70
33	SG15S	1632	2017		.74	.65	.50	.37	.45	.48	.30B	.40	.58	.71	.77	.65	.64	.73	.81
34	SG16S	1930	2017														.47	.52	.52
35	SG17E	1728	2017						.62	.69	.68	.79	.79	.70	.68	.69	.70	.74	.76
36	SG17S	1761	2008							.64	.68	.70	.65	.61	.68	.78	.75	.70	.78
37	SG18E	1830	2017										.49	.50	.65	.75	.68	.62	.49
38	SG18W	1938	2016														.55	.71	.78
39	SG20E	1840	2014										.73	.72	.52	.63	.71	.58	.69
40	SG20N	1876	2015												.74	.85	.75	.73	.85
41	SG21S	1882	2017												.82	.79	.67	.75	.83
42	SG25SW	1858	2017											.52	.75	.72	.70	.80	.77
43	SG26N	1886	2017												.55	.52	.62	.75	.81
44	SG27E	1722	2017					.79	.79	.63	.62	.78	.86	.78	.59	.67	.75	.73	.77
45	SG27N	1659	2017			.58	.57	.57	.62	.54	.62	.72	.74	.81	.69	.64	.66	.57	.61
46	SG27S	1778	2017								.55	.70	.70	.80	.81	.78	.70	.70	.74
47	SG27W	1672	2017			.34B	.30B	.54	.57	.23B	.38B	.74	.79	.85	.72	.70	.74	.63	.60
48	SG28W1	1945	2017														.49	.47	.64
49	SG28W2	1931	2017														.27B	.42	.62
50	SG29E	1861	2016											.22A	.30B	.61	.74	.75	.77
51	SG30N	1850	2017											.68	.72	.78	.75	.67	.68
52	SG31W	1857	2017											.78	.74	.62	.60	.36	.34
53	SG32E	1876	2015												.74	.73	.70	.73	.83
54	SG33W	1809	2017									.55	.60	.68	.79	.81	.74	.52	.60
55	SG34E	1885	2017												.68	.85	.64	.54	.56
56	SG34W	1885	2016												.83	.84	.72	.62	.64
57	SG35E	1837	2016										.57	.61	.71	.77	.71	.72	.83
58	SG35W	1770	2017							.50	.53	.67	.61	.63	.72	.64	.62	.73	.72
59	SG36N	1685	2017				.65	.67	.77	.75	.81	.74	.64	.49	.38	.55	.70	.70	.68
60	SG36W	1725	2017						.56	.76	.75	.73	.57	.21B	.40	.78	.75	.66	.68
61	SG37N	1687	2017				.66	.57	.54	.66	.74	.71	.59	.60	.67	.69	.73	.60	.58
62	SG37W	1864	2017											.55	.71	.63	.59	.80	.86
63	SG38E2	1825	2017										.40	.73	.72	.61	.39	.43	.59
64	SG38W	1800	2017									.59	.51	.60	.66	.73	.64	.57	.62
65	SG39S	1661	2017			.44	.64	.72	.73	.63	.66	.76	.70	.70	.75	.76	.74	.52	.53
66	SG39W	1608	2017	.55	.61	.71	.71	.52	.32A	.29B	.65	.75	.58	.58	.74	.75	.63	.65	.72
67	SG41W	1912	2017													.68	.75	.69	.78
68	SG42E	1900	2017													.80	.63	.40	.26A
69	SG42S	1873	2017											.36	.34	.70	.53	.44	.68
70	SG43E	1824	2017									.77	.80	.56	.60	.68	.55	.52	.59
71	SG43W	1729	2017						.64	.59	.59	.70	.56	.47	.67	.82	.68	.71	.82
72	STEB01	1920	2017													.64	.63	.58	.68
73	STEB02	1730	2012						.47	.36B	.19B	.29B	.58	.65	.72	.71	.69	.53	.41
Av segment correlation				0.45	0.55	0.58	0.58	0.60	0.62	0.58	0.62	0.68	0.66	0.62	0.67	0.71	0.64	0.62	0.67