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Reporting Summary

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Statistics

For all statistical analyses, confirm that the following items are present in the figure legend, table legend, main text, or Methods section.

n/a	Confirmed	
☐	☒	The exact sample size (*n*) for each experimental group/condition, given as a discrete number and unit of measurement
☐	☒	A statement on whether measurements were taken from distinct samples or whether the same sample was measured repeatedly
☐	☒	The statistical test(s) used AND whether they are one- or two-sided *Only common tests should be described solely by name; describe more complex techniques in the Methods section.*
☐	☒	A description of all covariates tested
☐	☒	A description of any assumptions or corrections, such as tests of normality and adjustment for multiple comparisons
☐	☒	A full description of the statistical parameters including central tendency (e.g. means) or other basic estimates (e.g. regression coefficient) AND variation (e.g. standard deviation) or associated estimates of uncertainty (e.g. confidence intervals)
☐	☒	For null hypothesis testing, the test statistic (e.g. *F*, *t*, *r*) with confidence intervals, effect sizes, degrees of freedom and *P* value noted *Give P values as exact values whenever suitable.*
☐	☒	For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings
☐	☒	For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes
☐	☒	Estimates of effect sizes (e.g. Cohen's *d*, Pearson's *r*), indicating how they were calculated

Our web collection on statistics for biologists contains articles on many of the points above.

Software and code

Policy information about availability of computer code

Data collection	Canopy foliage phenology data were extracted from the MCD12Q2 V6 Land Cover Dynamics product (a.k.a. MODIS Global Vegetation Phenology product) via Google Earth Engine (https://developers.google.com/earth-engine/datasets/catalog/MODIS_006_MCD12Q2#description).
Data analysis	Data were analysed in the open source statistical software R (version 4.0). We used packages climwin v.1.2.3 (https://cran.r-project.org/web/packages/climwin/index.html), dplR v.1.0.2, and bootRes v1.2.4, and functions from Rdendrom (https://github.com/seanmcm/RDendrom/). We used climpact software v.1.2.8 (see www.climpact-sci.org). All custom code is available through the EcoClimlab GitHub repository (https://github.com/EcoClimLab/growth_phenology) and archived in Zenodo (DOI: [TBD]).

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Portfolio guidelines for submitting code & software for further information.

Data

Policy information about availability of data

All manuscripts must include a data availability statement. This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A description of any restrictions on data availability
- For clinical datasets or third party data, please ensure that the statement adheres to our policy

The datasets generated and analysed during the current study are available via GitHub in the growth_phenology repository of the ForestGEO Ecosystems & Climate Lab @ SCBI, (https://github.com/EcoClimLab/growth_phenology) and archived in Zenodo (DOI [TBD]). Master versions of the dendrometer band data are available for SCBI via GitHub in the Dendrobands repository of the Smithsonian Conservation Biology Institute ForestGEO plot (https://github.com/SCBI-ForestGEO/Dendrobands), which is archived in Zenodo (DOI 10.5281/zenodo.5551143), and for Harvard Forest via the Harvard Forest Data Archive (https://harvardforest1.fas.harvard.edu/exist/apps/datasets/showData.html?id=HF149). Weather data for SCBI were obtained from the ForestGEO Climate Data Portal v1.0 (https://github.com/forestgeo/Climate/tree/master/Climate_Data/Met_Stations/SCBI), which is archived in Zenodo (DOI: 10.5281/zenodo.3958215), and the National Center for Environmental Information (NCEI) weather station located in Front Royal, Virginia (https://www.ncdc.noaa.gov/cdo-web/datasets/GHCND/stations/GHCND:USC00443229/detail). Weather data for Harvard Forest are available through the Harvard Forest Data Archive (https://harvardforest1.fas.harvard.edu/exist/apps/datasets/showData.html?id=HF001 AND https://harvardforest1.fas.harvard.edu/exist/apps/datasets/showData.html?id=HF000). Climate data were obtained from CRU v.4.04 via the ForestGEO Climate Data Portal v1.0 (https://github.com/forestgeo/Climate/tree/master/Climate_Data/CRU), which is archived in Zenodo (DOI: 10.5281/zenodo.3958215). The Standardised Precipitation-Evapotranspiration Index was obtained from the ForestGEO Climate Data Portal v1.0 (https://github.com/forestgeo/Climate/tree/master/Climate_Data/SPEI), which is archived in Zenodo (DOI: 10.5281/zenodo.3958215). Canopy foliage phenology data were extracted from the MCD12Q2 V6 Land Cover Dynamics product (a.k.a. MODIS Global Vegetation Phenology product) via Google Earth Engine (https://developers.google.com/earth-engine/datasets/catalog/MODIS_006_MCD12Q2#description). In addition to being archived in this project's repository, many tree-ring data sets are archived in the International Tree-Ring Data Bank (ITRDB;https://www.ncei.noaa.gov/products/paleoclimatology/tree-ring), the DendroEcological Network (DEN; https://www.uvm.edu/femc/dendro/), and/or the Harvard Forest Data Archive (https://harvardforest.fas.harvard.edu/harvard-forest-data-archive), as detailed in SI Table 1. Original tree cores are archived at the institutions of various members of the author team (Harvard Forest, Smithsonian Conservation Biology Institute, Indiana University, and University of Idaho) and will be made available upon reasonable request.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☐ Life sciences ☐ Behavioural & social sciences ☒ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Ecological, evolutionary & environmental sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	Using dendrometer band measurements from 440 trees across two forests, we show that warmer spring temperatures shifted the woody growth of deciduous trees earlier but had no consistent effect on peak growing season length, maximum daily growth rates, or annual growth. The latter finding was confirmed on the centennial scale by 207 tree-ring chronologies from 108 forests across eastern North America, where annual growth was far more sensitive to temperatures during the peak growing season than in the spring.
Research sample	The data used here were dendrometer band measurements from the Smithsonian Conservation Biology Institute (SCBI) and Harvard Forest. Tree core chronologies were created using cores from these two sites along with an additional 106 sites across eastern North America.
Sampling strategy	Dendrometer bands: At SCBI, dendrometer bands were installed on individuals of the two most dominant (in terms of contributions to woody productivity) ring-porous species (Quercus alba and Quercus rubra) and the two most dominant diffuse-porous species (Liriodendron tulipifera and Fagus grandifolia). Sampling was weighted towards large individuals. Banded trees were randomly located throughout the 25.6 ha ForestGEO plot, with some additional individuals within two 15 m radius plots in which all trees were banded. Details are available in Extended Data Table 1 and the SCBI-ForestGEO dendrobands repository (https://github.com/SCBI-ForestGEO/Dendrobands). At Harvard Forest, dendrometer bands were placed on trees in 36 circular, 10-m radius plots located randomly along eight 500-m transects that extended from the EMS eddy-flux tower (detailed in D'Orangeville et al., 2021; https://doi.org/10.1093/treephys/tpab101). We analyzed data for eight diffuse- and three ring-porous species (see Extended Data Table 1). Tree cores: At SCBI, we sampled the 12 species contributing most to woody productivity, sampling live and dead individuals randomly located throughout the plot (detailed in Helcoski et al. 2019; https://doi.org/10.1111/nph.15906). At Harvard Forest, all trees were cored within size-stratefied circular plots (detailed in Dye et al. 2016; https://doi.org/10.1002/ecs2.1454). The tree-ring records from our focal sites were complemented with a much larger collection of tree-ring chronologies spanning 106 deciduous and mixed forest sites in eastern North America, including both previously published (see Pederson 2005 PhD dissertation; D'Orangeville et al. 2018: https://doi.org/10.1111/gcb.14096; Maxwell et al. 2020: https://doi.org/10.5194/cp-16-1901-2020) and new chronologies. All of these samples were originally collected for other research projects, many for the estimation of the response of trees and species to climatic variation, and opportunistically included here. For the majority of sampled populations (i.e., site-species combinations), sampling focused on canopy trees (typically >20 trees per population), while ~15% of the total 207 chronologies came from plot-level collections where trees above a certain diameter (typically 10 cm DBH) were censused and cored.
Data collection	Dendrometer bands: Metal dendrometer bands were installed on a total of 941 trees within the SCBI and Harvard Forest ForestGEO plots. They were placed at ~1.4m above the base of the tree. Bands were measured with a digital caliper approximately every 1-2 weeks within the growing season from 2011-2020 at SCBI and 1998-2003 at Harvard Forest. The number of bands measured at each site fluctuated

slightly as trees were added or dropped from the census (e.g., because of tree mortality). Across years, the number of bands sampled averaged 129 (range: 91-138) at SCBI and 717 (range: 700-755) at Harvard Forest. In total, after data cleaning, our analysis included 2210 tree-years (Extended Data Table 1).

Measurements were timed to begin before the beginning of spring growth and to continue through the cessation of growth in the fall. At SCBI, the median start date was April 14, which was adjusted forward when early leaf-out of understory vegetation was observed, with the earliest start date being March 30 (in 2020). Measurements were continued through to fall leaf senescence, with the median end date being October 17 and the latest end date November 26 (2012). At Harvard Forest, all measurements from 1998 were dropped because of a late start date (May 26). Among the remaining years,the median start date was April 21 and median end date of October 27. 1999 was an anomalous year where initial measurements were taken on January 5, but not taken again until April 15. The latest end date was November 11, 2002. In our analysis, each band-year was treated independently, with no data overlap from one year to the next.

Leaf phenology:

Canopy foliage phenology data for the years 2001-2018 were extracted for SCBI and Harvard Forest from the MCD12Q2 V6 Land Cover Dynamics product (a.k.a. MODIS Global Vegetation Phenology product; Friedl et al. 2019, doi: DOI: 10.5067/MODIS/MCD12Q2.006) via Google Earth Engine. For each year at each site, we extracted data from the pixel containing the center of each forest plot (resolution of 500m). Using the daily MODIS 2-band Enhanced Vegetation Index data (EVI2), the product yields the timing of phenometrics (vegetation phenology) over each year, including timing of greenup, midgreenup, peak, and senescence as used in this study. Data points were included in the analysis if they were flagged as "good" or "best" quality.

Weather data:

Climate data corresponding to the measurement periods were obtained from local weather stations at each focal site. For SCBI, weather data were obtained from a meteorological tower adjacent to the ForestGEO plot, via the ForestGEO Climate Data Portal v1.0 (https://forestgeo.github.io/Climate/). The R package climpact (see www.climpact-sci.org) was used to plot temperatures for visual inspection and to identify readings that were >3 standard deviations away from yearly means, which were labeled as outliers and removed from the dataset. Gaps in the SCBI meteorological tower data were subsequently filled using temperature readings obtained from a National Center for Environmental Information (NCEI) weather station located in Front Royal, Virginia (https://www.ncdc.noaa.gov/cdo-web/datasets/GHCND/stations/GHCND:USC00443229/detail). Daily temperature records for Harvard Forest, which had already been gap-filled based on other local records, were obtained from the Harvard Forest weather station. For each site, we used records of daily maximum (T_max) and minimum temperatures (T_min).

Standardized Precipitation Evapotranspiration Index (SPEI) values were obtained from the ForestGEO Climate Data Portal v1.0 (https://forestgeo.github.io/Climate/).

Tree cores:

All tree cores had been previously collected, cross-dated, and measured using standard collection and processing methodologies. Details are provided in the original publications cited in the manuscript. For those chronologies not in previous publications, all tree cores were collected, processed, and analyzed with the same methods as those in the cited publications.

Timing and spatial scale

Dendrometer band measurements were taken within two large ForestGEO plots (SCBI: 25.6 ha; Harvard Forest: 35 ha) with no interruption in collection from 2011-2020 at SCBI and from 1998-2003 at Harvard Forest. Tree cores were taken at 108 sites across the eastern North America, with chronologies spanning from 1901-2016.

Data exclusions

Dendrometer bands:

Data exclusions were planned to remove erroneous measurements of dendrometer bands or those that were unable to be modeled.

The raw dendrometer band data were screened before analysis to remove records or entire tree-years that were either unreliable or inappropriate for our analysis. First, we manually screened the data for three classes of errors. First, when a measurement was drastically different from previous and following measurements, it was assumed to be a human error and removed. Second, when measurements remained essentially unchanged for several readings, followed by a sudden jump then return to a normal growth pattern, this was assumed to be a case where the band was stuck on the tree bark and then released. In these cases, the full annual record for the tree was removed. Third, data points that deviated substantially from normal growth patterns, but for unknown causes, were removed. If a majority of the data points fell into this class within a tree-year, the entire year was removed from the analysis. We also removed tree-years with small or negligible total growth (ΔDBH $\leq$0.005 cm; SCBI = 26, Harvard Forest = 253), and tree-years where first intraannual measurement was later than the first spring survey (trees that were missed in the initial census; SCBI = 22, Harvard Forest = 8). These were removed because they reduce the reliability of predicted growth in the modeled curves.

After fitting the growth model, we removed tree-years with poor fits. Models were judged to be poorly fit if modeled growth parameters were outliers, which were commonly indicative of unrealistic fits (e.g., growth occurring outside the growing season or over a very short period) and underlain by very slow tree growth or poor data records that passed the initial screening (described above). Modeled fits for tree-years were removed under two conditions: (1) g_max was $\geq$2.5 standard deviations away from the mean for each site-xylem architecture group combination (SCBI = 3, Harvard Forest = 11); (2) timing variables (DOY_ip, DOY_25, DOY_50, DOY_75) were $\geq$2.5 standard deviations away from the means for their site, xylem architecture group, and year (SCBI = 74, Harvard Forest = 101). At both sites the tree-years removed through this method were proportional to the original sample size, indicating that no species or size class was disproportionately removed compared to others. This process was repeated using 2 and 3 standard deviations as the cutoff for defining outliers, yielding qualitatively similar results.

Tree cores:

We did not exclude any tree-ring chronologies from the available set. Following standard dendrochronological practices, early years

	of chronologies were excluded if the subsample signal strength (SSS) was below 0.8.
Reproducibility	All analyses can be reproduced by rerunning of code in the statistical software R, where all analyses were performed. All data and code are publicly available via GitHub, as detailed in data and code availability statements.
Randomization	At SCBI, dendrometer bands were placed on a stratified random sample of trees within a the 25.6 ha ForestGEO plot, with additional trees from two 15-m radius plots in which all trees were sampled. Similarly, trees were cored on a stratified random sample of trees within the plot, and were also collected from all trees found dead in mortality censuses of 2015 and 2016. At Harvard Forest, dendrometer bands were placed on trees within 36 circular, 10-m radius plots located randomly along eight 500-m transects that extended from the EMS eddy-flux tower. Similarly, tree cores were taken on all trees in nested circular plots (detailed in Dye et al. 2016; https://doi.org/10.1002/ecs2.1454). Outside our focal sites, tree cores were collected either from canopy trees of the target species (majority of chronologies) or from trees above a certain diameter (typically 10 cm DBH) within a censused plot.
Blinding	Blinding is not applicable in this study because data was not generated from human subjects.

Did the study involve field work? ☒ Yes ☐ No

Field work, collection and transport

Field conditions	Dendrometer band measurements were made during the growing season from spring to autumn. Weather conditions have a modest effect on these readings. For example, stems shrink and swell depending upon hydration status (which, in turn, is affected by soil moisture and vapor pressure deficit), and metal bands may be modestly affected by temperatures (through thermal expansion of metal). These effects should be largely removed through the fitting of a seasonal growth model (detailed in methods section) and are not expected to bias our analysis. Tree ring cores were collected at various times of the year. Weather conditions at the time of collection would have no effect on these readings.
Location	Smithsonian Conservation Biology Institute (SCBI) ForestGEO plot (38.8935° N, 78.1454° W; 25.6 ha; elevation 273–338 m.a.s.l.) Harvard Forest ForestGEO plot (42.5388° N, 72.1755° W; 35 ha; 340-368 m.a.s.l.) 106 additional sites spanning the eastern North America (locations listed in Supplementary Information)
Access & import/export	All site access and sample collection was done with permission from the appropriate authorities.
Disturbance	Disturbance to the forests from which we collected samples was minimized to the best of our abilities by always adhering to leave no trace practices.

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study	
☒	☐	Antibodies
☒	☐	Eukaryotic cell lines
☒	☐	Palaeontology and archaeology
☒	☐	Animals and other organisms
☒	☐	Human research participants
☒	☐	Clinical data
☒	☐	Dual use research of concern

Methods

n/a	Involved in the study	
☒	☐	ChIP-seq
☒	☐	Flow cytometry
☒	☐	MRI-based neuroimaging