

Supplementary Information

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Appendix S1. Methods for reconstruction of *DBH*

This is still rough/ mostly notes.

For each core, *DBH* can be reconstructed outside-in (based on recent *DBH*, subtracting growth recorded in tree rings) or inside-out (summing *RW* from the inside out). We generally gave precedence to the outside-in approach. Specifically, when *DBH* was taken at the time of coring,

At some of our sites where *DBH* was not taken at the time of coring (*SCBI*), *DBH* measurements taken before or slightly after the time of coring could be used. (see issue #19 in ForestGEO_dendro) If before, ... If after... For all outside-in reconstructions, if a negative *DBH* was predicted...

When there were more than one cores for a tree, the *DBH* reconstructions from each core were averaged to produce a single estimate of the tree's *DBH* through time. When the start or end dates of the records from the cores differed, we extrapolated growth of the shorter core to match the years covered by the longer core. Specifically, to fill in years at the more recent end, we assumed that the average growth rate of the ten years prior to the missing records applied to the missing years. To fill in years at the beginning of the tree's lifespan, we likewise assumed that the ten years adjacent to the missing record applied to the missing years; however, if this yielded a negative *DBH* estimate for the earliest year in the reconstruction, we divided the existing minimum *DBH* by number of years missing and applied that value to each year. We note that these reconstructed growth records were used only for the reconstruction of *DBH* and were not included as response variables in any of our analyses.

In either case we need bark thickness—ideally allometries describing the relationship between *DBH* and bark thickness (Table S4). This is especially critical for thick-barked species. When bark thickness data were available, we generated allometries (issue #8 in ForestGEO_dendro)... lognormal model with intercept forced to zero: `lm(bark_depth.mm ~ -1 + log(dbh_no_bark.cm+1):bark_species, data = bark)`. When bark thickness data were not available, we used published bark allometries from other sources (Table S4)

Appendix S2. Methods for comparing climwin results with traditional methods

(ISSUE #35 in ForestGEO-climate-sensitivity)

To verify that our methods gave similar results to traditional methods, we conducted qualitative comparisons of our results to previous studies based on the same cores (Table S5). We also conducted a formal comparison using identical tree-ring and climate data for four well-studied species: PSME (Cedar Breaks, Utah), ABAL (Zofin), PIMA (Scotty Creek), and LITU (SCBI) (Fig. S1). We compared results from an analysis using conventional methods, as detailed below, to an analysis using our method as described in the Methods section, but with the *climwin* climate variable selection process limited to just the species of interest (as opposed to all species at the site), climate variables considered individually rather than additively, and with start date adjusted to match the conventional method.

The ring-width series from each core was standardized via ARSTAN using a 2/3rds n spline, where n is the number of years in the series (Cook, 1985; Cook & Kairiukstis, 1990- citations in Helcoski). *(The following italic text is plagiarized from Helcoski and needs to be reworded:)* The influence of outliers in all series was reduced using the adaptive power transformation, which also stabilises the variance over time (Cook & Peters, 1997). Next, each series was stabilised using either the average correlation between raw ring-width series ($rbar$) method or a 1/ 3rds spline method to adjust changes in variance as series replication decreased towards the earlier portion of each chronology (Jones et al., 1997). The 1/3rds spline method was chosen when replication in the inner portion of each chronology (c. the inner 30–50 yr of each record depending on full chronology length) dropped below three trees. Once that step was complete, a robust biweight mean chronology for each species was calculated from the ring-width indices (Cook, 1985). We chose to use residual chronologies because the autoregressive standardisation process in creating them removes much of the tree-level autocorrelation in growth and these chronologies would most likely contain the most conservative information on drivers of interannual growth (Cook, 1985).

Following Helcoski et al. (2019), we defined chronology start dates according to the subsample signal strength (SSS), using a cutoff of $SSS = 0.80$ (or 80% of the population signal). Thus, for this analysis only, we defined chronology start dates as the year the SSS exceeded 0.80 or two years after the start of the climate record, whichever came later. SSS exceeded 0.80 well before the start of the 1901 start of climate records for PSME (1800s), ABAL (1700), and PIMA (1850s). For LITU, SSS reached 0.8 with 11 trees in 1919, which we used as the start date for this series. We note that these start date criteria differ from those used in the main analysis (Table S3), which had earlier start dates because the analysis was not constrained by a need to represent the full population signal. End dates were defined as the last full year prior to sampling (Table S3).

Appendix S3. Dealing with rapidly changing climate and tree growth

ISSUE #25 in ForestGEO-climate-sensitivity

Our analysis included two sites where climate change has had pronounced effects on tree growth: Scotty Creek, NW Territories, Canada (SC) and Little Tesuque, New Mexico, USA (LT). At SC, [temperatures have increased by X° over X years]... , resulting in negative growth trends in basal area index (*BAI*) starting around 1950 and significant growth declines since 1970 in 56% of trees (Sniderhan & Baltzer, 2016). At LT, (*drought has increased dramatically*), resulting in many missing rings in recent years.

This is in process. We will try and compare 3 methods: (1) our standard approach, (2) detrending the climate variables (#53), (3) applying the climwin step only for older records—before the most rapid climate change. We will work with SC and LT researchers to determine which makes most sense, and use that as the main approach for these sites.

Table S1. Site Details

| site code | site name | latitude | longitude | elevation (m.a.s.l.) | cores within ForestGEO plot? | canopy positions | tree statuses | date range | dormant season | months in climwin |
|-----------|--|----------|-----------|-------------------------|------------------------------------|---------------------|---------------|------------|----------------|-------------------|
| BCI | Barro Colorado Island | 9.15430 | -79.8461 | 120-160 | no | canopy | live, dead | 1931-2014 | Nov-Apr | pOct-cDec |
| HKK | Huai Kha Khaeng | 15.63240 | 99.2170 | 549-638 | no | all | live | 1903-2011 | Nov-Apr | pOct-cDec |
| LT | Little Tesuque | 35.73838 | -105.8382 | 2682 | n.a. | all | live | 1903-2018 | | pMay-cAug |
| CB | Utah Forest Dynamics Plot | 37.66150 | -112.8525 | 3020-3169 | yes | | live | 1903-2007 | | pMay-cAug |
| SCBI | Smithsonian Conservation Biology Institute | 38.89350 | -78.1454 | 273-338 | yes | all | live, dead | 1903-2017 | Oct-Apr | pMay-cAug |
| LDW | Lilly Dickey Woods | 39.23590 | -86.2181 | 230-303 | | canopy | live, dead | 1903-2019 | | pMay-cAug |
| HF | Harvard Forest | 42.53880 | -72.1755 | 340-368 | yes | all | live, dead | 1903-2014 | | pMay-cAug |
| NE | Niobrara/Halsey | 42.78000 | -100.0210 | 644-702 | some | canopy | live | | Oct-Apr | pMay-cAug |
| ZOF | Zofin Forest Dynamics Plot | 48.66380 | 14.7073 | 736-829 | some | all | live, dead | 1903-2013 | Oct-Mar | pMay-cAug |
| SC | Scotty Creek | 61.30000 | -121.3000 | 258-274 | no | all | live, dead | 1903-2013 | | pMay-cAug |

Table S2. Species analyzed, their characteristics, and bark allometries applied*(ISSUE #72 in ForestGEO-climate-sensitivity)*

NOTE: bark.allometry field is not yet right– we will have just one latin name per site, corresponding to allometries in Table S4. But it does give correct info for what is currently applied. We also intend to find and apply more allometries.

| species code | family | latin name | sites sampled | leaf type | leaf phenology | light requirements | bark allometry |
|--------------|--------------|-------------------------|---------------|------------|---------------------------|--------------------|---|
| ABAL | Pinaceae | Abies alba | ZOF | needleleaf | evergreen | shade-tolerant | neglected in Zofin |
| ABBI | Pinaceae | Abies bifolia | CB | needleleaf | evergreen | | neglected in CedarBreaks |
| ACRU | Sapindaceae | Acer rubrum | HF | broadleaf | deciduous (cold) | | acru in HarvardForest |
| ACSA | Sapindaceae | Acer saccharum | LDW | broadleaf | deciduous (cold) | | acru in LillyDickey, acru in LillyDickey |
| AFX | Fabaceae | Azela xylocarpa | HKK | broadleaf | deciduous (drought) | | neglected in HKK |
| BEAL | Betulaceae | Betula alleghaniensis | HF | broadleaf | deciduous (cold) | | Betula alleghaniensis in HarvardForest |
| BEPA | Betulaceae | Betula papyrifera | NE | broadleaf | deciduous (cold) | | Betula papyrifera in Nebraska |
| CACO | Juglandaceae | Carya cordiformis | SCBI | broadleaf | deciduous (cold) | | caco in SCBI |
| CAGL | Juglandaceae | Carya glabra | SCBI | broadleaf | deciduous (cold) | | cagl in SCBI |
| CAOV | Juglandaceae | Carya ovata | LDW | broadleaf | deciduous (cold) | | cagl in LillyDickey |
| CAOVL | Juglandaceae | Carya ovalis | SCBI | broadleaf | deciduous (cold) | | caovl in SCBI |
| CATO | Juglandaceae | Carya tomentosa | SCBI | broadleaf | deciduous (cold) | | cato in SCBI |
| CHTA | Meliaceae | Chukrasia tabularis | HKK | broadleaf | brevi-deciduous (drought) | | neglected in HKK |
| FAGR | Fagaceae | Fagus grandifolia | HF, SCBI | broadleaf | deciduous (cold) | | neglected in HarvardForest, neglected in LillyDickey, neglected in SCBI |
| FASY | Fagaceae | Fagus sylvatica | ZOF | broadleaf | deciduous (cold) | shade-tolerant | neglected in Zofin |
| FRAM | Oleaceae | Fraxinus americana | LDW, SCBI | broadleaf | deciduous (cold) | | Fraxinus ssp. in LillyDickey, fram in SCBI |
| FRNI | Oleaceae | Fraxinus nigra | SCBI | broadleaf | deciduous (cold) | | fram in SCBI |
| JACO | Bignoniaceae | Jacaranada copaia | BCI | broadleaf | deciduous (drought) | light-demanding | JCO in BCI |
| JUNI | Juglandaceae | Juglans nigra | SCBI | broadleaf | deciduous (cold) | | juni in SCBI |
| JUVI | Cupressaceae | Juniperus virginiana | NE | | | | neglected in Nebraska |
| LITU | Magnoliaceae | Liriodendron tulipifera | LDW, SCBI | broadleaf | deciduous (cold) | | litu in LillyDickey, litu in LillyDickey, litu in SCBI |
| MEAZ | Meliaceae | Melia azedarach | HKK | broadleaf | deciduous (drought) | light-demanding | neglected in HKK |
| PIAB | Pinaceae | Picea abies | HF | needleleaf | evergreen | intermediate | neglected in HarvardForest, neglected in Zofin |
| PIEN | Pinaceae | Picea engelmannii | CB | needleleaf | evergreen | | Picea engelmannii in CedarBreaks |
| PIFL | Pinaceae | Pinus flexilis | CB | needleleaf | evergreen | | Pinus monticola in CedarBreaks |
| PILO | Pinaceae | Pinus longaeva | CB | needleleaf | evergreen | | neglected in CedarBreaks |
| PIMA | Pinaceae | Picea mariana | SC | needleleaf | evergreen | | PIMA in ScottyCreek |
| PIPO | Pinaceae | Pinus ponderosa | NE, LT | needleleaf | evergreen | | Pinus jeffreyi in Little Tesuque, Pinus jeffreyi in Nebraska |
| PIPU | Pinaceae | Picea pungens | CB | needleleaf | evergreen | | neglected in CedarBreaks |
| PIST | Pinaceae | Pinus strobus | HF, SCBI | needleleaf | evergreen | | Pinus strobus in HarvardForest, pist in SCBI |
| PIST2 | Pinaceae | Pinus strobiformis | LT | needleleaf | evergreen | | Pinus monticola in Little Tesuque |
| POTR | Salicaceae | Populus tremuloides | CB | broadleaf | deciduous (cold) | | Populus tremuloides in CedarBreaks |
| PSME | Pinaceae | Pseudotsuga menziesii | CB | needleleaf | evergreen | | Pseudotsuga menziesii in CedarBreaks |
| QUAL | Fagaceae | Quercus alba | LDW, SCBI | broadleaf | deciduous (cold) | | qual in LillyDickey, qual in SCBI |
| QUMO | Fagaceae | Quercus montana | LDW, SCBI | broadleaf | deciduous (cold) | | qupr in LillyDickey, qupr in SCBI |
| QURU | Fagaceae | Quercus rubra | HF, LDW, SCBI | broadleaf | deciduous (cold) | | quru in HarvardForest, Quercus rubra in LillyDickey, quru in SCBI |
| QUVE | Fagaceae | Quercus velutina | LDW, SCBI | broadleaf | deciduous (cold) | | quve in LillyDickey, quve in SCBI |
| TEPA | Burseraceae | Tetragastris panamensis | BCI | broadleaf | evergreen | shade-tolerant | TPA in BCI |
| TOCI | Meliaceae | Toona ciliata | HKK | broadleaf | deciduous (drought) | | neglected in HKK |
| TRTU | Meliaceae | Trichilia tuberculata | BCI | broadleaf | evergreen | shade-tolerant | TTU in BCI |
| TSCA | Pinaceae | Tsuga canadensis | HF | needleleaf | evergreen | | Tsuga canadensis in HarvardForest |

*Bark allometry field indicates the species and site sampled to construct the bark allometry. When neither raw data nor an allometric equation for the study species was available, we selected the most appropriate equation that could be located for similar species. Equations are given in Table S4.

Table S3. Sampling details for species by site

(*ISSUE #73 in ForestGEO-climate-sensitivity*)

| site | species code | n trees all | n cores all | n trees dbh | n cores dbh | dbh range sampled | dbh range reconstructed* | date range |
|------|--------------|-------------|-------------|-------------|-------------|-------------------|--------------------------|------------|
| BCI | JACO | 12 | 18 | 11 | 17 | 30.2-63.5 | 2.6-56.4 | 1931-2014 |
| BCI | TEPA | 18 | 29 | 17 | 26 | 22.1-59.5 | 2.7-49.4 | 1931-2014 |
| BCI | TRTU | 23 | 37 | 20 | 31 | 20.7-43.6 | 4.8-41.5 | 1931-2014 |
| CB | ABBI | 22 | 41 | 20 | 37 | 13.9-54.2 | 0.9-46.4 | 1903-2000 |
| CB | PIEN | 12 | 21 | 10 | 15 | 14-54.9 | 0.9-33.1 | 1903-2000 |
| CB | PIFL | 13 | 22 | 12 | 21 | 17.6-64.1 | 1.5-47.5 | 1903-1998 |
| CB | PILO | 11 | 16 | 8 | 12 | 45.8-121.6 | 35.4-118.5 | 1903-1999 |
| CB | PIPU | 15 | 28 | 15 | 28 | 22.4-50.8 | 9.5-48.4 | 1903-2000 |
| CB | POTR | 17 | 27 | 17 | 26 | 23.6-47.6 | 4.3-35.4 | 1903-2000 |
| CB | PSME | 11 | 20 | 10 | 18 | 20.7-64.2 | 0.5-41.5 | 1903-1999 |
| HF | ACRU | 18 | 59 | 18 | 59 | 10.1-22.1 | 0.9-20.4 | 1903-2013 |
| HF | BEAL | 13 | 44 | 13 | 44 | 10.2-37.9 | 0-17.2 | 1904-2013 |
| HF | QURU | 74 | 180 | 73 | 177 | 19.5-53 | 1.1-48.3 | 1903-2014 |
| HF | TSCA | 32 | 83 | 32 | 71 | 10.6-37 | 0-28.4 | 1923-2014 |
| HKK | AFXY | 39 | 127 | 39 | 127 | 20.1-98.7 | 0.1-81.4 | 1903-2011 |
| HKK | CHTA | 28 | 70 | 28 | 70 | 16-64.6 | 0.2-59.5 | 1904-2010 |
| HKK | MEAZ | 46 | 130 | 46 | 130 | 25.6-98.1 | 3.8-80.3 | 1914-2011 |
| HKK | TOCI | 45 | 143 | 45 | 143 | 16.6-116.4 | 1.7-80.5 | 1903-2011 |
| LDW | ACSA | 35 | 66 | 34 | 64 | 9-64.6 | 0-52.4 | 1903-2019 |
| LDW | CAOV | 9 | 18 | 8 | 15 | NA-NA | 1.4-37.4 | 1903-2013 |
| LDW | LITU | 15 | 28 | 14 | 25 | NA-NA | 1.2-69.4 | 1903-2019 |
| LDW | QUAL | 10 | 20 | NA | NA | NA | NA | 1903-2013 |
| LDW | QUMO | 10 | 20 | 8 | 16 | NA-NA | 1.1-52.4 | 1903-2013 |
| LDW | QUVE | 9 | 18 | NA | NA | NA | NA | 1903-2013 |
| NE | BEPA | 28 | 84 | 28 | 84 | NA-NA | 0-25.5 | 1903-1995 |
| NE | JUVI | 29 | 60 | 29 | 60 | 16.6-21.5 | 0.3-18.4 | 1938-1994 |
| NE | PIPO | 71 | 134 | 70 | 129 | 19.3-64 | 0-41.1 | 1934-1994 |
| LT | PIPO | 10 | 20 | 10 | 20 | 23.2-52.8 | 14.4-48.4 | 1903-2018 |
| LT | PIST2 | 7 | 14 | 7 | 14 | 25.7-39.8 | 3.9-34.5 | 1903-2018 |
| SCBI | CACO | 15 | 15 | 14 | 14 | 10.62-38.52 | 1.7-32.2 | 1903-2015 |
| SCBI | CAGL | 39 | 39 | 36 | 36 | 10.28-52.31 | 1.6-49.3 | 1903-2015 |
| SCBI | CAOVL | 25 | 25 | 24 | 24 | 15.11-60.32 | 2.6-47.2 | 1903-2015 |
| SCBI | CATO | 15 | 15 | 14 | 14 | 12.86-35.95 | 3.7-28.4 | 1903-2015 |
| SCBI | FAGR | 76 | 76 | 74 | 74 | 10.05-41.02 | 0.1-41.2 | 1920-2009 |
| SCBI | FRAM | 66 | 66 | 61 | 61 | 8.11-94.73 | 0.1-84.4 | 1903-2016 |
| SCBI | FRNI | 12 | 12 | 12 | 12 | 11.04-39.2 | 0.5-27.3 | 1903-1996 |
| SCBI | JUNI | 30 | 30 | 28 | 28 | 20.4-76.19 | 5.6-59.5 | 1903-2010 |
| SCBI | LITU | 106 | 106 | 104 | 104 | 10-91.42 | 0.1-81.1 | 1903-2010 |
| SCBI | PIST | 36 | 36 | 36 | 36 | 13.92-50.96 | 1.6-45.2 | 1931-2010 |
| SCBI | QUAL | 66 | 66 | 66 | 66 | 11.4-76.73 | 0.3-70.4 | 1903-2009 |
| SCBI | QUMO | 67 | 67 | 67 | 67 | 10.22-84.59 | 0.3-69.5 | 1903-2017 |
| SCBI | QURU | 70 | 70 | 70 | 70 | 11.07-87.65 | 2.5-79.2 | 1903-2016 |
| SCBI | QUVE | 81 | 81 | 81 | 81 | 16.02-82.33 | 0.5-78.4 | 1903-2009 |
| SC | PIMA | 442 | 442 | 101 | 101 | 7-14.9 | 0.5-12.5 | 1903-2013 |
| ZOF | ABAL | 55 | 55 | 50 | 50 | 41-121 | 21.3-108.5 | 1903-2011 |
| ZOF | FASY | 1369 | 1369 | 1358 | 1358 | NA-NA | 0.1-115.3 | 1903-2013 |
| ZOF | PCAB | 644 | 644 | 599 | 599 | NA-NA | 0.5-126.4 | 1903-2011 |

*Maximum reconstructed *DBH*'s analyzed are less than maximum sampled *DBH*'s because we discard size ranges with < 3 conspecific trees.

Table S4. Allometric equations for bark thickness

| species | equation | n | DBH.range.cm | site | source |
|--------------------------------|---|----|--------------|---------------------------------------|---|
| <i>Acer rubrum</i> | $bark.mm = 0.619 * \log(dbh.cm + 1)$ | 10 | 8.2-39.6 | SCBI | Anderson-Teixeira et al. (2015) |
| <i>Betula alleghaniensis</i> | $bark.mm = (0.15 + 0.03 * dbh.cm)/2$ | NA | | North America average of its range | Miles, Patrick D.; Smith, W. Brad. 2009. |
| <i>Betula papyrifera</i> | $bark.mm = (0.13 + 0.05 * dbh.cm)/2$ | NA | | North America average of its range | Miles, Patrick D.; Smith, W. Brad. 2009. |
| <i>Carya cordiformis</i> | $bark.mm = 0.793 * \log(dbh.cm + 1)$ | 9 | 5.9-68.2 | SCBI | Anderson-Teixeira et al. (2015) |
| <i>Carya ovalis</i> | $bark.mm = 1.531 * \log(dbh.cm + 1)$ | 8 | 6.4-63.1 | SCBI | Anderson-Teixeira et al. (2015) |
| <i>Carya ovata</i> | $bark.mm = 1.035 * \log(dbh.cm + 1)$ | 8 | 19.1-78 | SCBI | Anderson-Teixeira et al. (2015) |
| <i>Carya tomentosa</i> | $bark.mm = 1.105 * \log(dbh.cm + 1)$ | 8 | 5-57.3 | SCBI | Anderson-Teixeira et al. (2015) |
| <i>Frazinus americana</i> | $bark.mm = 2.223 * \log(dbh.cm + 1)$ | 9 | 6.1-94.2 | SCBI | Anderson-Teixeira et al. (2015) |
| <i>Frazinus americana</i> | $bark.mm = (0.38 + 0.05 * dbh.cm)/2$ | NA | | North America average of its range | Miles, Patrick D.; Smith, W. Brad. 2009. |
| <i>Jacarana copaia</i> | $bark.mm = 2.993 * \log(dbh.cm + 1)$ | 5 | 45.6-75 | Panama | Raquel Alfaro-Sánchez (unpublished data) |
| <i>Juglans nigra</i> | $bark.mm = 2.107 * \log(dbh.cm + 1)$ | 9 | 13.6-85.4 | SCBI | Anderson-Teixeira et al. (2015) |
| <i>Liriodendron tulipifera</i> | $bark.mm = 1.637 * \log(dbh.cm + 1)$ | 9 | 27.5-136.5 | SCBI | Anderson-Teixeira et al. (2015) |
| <i>Picea engelmannii</i> | $bark.mm = (0.15 + 0.04 * dbh.cm)/2$ | NA | | North America average of its range | Miles, Patrick D.; Smith, W. Brad. 2009. |
| <i>Picea mariana</i> | $bark.mm = 3.726 * \log(dbh.cm + 1)$ | 12 | 6.9-7.9 | Scotty Creek | Anastasia Sniderhan and Jennifer Baltzer (unpublished data) |
| <i>Pinus flexilis</i> | $bark.mm = (1.299 * \sqrt{(dbh.cm)^{0.609}})^2$ | 29 | 10-130 | California (3 montane sites) | Zeibig-Kichas et al. (2016) |
| <i>Pinus ponderosa</i> | $bark.mm = (1.298 * \sqrt{(dbh.cm)^{0.802}})^2$ | 81 | 5-160 | California (4 montane sites) | Zeibig-Kichas et al. (2016) |
| <i>Pinus strobus</i> | $bark.mm = 1.568 * \log(dbh.cm + 1)$ | 1 | 28.4-28.4 | Illinois | Miles and Smith (2009) |
| <i>Pinus strobus</i> | $bark.mm = (0.02 + 0.10 * dbh.cm)/2$ | NA | | North America average of its range | Miles, Patrick D.; Smith, W. Brad. 2009. |
| <i>Pinus strobus</i> | $bark.mm = (0.02 + 0.10 * dbh.cm)/2$ | NA | | North America average of its range | Miles, Patrick D.; Smith, W. Brad. 2009. |
| <i>Populus tremuloides</i> | $bark.mm = (0.10 + 0.07 * dbh.cm)/2$ | NA | | North America average of its range | Miles, Patrick D.; Smith, W. Brad. 2009. |
| <i>Pseudotsuga menziesii</i> | $bark.mm = (0.785 * \sqrt{(dbh.cm)})^2$ | 30 | 10-200 | California (3 montane sites) | Zeibig-Kichas et al. (2016) |
| <i>Pseudotsuga menziesii</i> | $bark.mm = (0.40 + 0.17 * dbh.cm)/2$ | NA | | North America average of its range | Miles, Patrick D.; Smith, W. Brad. 2009. |
| <i>Quercus alba</i> | $bark.mm = 1.828 * \log(dbh.cm + 1)$ | 10 | 9.3-101.8 | SCBI | Anderson-Teixeira et al. (2015) |
| <i>Quercus montana</i> | $bark.mm = 2.083 * \log(dbh.cm + 1)$ | 8 | 5.8-99.1 | SCBI | Anderson-Teixeira et al. (2015) |
| <i>Quercus rubra</i> | $bark.mm = 0.98 * \log(dbh.cm + 1)$ | 10 | 24.1-143.2 | SCBI | Anderson-Teixeira et al. (2015) |
| <i>Quercus rubra</i> | $bark.mm = (0.19 + 0.07 * dbh.cm)/2$ | NA | | North America average of its range | Miles, Patrick D.; Smith, W. Brad. 2009. |
| <i>Quercus velutina</i> | $bark.mm = 1.394 * \log(dbh.cm + 1)$ | 8 | 16.2-110.7 | SCBI | Anderson-Teixeira et al. (2015) |
| <i>Tetragastris panamensis</i> | $bark.mm = 1.672 * \log(dbh.cm + 1)$ | 4 | 22.7-48.8 | Panama | Raquel Alfaro-Sánchez (unpublished data) |
| <i>Trichilia tuberculata</i> | $bark.mm = 1.367 * \log(dbh.cm + 1)$ | 12 | 21-40.5 | Panama | Raquel Alfaro-Sánchez (unpublished data), Pete Kerby-Miller and Helene Muller-Landau (unpublished data) |
| <i>Tsuga canadensis</i> | $bark.mm = (0.18 + 0.08 * dbh.cm)/2$ | NA | | North America average of its range | Miles, Patrick D.; Smith, W. Brad. 2009. |

For assignments of species as proxies for those with out available bark allometries, see Table S2.

Table S5. Qualitative comparison of results from this study with previous studies employing conventional methods

| species | Precipitation response | | Temperature response | | reference |
|-------------------------------|---|---|---|--|----------------------------|
| | previously observed | observed here | previously observed | observed here | |
| Barro Colorado Island, Panama | | | | | |
| JACO | pos. correlation to Apr-Dec <i>PPT</i> (strongest of the 3 species) | pos. correlation to Mar-Dec <i>PPT</i> (strongest of the 3 species) | no sig. correlation to annual T_{mean} or T_{min} | neg. response to Feb-Mar T_{min} | Alfaro-Sánchez et al. 2017 |
| TEPA | pos. correlation to Apr-Dec <i>PPT</i> (response weaker than JACO, similar to TRTU) | pos. correlation to Mar-Dec <i>PPT</i> (response weaker than JACO, similar to TRTU) | no sig. correlation to annual T_{mean} or T_{min} | no sig. correlation to Feb-Mar T_{min} | Alfaro-Sánchez et al. 2017 |
| TRTU | pos. correlation to Apr-Dec <i>PPT</i> (response weaker than JACO, similar to TEPA) | pos. correlation to Mar-Dec <i>PPT</i> (response weaker than JACO, similar to TEPA) | no sig. correlation to annual T_{mean} or T_{min} | non-sig. slight pos. response to Feb-Mar T_{min} | Alfaro-Sánchez et al. 2017 |
| Huai Kha Khaeng, Thailand | | | | | |
| AFXV | sig. pos. correlation with June <i>PPT</i> , otherwise n.s. | slight concave-down response to p.Sept-June <i>PPT</i> frequency | sig. neg. correlation with T_{max} in Aug and Dec; T_{min} in p.Oct., Jul, Aug | slight concave-down response to Apr-Oct T_{max} | Vlam et al. 2013 |
| CHTA | sig. pos. correlation with April <i>PPT</i> , otherwise n.s. | slight concave-down response to p.Sept-June <i>PPT</i> frequency | sig. neg. correlation with T_{max} in May, Aug-Sept; T_{min} in Feb, May, Aug | slight neg. response to Apr-Oct T_{max} | Vlam et al. 2013 |
| MEAZ | sig. pos. correlation with April <i>PPT</i> , otherwise n.s. | concave-down response to p.Sept-June <i>PPT</i> frequency | sig. neg. correlation with T_{max} in May-Aug; T_{min} in May-Aug | neg. response to Apr-Oct T_{max} | Vlam et al. 2013 |
| TOCI | sig. pos. correlation with p.Oct-p.Nov and April-May <i>PPT</i> | concave-down /increasing response to p.Sept-June <i>PPT</i> frequency | sig. neg. correlation with T_{max} every month from pOct-June (excluding March); T_{min} in Jan and Mar-Aug | neg. response to Apr-Oct T_{max} | Vlam et al. 2013 |
| PIPO | | | | | - |
| PIST2 | | | | | - |
| | | | | | - |

Table S5, cont.

| species | Precipitation response | | Temperature response | | reference |
|---|--|---------------|--|---|----------------------|
| | previously observed | observed here | previously observed | observed here | |
| Smithsonian Conservation Biology Institute, Virginia, USA | | | | | |
| CACO | pos. correlations with May-Aug <i>PPT</i> (sig. May, July) | NA | neg. correlations with May-Aug <i>PET</i> (sig. May-July) | ** (sig or ns)** neg. response to May-July <i>PET</i> | Helcoski et al. 2019 |
| CAGL | pos. correlations with May-Aug <i>PPT</i> (sig. May) | NA | neg. correlations with May-Aug <i>PET</i> (n.s.) | ** (sig or ns)** neg. response to May-July <i>PET</i> | Helcoski et al. 2019 |
| CAOVL | pos. correlations with May-Aug <i>PPT</i> (sig. Aug) | NA | neg. correlations with May-Aug <i>PET</i> (sig. all months) | ** (sig or ns)** neg. response to May-July <i>PET</i> | Helcoski et al. 2019 |
| CATO | pos. correlations with May-Aug <i>PPT</i> (n.s.) | NA | neg. correlations with May-Aug <i>PET</i> (sig. June) | ** (sig or ns)** neg. response to May-July <i>PET</i> | Helcoski et al. 2019 |
| FAGR | pos. correlations with May-Aug <i>PPT</i> (sig. July-Aug) | NA | neg. correlations with May-Aug <i>PET</i> (sig. July-Aug) | ** (sig or ns)** neg. response to May-July <i>PET</i> | Helcoski et al. 2019 |
| FRAM | pos. correlations with May-Aug <i>PPT</i> (sig. May-June) | NA | neg. correlations with May-Aug <i>PET</i> (sig. May-June) | ** (sig or ns)** neg. response to May-July <i>PET</i> | Helcoski et al. 2019 |
| FRNI | no sig. correlations with peak growing season <i>PPT</i> | NA | no sig. correlations with peak growing season <i>PET</i> | ** (sig or ns)** neg. response to May-July <i>PET</i> | Helcoski et al. 2019 |
| JUNI | pos. correlations with May-Aug <i>PPT</i> (sig. Jun-Aug) | NA | neg. correlations with May-Aug <i>PET</i> (sig. July-Aug) | non-sig. neg. response to May-July <i>PET</i> | Helcoski et al. 2019 |
| LITU | pos. correlations with May-Aug <i>PPT</i> (sig. May-July) | NA | neg. correlations with May-Aug <i>PET</i> (sig. all months) | ** (sig or ns)** neg. response to May-July <i>PET</i> | Helcoski et al. 2019 |
| PIST | pos. correlations with May-Aug <i>PPT</i> (n.s.) | NA | neg. correlations with May-Aug <i>PET</i> (n.s.) | ** (sig or ns)** neg. response to May-July <i>PET</i> | Helcoski et al. 2019 |
| QUAL | pos. correlations with May-Aug <i>PPT</i> (sig. May) | NA | neg. correlations with May-Aug <i>PET</i> (sig. all months) | ** (sig or ns)** neg. response to May-July <i>PET</i> | Helcoski et al. 2019 |
| QUMO | pos. correlations with May-Aug <i>PPT</i> (sig. May) | NA | neg. correlations with May-Aug <i>PET</i> (sig. May-June, Aug) | ** (sig or ns)** neg. response to May-July <i>PET</i> | Helcoski et al. 2019 |
| QURU | pos. correlations with May-Aug <i>PPT</i> (n.s.) | NA | neg. correlations with May-Aug <i>PET</i> (sig. May, July-Aug) | ** (sig or ns)** neg. response to May-July <i>PET</i> | Helcoski et al. 2019 |
| QUVE | pos. correlations with May-Aug <i>PPT</i> (sig. May-July) | NA | neg. correlations with May-Aug <i>PET</i> (sig. all months) | ** (sig or ns)** neg. response to May-July <i>PET</i> | Helcoski et al. 2019 |

Table S5, cont.

| species | Precipitation response | | Temperature response | | reference |
|--|--|---|---|--------------------------------------|--|
| | previously observed | observed here | previously observed | observed here | |
| Lilly Dickey Woods, Indiana, USA | | | | | |
| LITU | pos. correlations with Jun-Aug PDSI | pos. response to June <i>PPT</i> | neg. response to Jun-Aug T_{max} | neg. response to June <i>PET</i> | Maxwell, Harley, and Robeson 2016 |
| QUAL | pos. correlations with Jun-Aug PDSI | pos. response to June <i>PPT</i> | neg. response to Jun-Aug T_{max} | neg. response to June <i>PET</i> | Maxwell, Harley, and Robeson 2016 |
| QUMO | pos. correlations with Jun-Aug PDSI | pos. response to June <i>PPT</i> | neg. response to Jun-Aug T_{max} | neg. response to June <i>PET</i> | Maxwell, Harley, and Robeson 2016 |
| QUVE | pos. correlations with Jun-Aug PDSI | pos. response to June <i>PPT</i> | neg. response to Jun-Aug T_{max} | neg. response to June <i>PET</i> | Maxwell, Harley, and Robeson 2016 |
| Harvard Forest, Massachusetts, USA | | | | | |
| - | | | | | |
| Niobrara and Hansley, Nebraska, USA | | | | | |
| BEPA | little relationship to ppt within analysis timeframe (exception: pos. corr. with pAug pre); stronger relationship to streamflow and PDSI | | little relationship to T_{mean} within analysis timeframe (exception: neg. corr. with pJune and cJan T_{mean}) | | Bumann et al. 2019 |
| JUVI | pos. correlations with <i>PPT</i> pJul-cJune | | neg. correlation to cJun-cJul T_{mean} | | Aus de Ar et al. 2018 |
| PIPO | pos. correlations with <i>PPT</i> cApr-cAug | | neg. correlation to T_{mean} in pJul, pSep, cMay, cJul | | Aus de Ar et al. 2018 |
| Žofin Forest Dynamics Plot, Czech Republic | | | | | |
| ABAL | no sig. correlations with June-July <i>PPT</i> | slight concave-down response to p.Jun-p.July <i>PPT</i> frequency | sig. pos. correlation to April T (strongest T correlation) | pos. response to Jan-March T_{max} | Kášpar, Tumajer, Vašíčková, and Šamonil, in review |
| FASY | no sig. correlations with June-July <i>PPT</i> | pos. response to p.Jun-p.July <i>PPT</i> frequency | sig. pos. correlation to Jan T (strongest T correlation) | pos. response to Jan-March T_{max} | Kášpar, Tumajer, Vašíčková, and Šamonil, in review |
| PIAB | modest pos. correlations (n.s) with June-July <i>PPT</i> | pos. response to p.Jun-p.July <i>PPT</i> frequency | sig. pos. correlation to March T (strongest current-year T correlation) | pos. response to Jan-March T_{max} | Kášpar, Tumajer, Vašíčková, and Šamonil, in review |
| | >700m elev. sites moisture limited June-Aug | | >700m elev. sites temperature limited except June-Aug | | Tumajer et al. 2017 |
| Scotty Creek, NW Territories, Canada | | | | | |
| | | | | | Sniderhan and Baltzer 2016 |

Results from this study are the climate-only model. Where previous studies examined numerous climate variables or time windows (e.g., Helcoski et al., 2019), we focus on those most relevant to our findings. Beyond the methodological differences, original studies vary from this one and from one another in factors including exact set of cores analyzed, climate data sources, time frame of analysis, approaches to identifying candidate climate variables and windows (including whether this is done on a site or species level), methods for

detrending and standardizing to build chronologies, and whether the effects of temperature and precipitation are considered separately (original studies) or additively (this study). An analysis standardizing all of these factors for four species is present in Appendix **S2** and Fig. **S1**.

Table S6. Frequency of *DBH*-climate interactions across all sites and growth metrics

Figure S1 | (Comparison of traditional approaches with ours). (THIS FIGURE IS JUST A MOCK-UP –NOT REAL DATA. REAL FIGURE WILL INCLUDE 3-4 COMMONLY STUDIED SPECIES FROM DIFFERENT SITES.)



SI References

- Aus de Ar, R. (2018). Tree Rings of *Pinus ponderosa* and *Juniperus virginiana* Show Different Responses to Stand Density and Water Availability in the Nebraska Grasslands. *The American Midland Naturalist*, 180(1), 18. doi:10.1674/0003-0031-180.1.18
- Bumann, E., Awada, T., Wardlow, B., Hayes, M., Okalebo, J., Helzer, C., ... Cherubini, P. (2019). Assessing responses of *Betula Papyrifera* to climate variability in a remnant population along the Niobrara River Valley in Nebraska, U.S.A., Through dendroecological and remote-sensing techniques. *Canadian Journal of Forest Research*, 49(5), 423–433. doi:10.1139/cjfr-2018-0206
- Helcoski, R., Tepley, A. J., Pederson, N., McGarvey, J. C., Meakem, V., Herrmann, V., ... Anderson-Teixeira, K. J. (2019). Growing season moisture drives interannual variation in woody productivity of a temperate deciduous forest. *New Phytologist*, 223(3), 1204–1216. doi:10.1111/nph.15906
- Kašpar, K., Tumajer, J., Vašíčková, I., & Šamonil, P. (n.d.). Species-specific climate-growth interactions determine the future tree species dynamics of the mixed Central European mountain forests.
- Maxwell, J. T., Harley, G. L., & Robeson, S. M. (2016). On the declining relationship between tree growth and climate in the Midwest United States: The fading drought signal. *Climatic Change*, 138(1-2), 127–142. doi:10.1007/s10584-016-1720-3
- Sniderhan, A. E., & Baltzer, J. L. (2016). Growth dynamics of black spruce (*Picea Mariana*) in a rapidly thawing discontinuous permafrost peatland: Growth Dynamics Boreal Peatlands. *Journal of Geophysical Research: Biogeosciences*, 121(12), 2988–3000. doi:10.1002/2016JG003528
- Tumajer, J., Altman, J., Štěpánek, P., Tremml, V., Doležal, J., & Cienciala, E. (2017). Increasing moisture limitation of Norway spruce in Central Europe revealed by forward modelling of tree growth in tree-ring network. *Agricultural and Forest Meteorology*, 247, 56–64. doi:10.1016/j.agrformet.2017.07.015
- Vlam, M., Baker, P. J., Bunyavejchewin, S., & Zuidema, P. A. (2014). Temperature and rainfall strongly drive temporal growth variation in Asian tropical forest trees. *Oecologia*, 174(4), 1449–1461. doi:10.1007/s00442-013-2846-x