Supplementary Information

Contents

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 Δr 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

This is in process. For ~4 selected species (well-studied), we will build chronologies that exactly match the data used in this analysis. We'll then generate a figure like Fig. S1. We expect a pretty good match, as our results are basically consistent with previous studies at all these sites.

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_growth_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		pOct-cDec
LT	Little Tesuque	35.73838	-105.8382		n.a.	all	live	1903-2018		pMay-cAug
CB	Utah Forest Dynamics Plot	37.66150	-112.8525	3020-3169				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
NB	Niobrara/Hansley	42.78000	-100.0210	644-702						pMay-cAug
ZOF	Zofin Forest Dynamics Plot	48.66380	14.7073	745-822	some	all		1903-2013		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		neglected in Zofin
ABBI	Pinaceae	Abies bifolia	CB	needleleaf	evergreen		neglected in Cedar Breaks
ACRU	Sapindaceae	Acer rubrum	HF	broadleaf	deciduous (cold)		acru in Harvard
ACSA	Sapindaceae	Acer saccharum	LDW	broadleaf	deciduous (cold)		acru in Lilly Dickey, acru in Lilly Dickey
AFXY	Fabaceae	Afzelia xylocarpa	HKK	broadleaf	deciduous (drought)		neglected in HKK
BEAL	Betulaceae	Betula alleghaniensis	HF	broadleaf	deciduous (cold)		neglected in Harvard
BELE	Betulaceae	Betula lenta	NA	broadleaf	deciduous (cold)		neglected in Harvard
BEPA	Betulaceae	Betula papyrifera	NA	broadleaf	deciduous (cold)		neglected in NB
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, SCBI	broadleaf	deciduous (cold)		cagl in Lilly Dickey, caovl in SCBI
CAOV	Juglandaceae	Carya ovalis	LDW, SCBI	broadleaf	deciduous (cold)		cagl in Lilly Dickey, 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 Harvard, neglected in Lilly Dickey, neglected in SCBI
FASY	Fagaceae	Fagus sylvatica	ZOF	broadleaf	deciduous (cold)		neglected in Zofin
FRAM	Oleaceae	Fraxinus americana	LDW, SCBI	broadleaf	deciduous (cold)		fram in Lilly Dickey, 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
LITU	Magnoliaceae	Liriodendron tulipifera	LDW, SCBI	broadleaf	deciduous (cold)		litu in Lilly Dickey, litu in Lilly Dickey, litu in SCBI
MEAZ	Meliaceae	Melia azedarach	HKK	broadleaf	deciduous (drought)	light-demanding	neglected in HKK
NEOB	Lauraceae	Neolitsea obtusifolia	NA	broadleaf	evergreen		neglected in HKK
PIAB	Pinaceae	Picea abies	HF	needleleaf	evergreen		neglected in Harvard, neglected in Zofin
PIFL	Pinaceae	Pinus flexilis	CB	needleleaf	evergreen		Pinus monticola in Cedar Breaks
PILO	Pinaceae	Pinus longaeva	CB	needleleaf	evergreen		neglected in Cedar Breaks
PIMA	Pinaceae	Picea mariana	SC	needleleaf	evergreen		PIMA in Scotty Creek
PIPO	Pinaceae	Pinus ponderosa	LT	needleleaf	evergreen		Pinus jeffreyi in Little Tesuque, Pinus jeffreyi in NB
PIST	Pinaceae	Pinus strobus	HF, SCBI	needleleaf	evergreen		neglected in Harvard, pist in SCBI
PIST2	Pinaceae	Pinus strobiformis	LT	needleleaf	evergreen		Pinus monticola in Little Tesuque
PSME	Pinaceae	Pseudotsuga menziesii	CB	needleleaf	evergreen		PSME in Cedar Breaks
QUAL	Fagaceae	Quercus alba	LDW, SCBI	broadleaf	deciduous (cold)		qual in Lilly Dickey, qual in SCBI
QUMO	Fagaceae	Quercus montana	LDW, SCBI	broadleaf	deciduous (cold)		qupr in Lilly Dickey, qupr in SCBI
QURU	Fagaceae	Quercus rubra	HF, LDW, SCBI	broadleaf	deciduous (cold)		quru in Harvard, quru in Lilly Dickey, quru in SCBI
QUVE	Fagaceae	Quercus velutina	LDW, SCBI	broadleaf	deciduous (cold)		quve in Lilly Dickey, 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		neglected in Harvard

*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	3.8-59.4	1931-2014
BCI	TEPA	18	29	17	26	22.1-59.5	2.6-51.2	1931-2014
BCI	TRTU	23	37	20	31	20.7-43.6	5.3-42.4	1931-2014
CB	PIFL	9	13	NA	NA	NA	NA	1903-2007
CB	PILO	11	12	NA	NA	NA	NA	1903-2007
CB	PSME	10	13	NA	NA	NA	NA	1903-2007
HF	ACRU	18	59	18	59	10.1-22.1	1-20.4	1903-2013
HF	BEAL	13	44	13	44	10.2-37.9	1.6-20.5	1904-2013
HF	QURU	74	180	73	177	19.5-53	1.6-48.3	1903-2014
HF	TSCA	32	83	32	83	10.6-37	0.6-34.4	1923-2014
HKK	AFXY	NA	NA	NA	NA			
HKK	CHTA	NA	NA	NA	NA			
HKK	MEAZ	NA	NA	NA	NA			
HKK	TOCI	NA	NA	NA	NA			
LDW	ACSA	NA	NA	NA	NA			
LDW	CAOV	NA	NA	NA	NA			
LDW	FRAM	NA	NA	NA	NA			
LDW	LITU	NA	NA	NA	NA			
LDW	QUAL	NA	NA	NA	NA			
LDW	QUMO	NA	NA	NA	NA			
LDW	QURU	NA	NA	NA	NA			
LDW	QUVE	NA	NA	NA	NA			
LT	PIPO	NA	NA	NA	NA			
LT	PIST2	NA	NA	NA	NA			
SC	PIMA	NA	NA	NA	NA			
SCBI	CACO	NA	NA	NA	NA			
SCBI	CAGL	NA	NA	NA	NA			
SCBI	CAOVL	NA	NA	NA	NA			
SCBI	CATO	NA	NA	NA	NA			
SCBI	FAGR	NA	NA	NA	NA			
SCBI	FRAM	NA	NA	NA	NA			
SCBI	FRNI	NA	NA	NA	NA			
SCBI	JUNI	NA	NA	NA	NA			
SCBI	LITU	NA	NA	NA	NA			
SCBI	PIST	NA	NA	NA	NA			
SCBI	QUAL	NA	NA	NA	NA			
SCBI	QUMO	NA	NA	NA	NA			
SCBI	QURU	NA	NA	NA	NA			
SCBI	QUVE	NA	NA	NA	NA			
ZOF	ABAL	NA	NA	NA	NA			
ZOF	FASY	NA	NA	NA	NA			
ZOF	PCAB	NA	NA	NA	NA			

*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
Acer rubrum	$bark.mm = 0.619 * log(dbh.cm + 1)$	10	8.2-39.6	SCBI	Anderson-Teixeira et al. (2015)
Carya cordiformis	$bark.mm = 0.793 * log(dbh.cm + 1)$	9	5.9-68.2	SCBI	Anderson-Teixeira et al. (2015)
Carya ovalis	$bark.mm = 1.531 * log(dbh.cm + 1)$	8	6.4-63.1	SCBI	Anderson-Teixeira et al. (2015)
Carya ovata	$bark.mm = 1.035 * log(dbh.cm + 1)$	8	19.1-78	SCBI	Anderson-Teixeira et al. (2015)
Carya tomentosa	$bark.mm = 1.105 * log(dbh.cm + 1)$	8	5-57.3	SCBI	Anderson-Teixeira et al. (2015)
Fraxinus americana	$bark.mm = 2.223 * log(dbh.cm + 1)$	9	6.1-94.2	SCBI	Anderson-Teixeira et al. (2015)
Jacaranada copaia	$bark.mm = 2.993 * log(dbh.cm + 1)$	5	45.6-75	Panama	Raquel Alfaro-Sanchez (unpublished data)
Juglans nigra	$bark.mm = 2.107 * log(dbh.cm + 1)$	9	13.6-85.4	SCBI	Anderson-Teixeira et al. (2015)
Liriodendron tulipifera	$bark.mm = 1.637 * log(dbh.cm + 1)$	9	27.5-136.5	SCBI	Anderson-Teixeira et al. (2015)
Picea mariana	$bark.mm = 3.726 * log(dbh.cm + 1)$	12	6.9-7.9	Scotty Creek	Anastasia Sniderhan and Jennifer Baltzer (unpublished data)
Pinus flexilis	$bark.mm = (1.299 * \sqrt{(dbh.cm)^{0.609}})^2$	29	10-130	California (3 montane sites)	Zeibig-Kichas et al. (2016)
Pinus ponderosa	$bark.mm = (1.298 * \sqrt{(dbh.cm)^{0.802}})^2$	81	5-160	California (4 montane sites)	Zeibig-Kichas et al. (2016)
Pinus strobus	$bark.mm = 1.568 * log(dbh.cm + 1)$	1	28.4-28.4	Illinois	Miles and Smith (2009)
Pseudotsuga menziesii	$bark.mm = (0.785 * \sqrt{(dbh.cm)})^2$	30	10-200	California (3 montane sites)	Zeibig-Kichas et al. (2016)
Quercus alba	$bark.mm = 1.828 * log(dbh.cm + 1)$	10	9.3-101.8	SCBI	Anderson-Teixeira et al. (2015)
Quercus montana	$bark.mm = 2.083 * log(dbh.cm + 1)$	8	5.8-99.1	SCBI	Anderson-Teixeira et al. (2015)
Quercus rubra	$bark.mm = 0.98 * log(dbh.cm + 1)$	10	24.1-143.2	SCBI	Anderson-Teixeira et al. (2015)
Quercus velutina	$bark.mm = 1.394 * log(dbh.cm + 1)$	8	16.2-110.7	SCBI	Anderson-Teixeira et al. (2015)
Tetragastris panamensis	$bark.mm = 1.672 * log(dbh.cm + 1)$	4	22.7-48.8	Panama	Raquel Alfaro-Sanchez (unpublished data)
Trichilia tuberculata	$bark.mm = 1.367 * log(dbh.cm + 1)$	12	21-40.5	Panama	Raquel Alfaro-Sanchez (unpublished data), Pete Kerby-Miller and Helene Muller-Landau (unpublished data)

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

Table S5. Frequency of DBH-climate interactions across all sites and growth metrics

Figure S1. Comparison of our approach with traditional methods of identifying climate signals

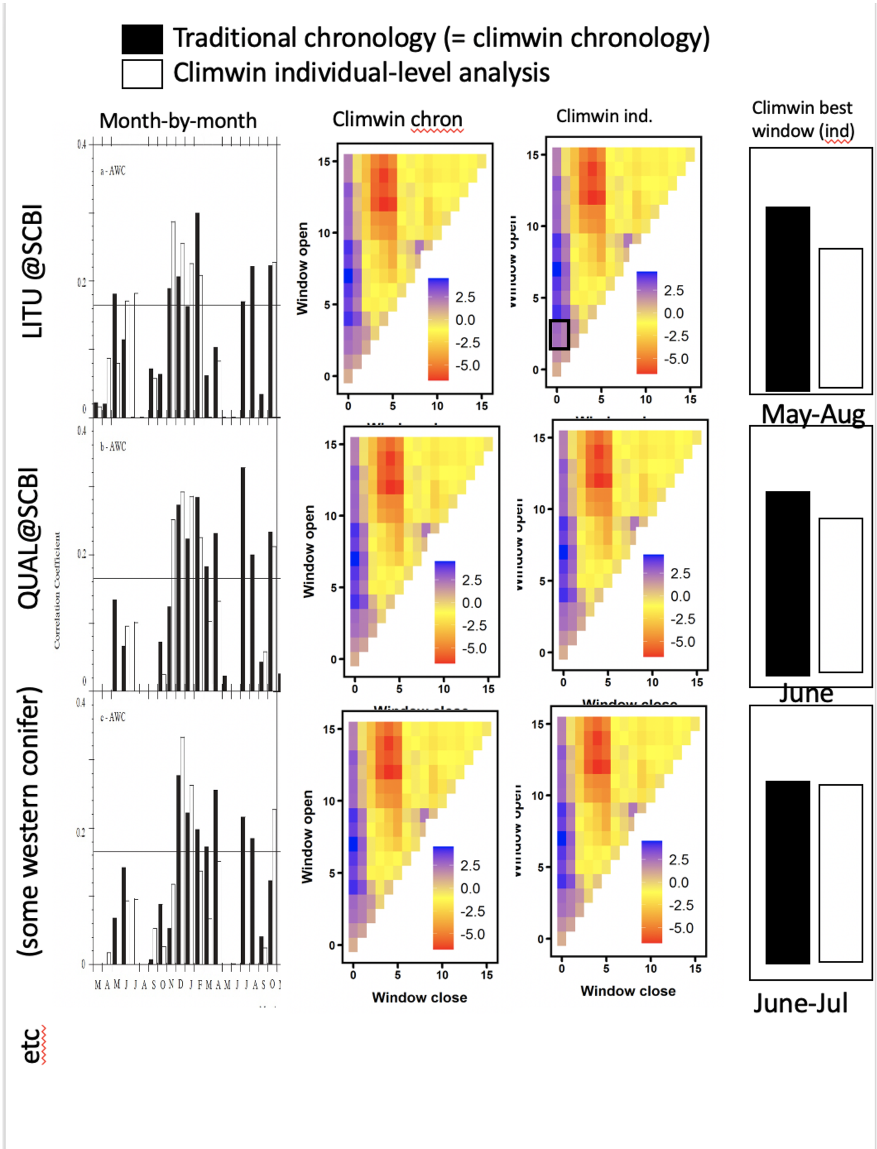

Figure S1 | (Comparison of traditional approaches with ours). (THIS FIGURE IS JUST A MOCK-UP –NOT REAL DATA. REAL FIGURE WILL INCLUDE 3-4 COMMONLY STUDIED SPECIES FROM DIFFERENT SITES.)

Figure S2. Comparison of climwin output across growth metrics for the temperature variable group at Little Tesuque (New Mexico, USA)

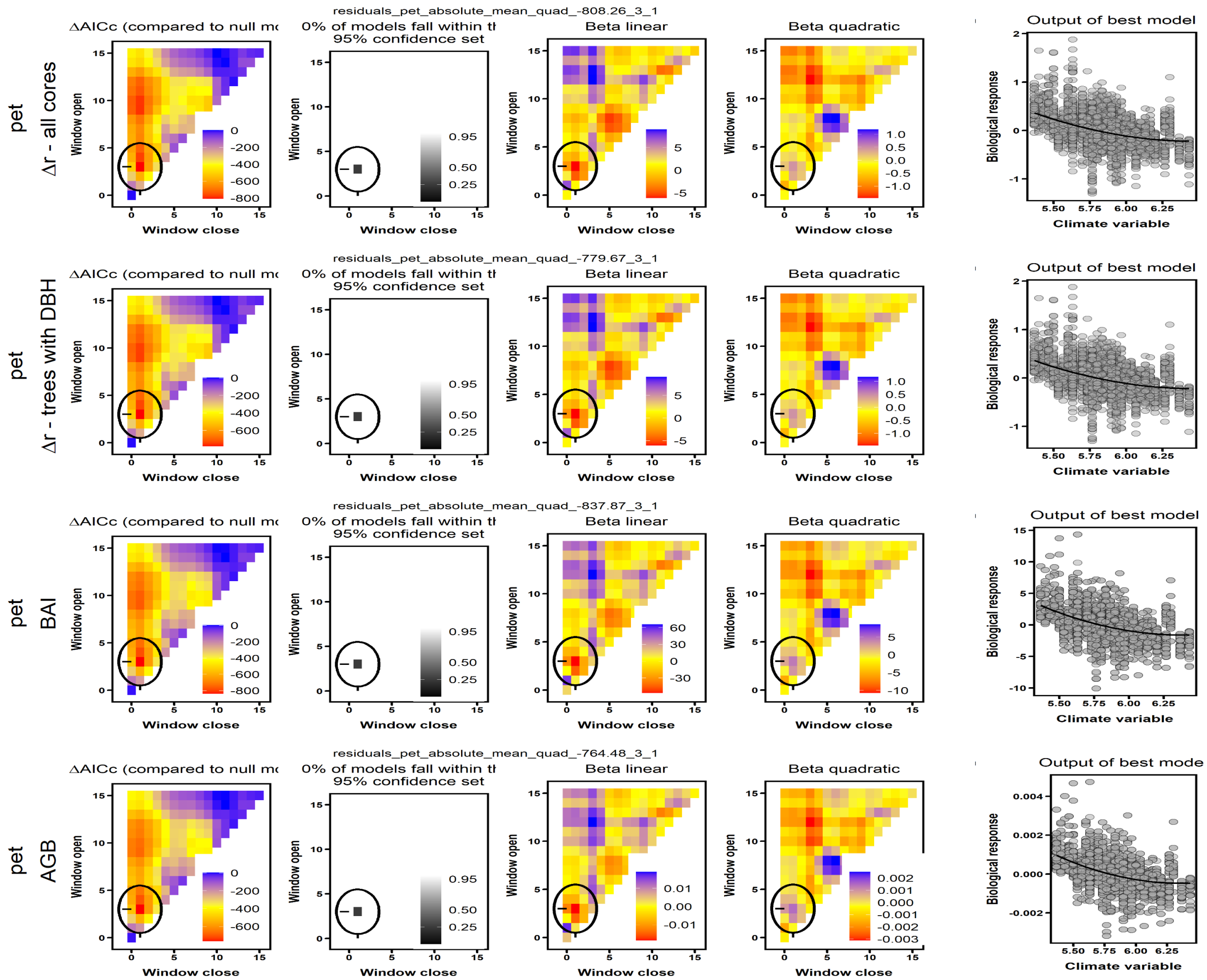

Figure S2 | Comparison of climwin output across growth metrics for the temperature variable group at Little Tesuque (New Mexico, USA). Here, *climwin* identified potential evapotranspiration (PET) as the strongest climate variable across all three metrics of growth (Δr, BAI, ΔAGB) and regardless of whether all cores were included in the analysis, or only those for which DBH could be reconstructed (Δr-trees with DBH, BAI, ΔAGB).)

Figure S3. Comparison of climwin output across growth metrics for the precipitation variable group at Little Tesuque (New Mexico, USA)

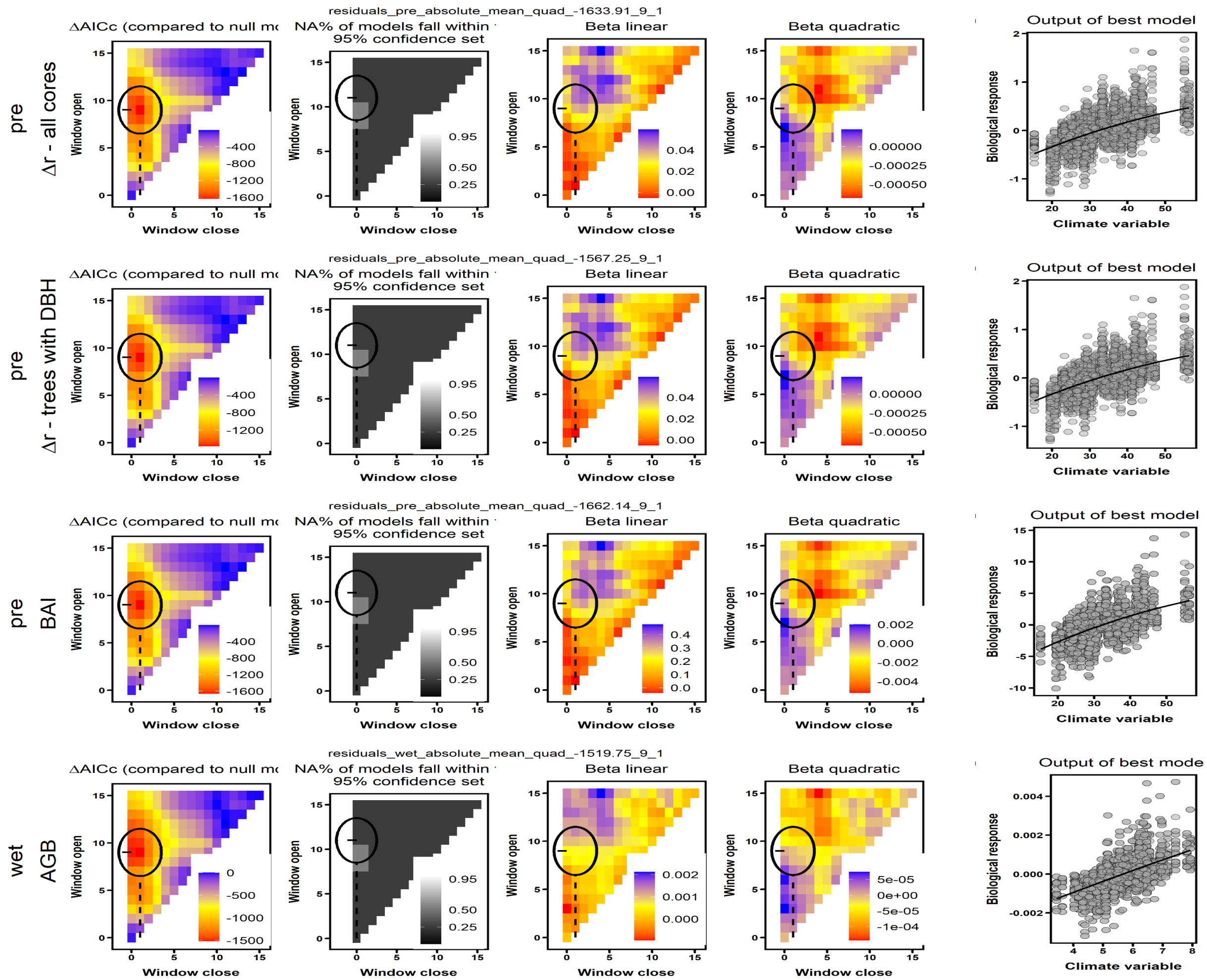

Figure S3 | Comparison of climwin output across growth metrics for the precipitation variable group at Little Tesuque (New Mexico, USA). Here, *climwin* identified precipitation (PRE) as the strongest climate variable for Δr and BAI, but precipitation day frequency (WET) as the strongest climate variable for ΔAGB.

Figure S4. Comparison of climwin output across growth metrics for the precipitation variable group at Harvard Forest (Massachusetts, USA)

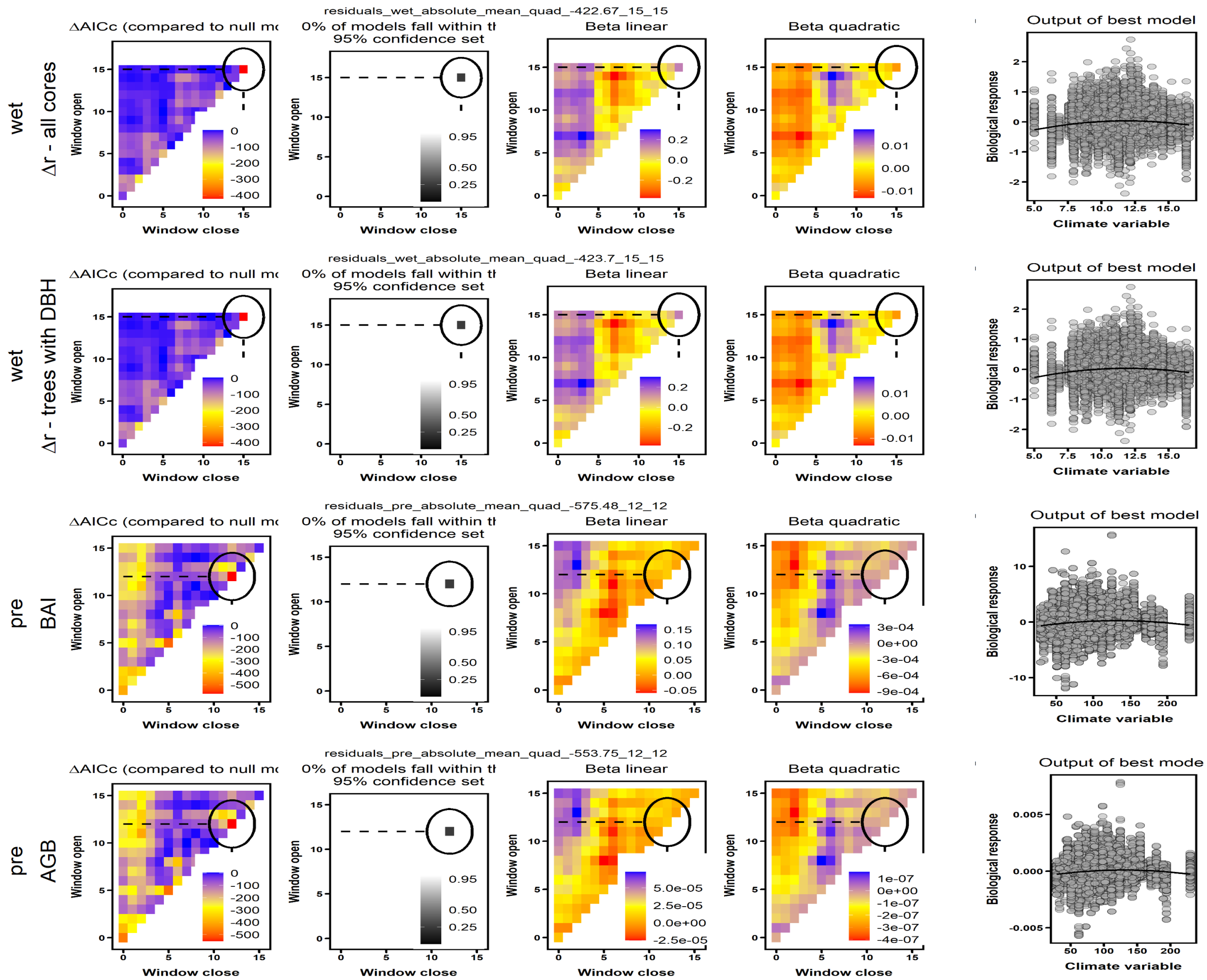

Figure S4 | Comparison of climwin output across growth metrics for the precipitation variable group at Harvard Forest (Massachusetts, USA). Here, *climwin* identified precipitation frequency (WET) as the strongest climate variable for Δr, but precipitation amount (PRE) as the strongest climate variable for BAI and ΔAGB. The optimal time window (circled) also differed across growth metrics.

Figure S5. Best GLS models for Barro Colorado Island (Panama)

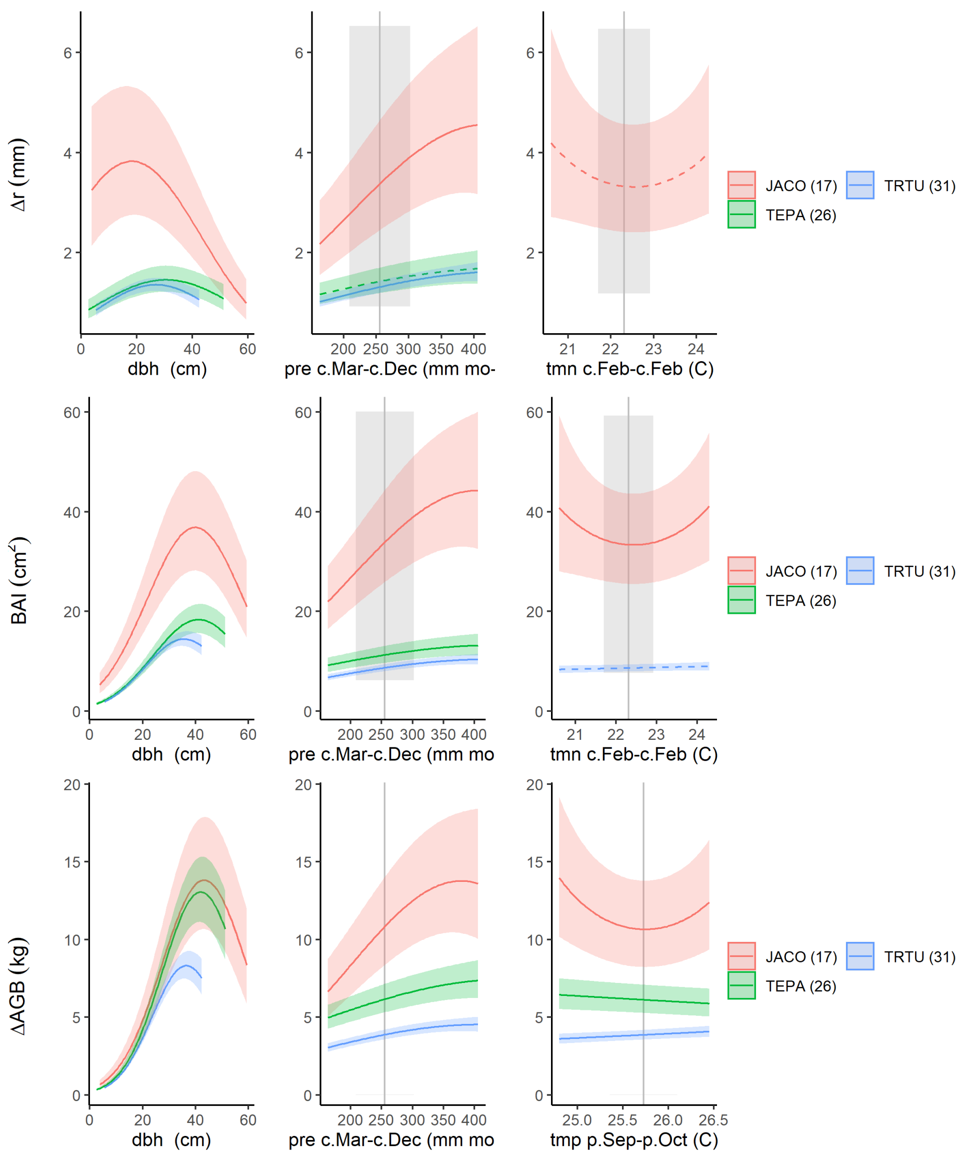

Figure S5 | Best GLS models for Barro Colorado Island (Panama) for all three growth metrics: Δr, BAI, and ΔAGB. Precipitation and temperature group variables are as selected by *climwin*. For each species, relationships are plotted if included in top model, with dashed lines indicating terms that do not significantly improve the model (relative to a model without). Vertical grey lines indicate the long-term mean for the climate variable, shading indicates 1 SD.

Figure S6. Best GLS models for Huai Kha Khaeng (Thailand)

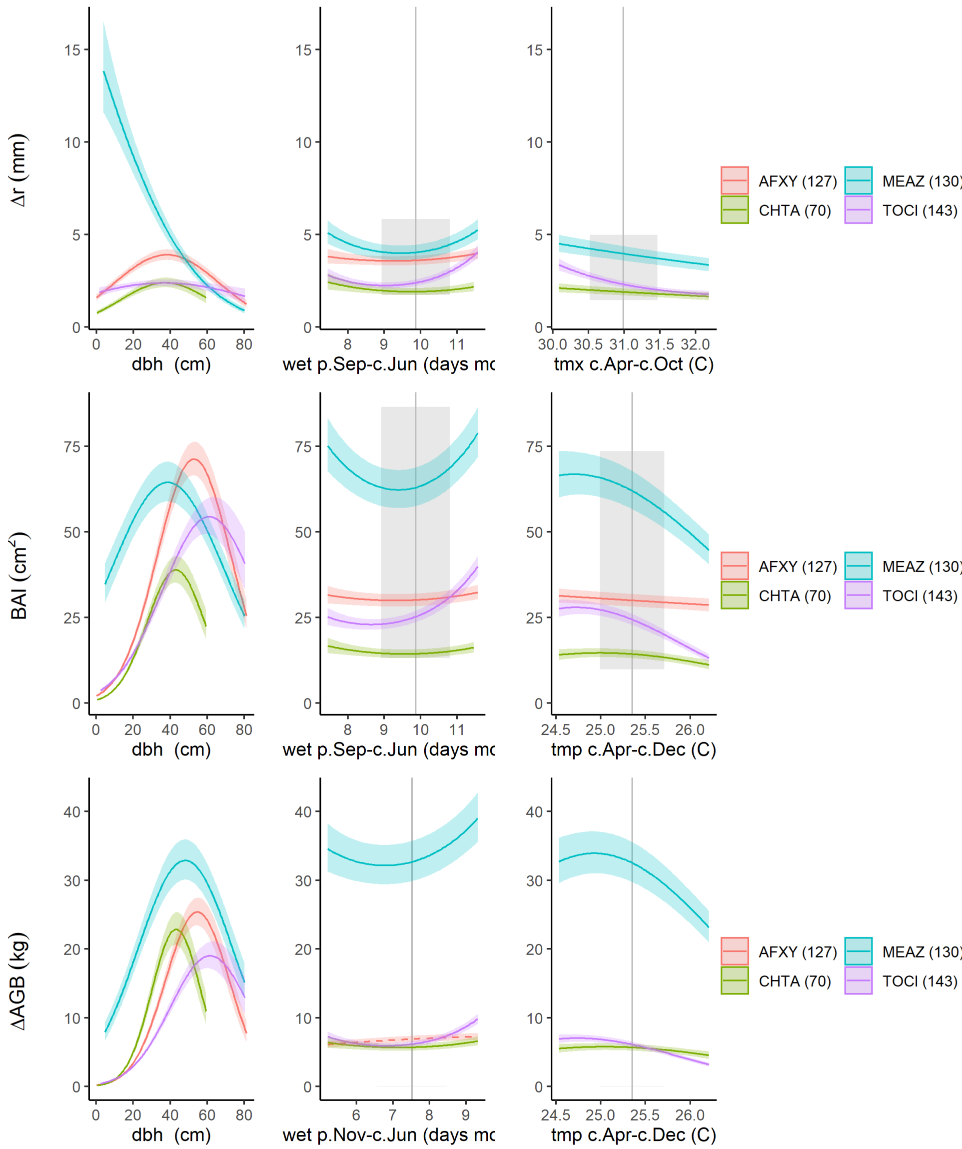

Figure S6 | Best GLS models for Huai Kha Khaeng (Thailand) for all three growth metrics: Δr, BAI, and ΔAGB. Precipitation and temperature group variables are as selected by *climwin*. For each species, relationships are plotted if included in top model, with dashed lines indicating terms that do not significantly improve the model (relative to a model without). Vertical grey lines indicate the long-term mean for the climate variable, shading indicates 1 SD.

Figure S7. Best GLS models for Little Tesuque (New Mexico, USA)

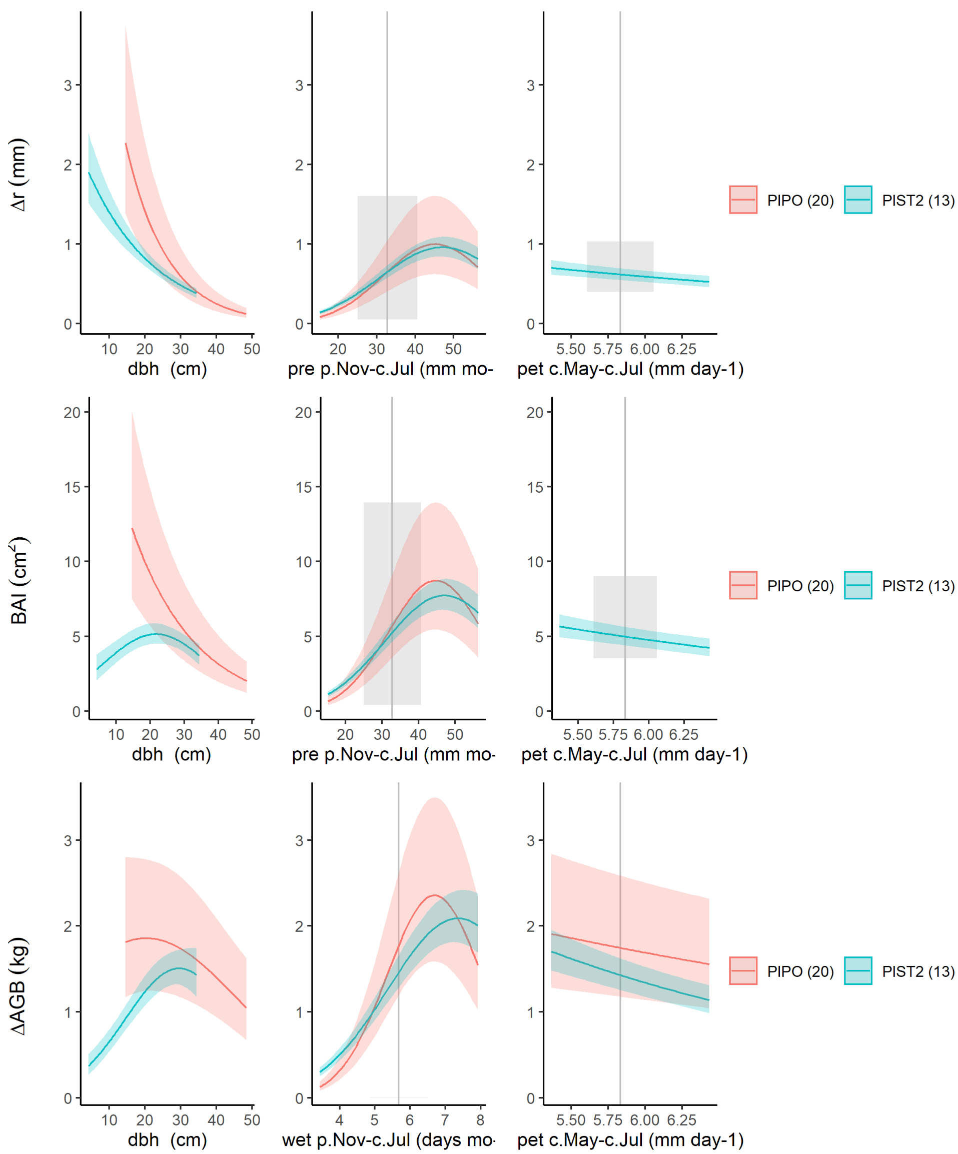

Figure S7 | Best GLS models for Little Tesuque (New Mexico, USA) for all three growth metrics: Δr, BAI, and ΔAGB. Precipitation and temperature group variables are as selected by *climwin*. For each species, relationships are plotted if included in top model, with dashed lines indicating terms that do not significantly improve the model (relative to a model without). Vertical grey lines indicate the long-term mean for the climate variable, shading indicates 1 SD.

Figure S8. Best GLS models for Cedar Breaks (Utah, USA)

[**Figure S8 | Best GLS models for Cedar Breaks (Utah, USA) for all three growth metrics: Δr, BAI, and ΔAGB.** Precipitation and temperature group variables are as selected by *climwin*. For each species, relationships are plotted if included in top model, with dashed lines indicating terms that do not significantly improve the model (relative to a model without). Vertical grey lines indicate the long-term mean for the climate variable, shading indicates 1 SD.]

Figure S9. Best GLS models for SCBI (Virginia, USA)

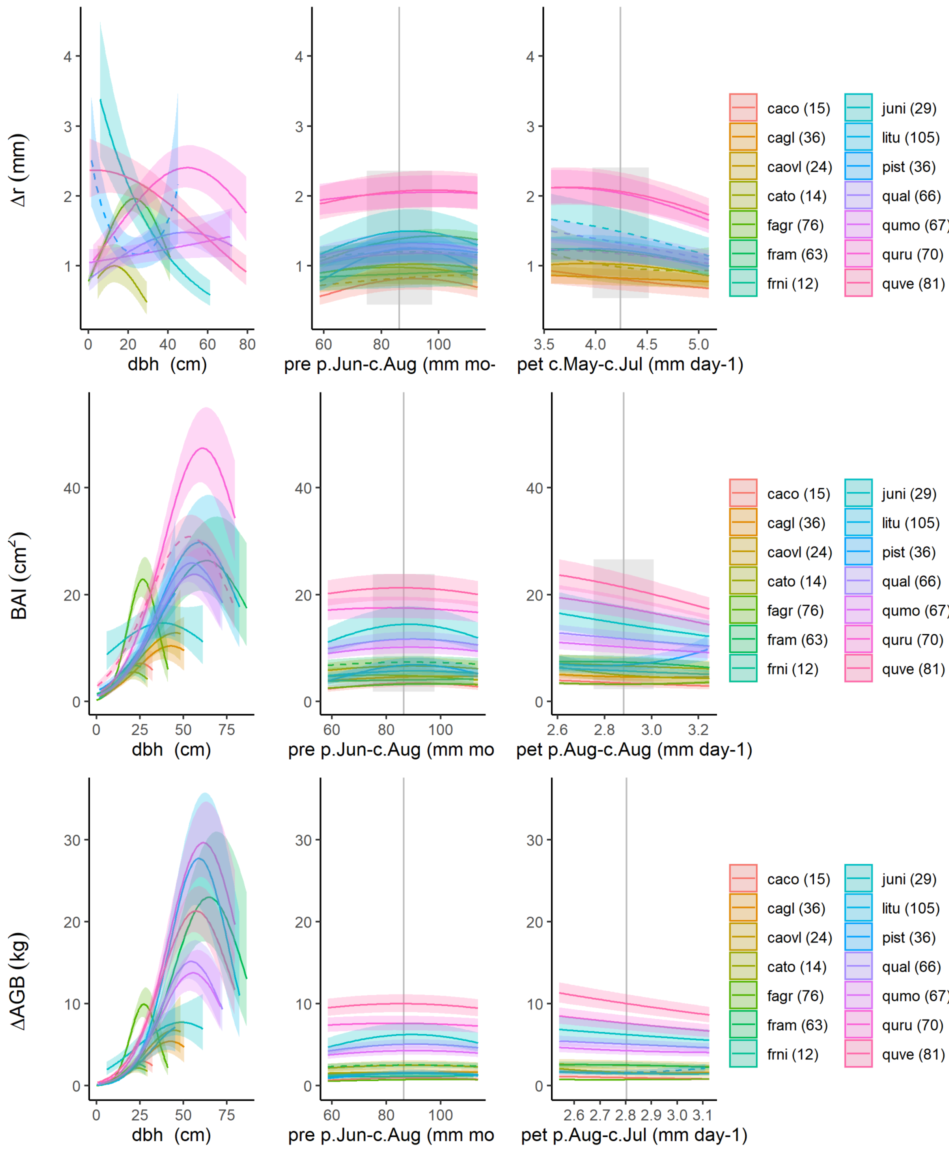

Figure S9 | Best GLS models for SCBI (Virginia, USA) for all three growth metrics: Δr, BAI, and ΔAGB. Precipitation and temperature group variables are as selected by *climwin*. For each species, relationships are plotted if included in top model, with dashed lines indicating terms that do not significantly improve the model (relative to a model without). Vertical grey lines indicate the long-term mean for the climate variable, shading indicates 1 SD.

Figure S10. Best GLS models for Lilly Dickey Woods (Indiana, USA)

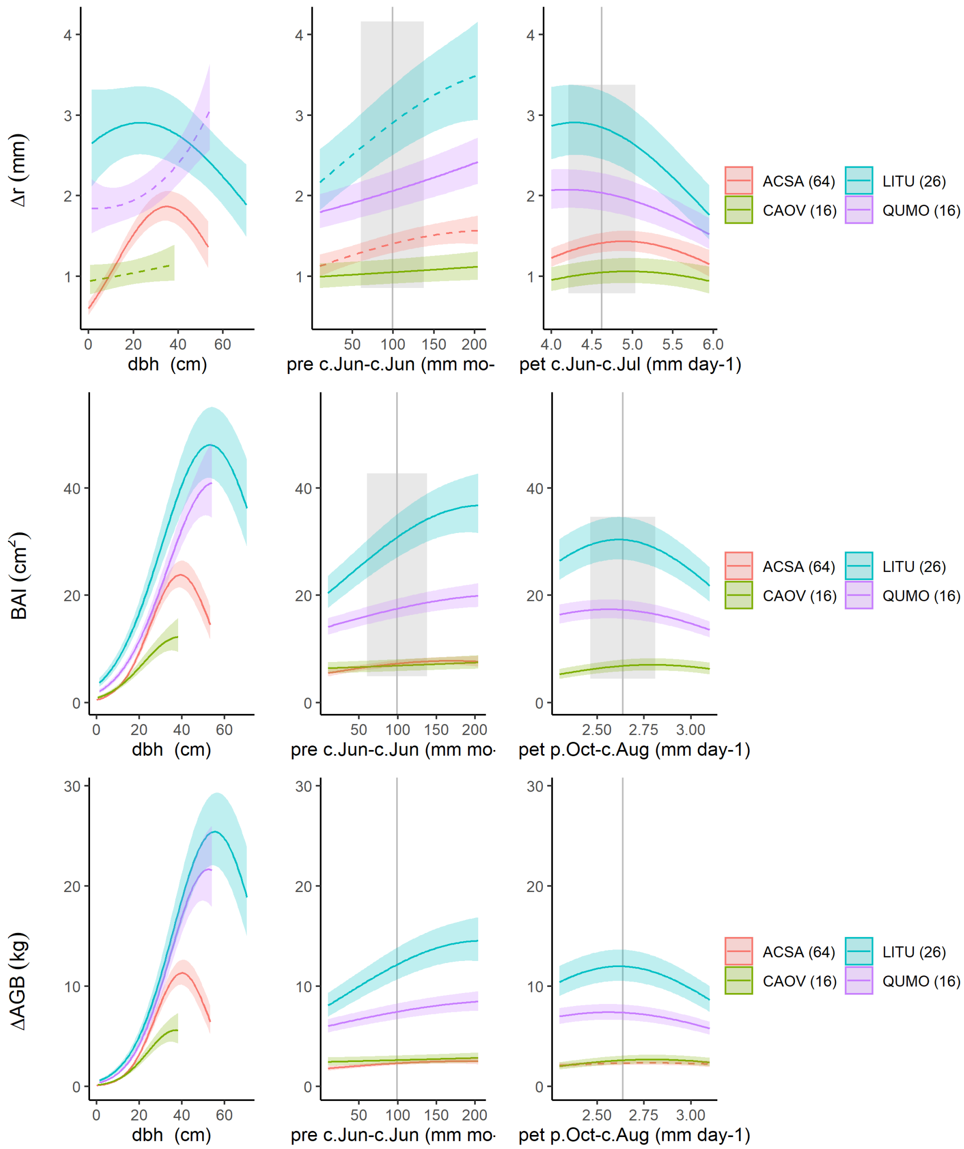

Figure S10 | Best GLS models for Lilly Dickey Woods (Indiana, USA) for all three growth metrics: Δr, BAI, and ΔAGB. Precipitation and temperature group variables are as selected by *climwin*. For each species, relationships are plotted if included in top model, with dashed lines indicating terms that do not significantly improve the model (relative to a model without). Vertical grey lines indicate the long-term mean for the climate variable, shading indicates 1 SD.

Figure S11. Best GLS models for Harvard Forest (Massachusetts, USA)

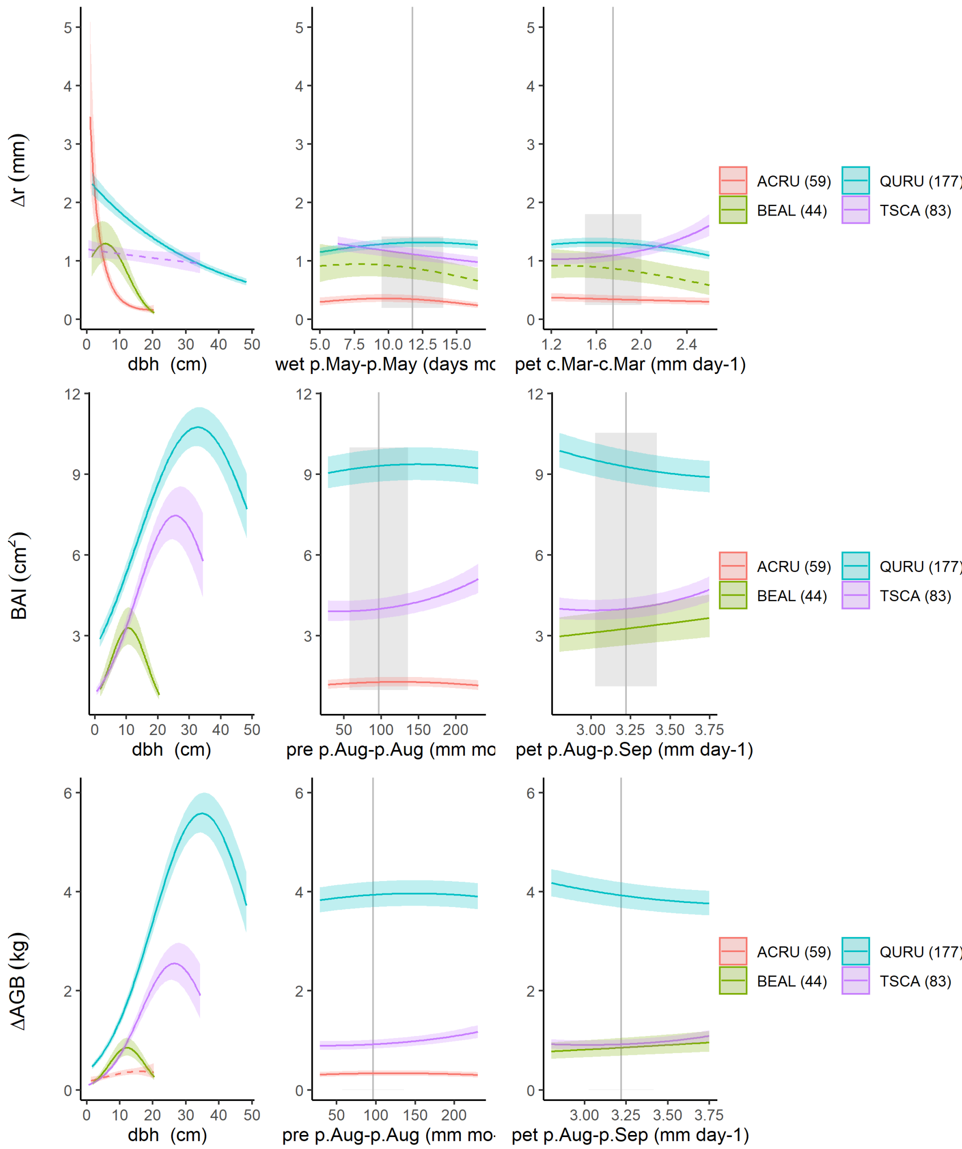

Figure S11 | Best GLS models for Harvard Forest (Massachusetts, USA) for all three growth metrics: Δr, BAI, and ΔAGB. Precipitation and temperature group variables are as selected by *climwin*. For each species, relationships are plotted if included in top model, with dashed lines indicating terms that do not significantly improve the model (relative to a model without). Vertical grey lines indicate the long-term mean for the climate variable, shading indicates 1 SD.

Figure S12. Best GLS models for Niobrara/ Hansley (Nebraska, USA)

Figure S13. Best GLS models for Zofin (Czech Republic)

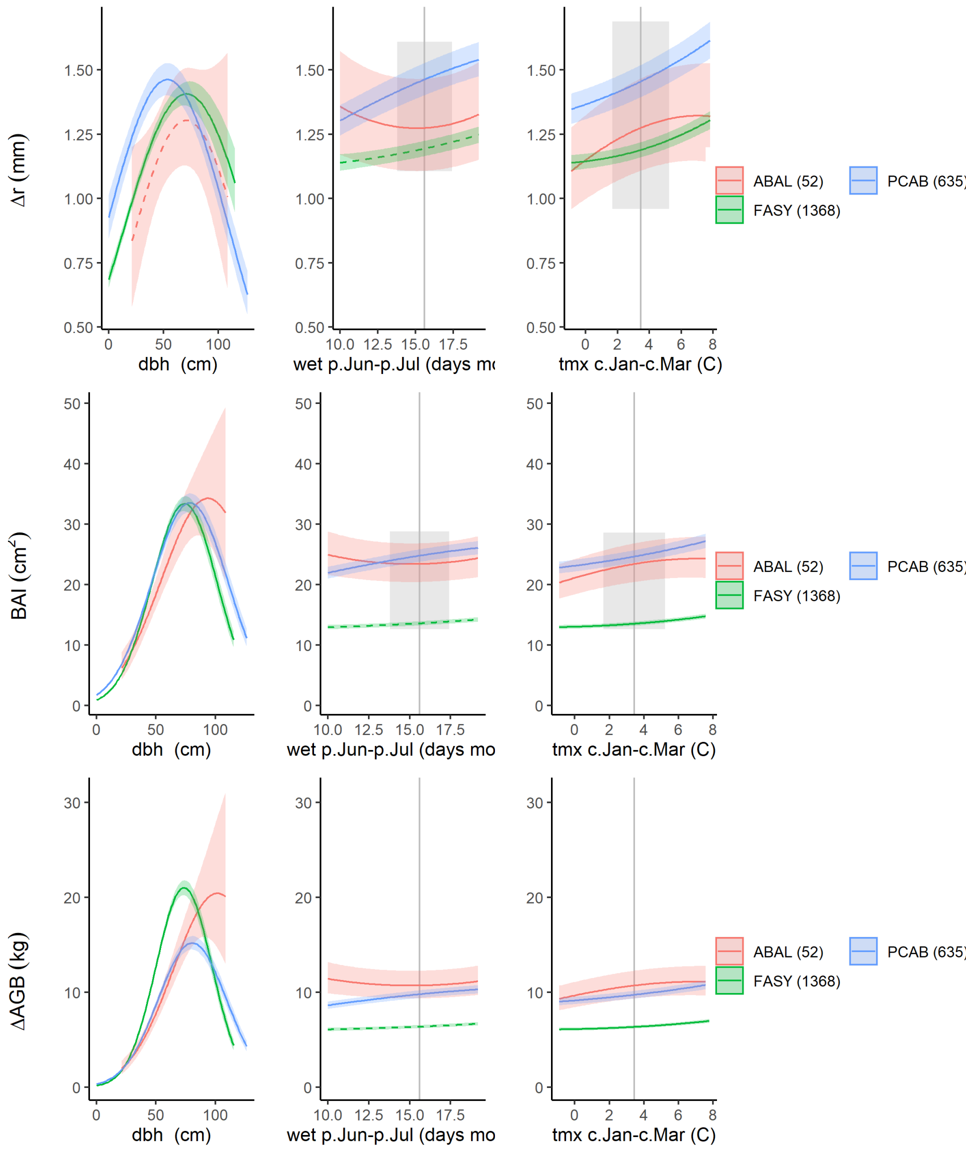

Figure S13 | Best GLS models for Zofin (Czech Republic) for all three growth metrics: Δr, BAI, and ΔAGB. Precipitation and temperature group variables are as selected by *climwin*. For each species, relationships are plotted if included in top model, with dashed lines indicating terms that do not significantly improve the model (relative to a model without). Vertical grey lines indicate the long-term mean for the climate variable, shading indicates 1 SD.

Figure S14. Best GLS models for Scotty Creek (NW Territories, Canada)

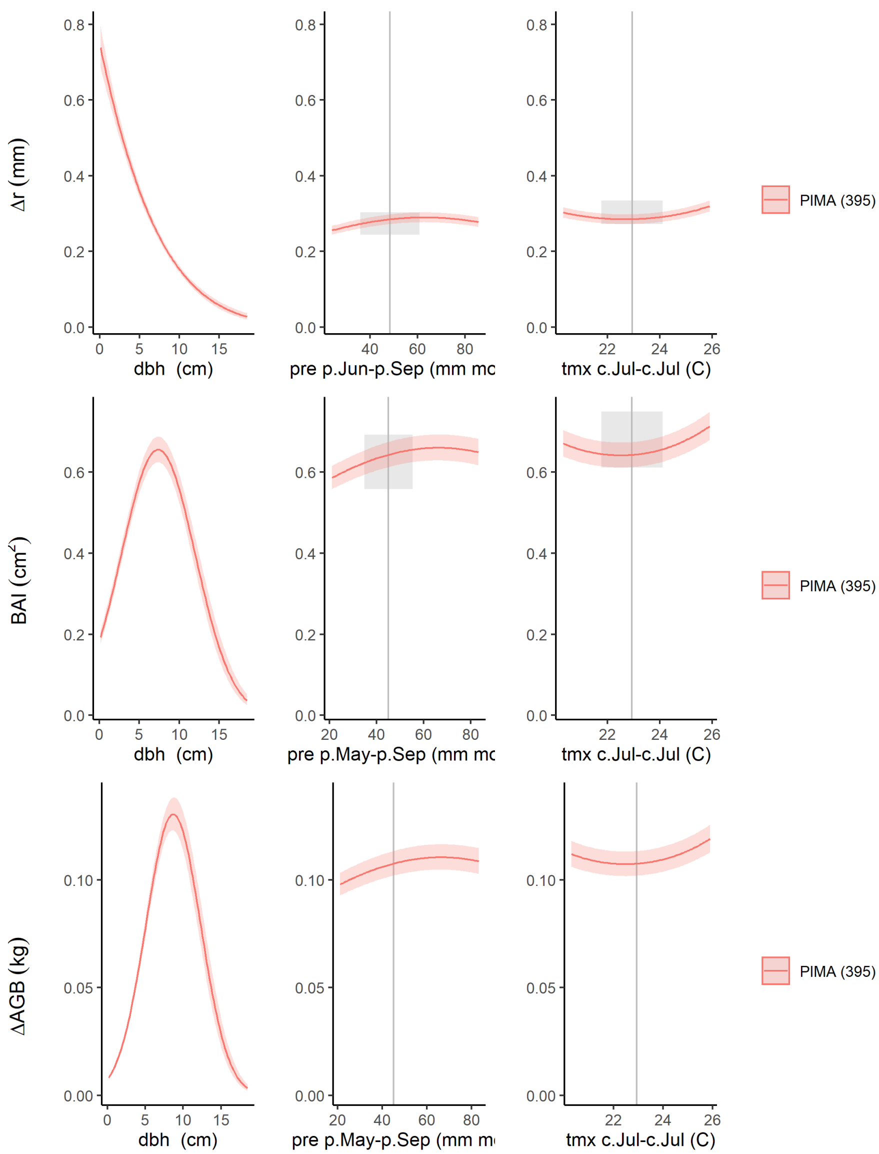

Figure S14 | Best GLS models for Scotty Creek (NW Territories, Canada) for all three growth metrics: Δr, BAI, and ΔAGB. Precipitation and temperature group variables are as selected by *climwin*. For each species, relationships are plotted if included in top model, with dashed lines indicating terms that do not significantly improve the model (relative to a model without). Vertical grey lines indicate the long-term mean for the climate variable, shading indicates 1 SD.