Tree-Ring Analysis
Kalkalpen Nationalpark

December 2021

Responsible of the Research Project

Prof. Alfredo Di Filippo, PhD

Members of the research project

Dr. Michele Baliva, PhD

Dr. Luca Di Fiore, PhD

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Field and cartographic support

Simone Mayrhofer

Christian Fuxjäger

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TREE-RING EXPLPORA

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1. **Synthesis of the Main Scientific Findings**

- **General considerations.**
  - We found well conserved old-growth forests hosting trees 400-500+ yo.
  - Beech and conifer tree species responded differently to climate variability along the elevation gradient.
  - Our results could be used to predict changes in forest composition and productivity with climate change and the contribution of the National Park's forests to the carbon cycle and climate-change mitigation along the main environmental gradients.
- **Tree Longevity.**
  - The oldest cored tree remains the beech in Zwielauf (c. 550 yo) but exceptionally old beech trees close to 500 yo have discovered in Schirmkögel and Gamspitzgraben too, confirming the big potential of the National Park for having old trees and forests.
  - Zwielauf confirmed is high naturalness, by hosting exceptionally old fir tree (407 yo): firs older than 400 yo are extremely rare in Europe, there are only a few cases reported in literature (2 Italian Alps, 1 Croatia).
  - In general, spruce and fir can live more than 300 years in old-growth forests with beech.

    - The oldest trees in each site, especially beech and fir, showed complex growth histories, characterized by repeated suppression and release events, typical of well conserved, highly natural temperate forests.
- **Productivity changes with species and elevation.**
    - Great differences in Productivity were detected according to tree species and geographic position. Productivity was strongly connected both to elevation and aspect.
    - The low-elevation beech forest (Hütberg) showed exceptionally high productivity, comparable to hilly sites on fertile volcanic soils in central Italy.
    - Fir and beech were the most productive species
    - Spruce generally showed lower productivity than beech and fir within the same forest.
    - The only larch population sampled showed low productivity and declining trends because its low elevation.
- **Species response to climate-change.**
    - All tree species showed a good sensitivity to climate variability
    - Fir is the specie showing the most positive response to climate variability in the last decade
    - Spruce showed generalized productivity declines, especially in the last 20 years.
    - According to the analyses done so far, we can hypothesize a decline in spruce populations and an increase in fir ones in the future, under current conditions.

List of Acronyms

ABAL = *Abies alba* Mill.

BAI = Basal Area Increment

DBH = Diameter at Breast Height

FASY = *Fagus sylvatica* L.

LADE = *Larix decidua* Mill.

PIAB = *Picea abies* L.

1. Results

1.1. Tree Age, Size, and Growth Rates

A total of 202 co-dominant trees were sampled (76 at Zwielauf, 76 at Schirmkögel, 28 at Gamskitzgraben and 22 at Hütberg) building 9 site chronologies: 3 for Zwielauf, 4 for Schirmkögel, and 1 for Gamskitzgraben and Hütberg (Tab. 1). The analysis of the sampled trees showed a wide dimensional variability with a higher diameter variation registered at Zwielauf spruce stand (Table 1).

The mean correlation among trees (MC) ranks from 0.48 ± 0.06 at Zwielauf silver fir stand to 0.70 ± 0.08 at Zwielauf beech stand (Table 2).

Table 1. Characteristics of the sampled sites

SITE	LAT (°N)	LON (°E)	Elevation (m a.s.l.)	TREES	DBH [2] (cm)	EPS>0.85
Hütberg	47.7845	14.3955	750–853			
FASY				22	62 ±7 (52–78)	1843–2021
Kholersgraben	47.8145	14.4443	805–994			
FASY				28	64 ± 12 (37–82)	1690–2012
Schirmkögel	47.7818	14.4119	1088–1158			
FASY				22	59 ± 8 (43–78)	1618–2021
PIAB				16	60 ± 7 (49–76)	1864–2021
ABAL				18	60 ± 7 (49–78)	1853–2015
Schirmkögel	47.7682	14.4087	1296–1381			
LADE				20	58 ± 6 (46–71)	1835–2021
Zwielauf	47.7953	14.3338	1196–1360			
FASY				43	64 ± 9 (47–82)	1679–2021
PIAB				18	72 ± 15 (48–107)	1758–2021
ABAL				15	66 ± 14 (49–96)	1883–2021
Gamskitzgraben	47.7751	14.3720	1143–1356			
FASY				21	61 ± 10 (42–82)	1635–2021
Geisslücke	47.7941	14.4284	1191–1339			
FASY				23	66 ± 12 (45–83)	1734–2012

1: Range in parentheses; 2: Mean values and standard deviation with range in parentheses; DBH = diameter at breast height; Lat = Latitude, Lon = Longitude; Trees = Number of sampled trees per site. Elevation = mean elevation of the sampled trees. EPS = Expressed Population Signal.

Table 2. Tree–ring statistics of the four study sites. Ring width and Basal area increment (BAI) values are referred to the period with Expressed population signal (EPS) and to the common 50–year period (1972–2021; bold). MC = mean correlation between trees; MS = Mean Sensitivity, AC1 = First order Autocorrelation.

SITE		AGE [1] (yr)	BAI [1] (cm²/yr)	MC[1]	MS[1]	AC1[1]
Hütberg	FASY	186 ± 23 (103–218)	16.3 ± 6.0 **23.0 ± 6.0**	0.5 ± 0.09	0.3 ± 0.04	0.7 ± 0.13
Schirmkögel	FASY	323 ± 76 (175–464)	6.7 ± 4.4 **11.8 ± 3.4**	0.5 ± 0.10	0.4 ± 0.11	0.7 ± 0.11
	PIAB	242 ± 67 (160–398)	13.8 ± 2.6 **12.8 ± 2.5**	0.5 ± 0.10	0.2 ± 0.02	0.9 ± 0.05
	ABAL	231 ± 68 (145–367)	14.6 ± 5.0 **18.4 ± 4.2**	0.6 ± 0.07	0.2 ± 0.02	0.8 ± 0.10
	LADE	200 ± 63 (100–416)	13.4 ± 2.9 **14.2 ± 3.5**	0.5 ± 0.06	0.2 ± 0.03	0.8 ± 0.12
Zwielauf	FASY	291 ± 87 (91–548)	10.0 ± 7.5 **21.9 ± 7.0**	0.7 ± 0.08	0.4 ± 0.07	0.7 ± 0.09
	PIAB	244 ± 70 (94–344)	16.7 ± 4.99 **24.5 ± 4.2**	0.5 ± 0.10	0.2 ± 0.02	0.9 ± 0.05
	ABAL	245 ± 93 (106–407)	16.2 ± 8.3 **23.9 ± 9.0**	0.4 ± 0.06	0.2 ± 0.02	0.9 ± 0.03
Gamskitz-graben	FASY	291 ± 100 (94–477)	9.0 ± 5.5 **16.5 ± 4.3**	0.6 ± 0.09	0.3 ± 0.05	0.7 ± 0.11

1: Mean values and standard deviation, range in parentheses

Descriptive statistics indicate higher MS values for beech populations and homogeneous AC1 values among the 9 chronologies. Beech showed a maximum value for MS, ranging from 0.42 ± 0.11 at

Schirmkögel to 0.37 ± 0.07 at Zwielauf, opposite to the AC1 that has lower values ranging from 0.66 ± 0.09 at Zwielauf to 0.75 ± 0.11 at Schirmkögel (Table 2), which indicate a higher common signal and lower year-to-year growth variability, respectively.

Although beech mean age was higher at Schirmkögel (323 ± 76) than Zwielauf (291 ± 87), the latter showed a higher maximum age of 548 years. In addition, all sites and tree species (FASY, PIAB, ABAL, LADE) showed maximum ages higher or close to 400 years and a mean age above 200 years, spanning over a rather broad age distribution.

Both mean and maximum age were instead lower for Hütberg beech population. Tree growth, quantified with BAI, differed among the sites, reaching maximum growth rates in the overall period at Zwielauf silver fir population (23.48 ± 9.07 cm^2yr^{-1}) and minimum at Schirmkögel beech population (6.74 ± 4.49 cm^2yr^{-1}).

Except for spruce in Schirmkögel stand, both sites and species showed higher values on the common 50-year period of analysis (1972–2021; Table 2).

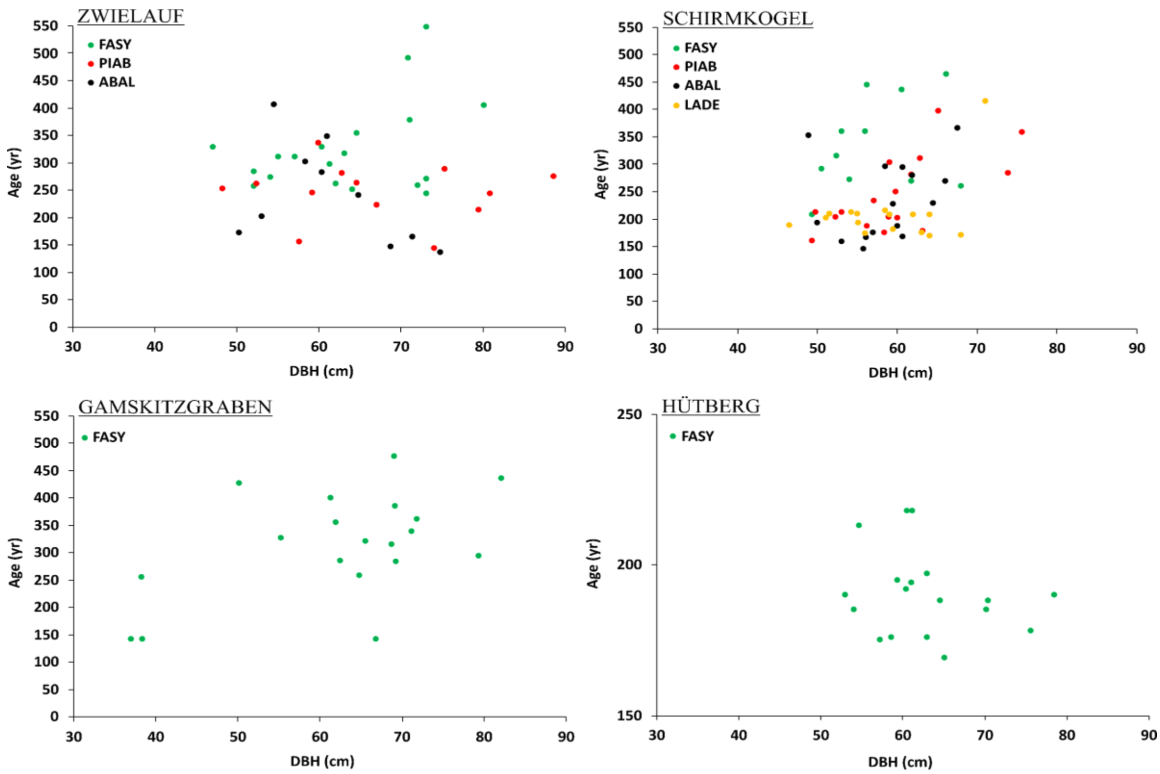


Figure 1. The relationship between diameter at breast height (DBH) and age (number of years, yr) grouped by site. No significant age-dbh relationship was detected using linear regression. Only samples with pith were used. Different colors identify species (green–FASY; red–PIAB; black–ABAL; orange–LADE) within the same site.

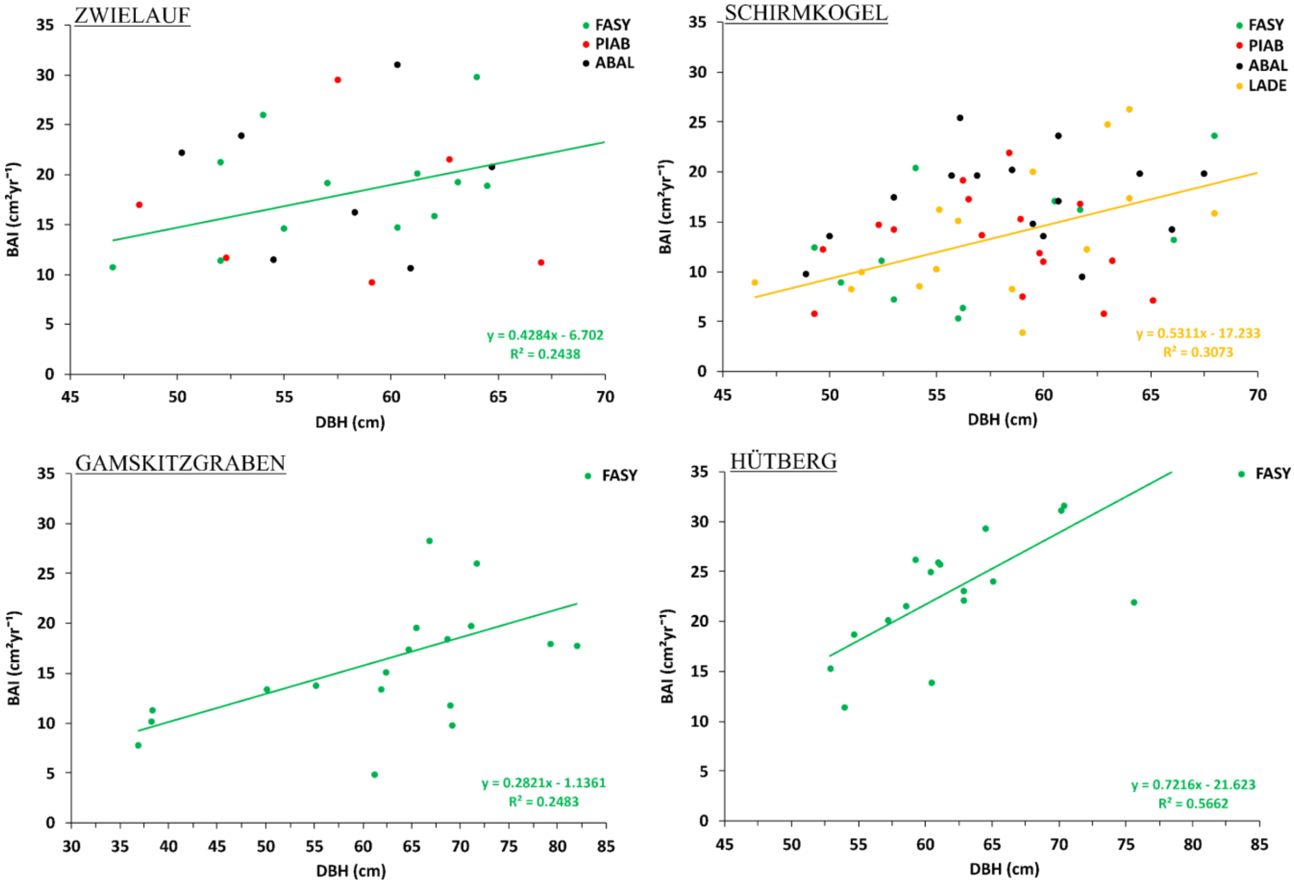


Figure 2. Linear regression between BAI (1972–2021) vs. trees age by site, modeled by a simple linear regression. Only samples with pith were used. Continuous lines represent a significant regression ($p < 0.05$), whose equations are reported in the plot with color corresponding to the species (green–FASY; red–PIAB; black–ABAL; orange–LADE).

The age structure of dominant/codominant trees showed a rather continuous recruitment, with the absence of synchronized regeneration peaks, which may suggest that natural dynamics have structured all populations in each site, moreover, highlighted by no significant age–DBH relationship (Figure 1). Considering DBH as a predictor of BAI (1972–2021), relationships were significant and older trees showed higher growth rates in beech stands excluding Schirmkögel where the relationship becomes significant for larch (Figure 2).

3.2 *Productivity Trends*

Comparing Raw BAI chronologies by species, beech stands showed similar patterns along the elevation gradient with a common constant increasing trend until the end of the 70s, followed by a less steep increase for Hütberg, Zwielauf and Gamskitzgraben (Figure 3). On the contrary, Schirmkögel showed a decreasing trend during the last 50 years, resulting in actual BAI values much lower (less than half) than the other sites. Despite these differences, over the last 100–year the sites showed a strong intra-annual variability synchronization, roughly scaled according to the elevation of each site (Figure 3b). This pattern is confirmed also by the intraspecific teleconnection between mean standardized (50–year spline) ring width chronologies of the six beech study sites, referred to the common 50–year period (1972–2021) (Table 3a).

Intraspecific teleconnection showed higher values in Gamskitzgraben vs Zwielauf (0.94) and Gamskitzgraben vs Geisslücke (0.92) while the lowest values were those between Hütberg and the other sites, except for Kholersgraben (Table 3a).

Spruce mean BAI trends were stable until the early 1940s for both Zwielauf and Schirmkögel, followed by a fairly constant and still ongoing decreasing trend at Schirmkögel (Figure 4a). Conversely at Zwielauf, BAI showed an increasing trend, associated with higher interannual values and variability, culminated in the early 1990s, followed by a decreasing phase later stabilized starting mid–2000s (Figure 4).

Despite mean BAI values over the common 50-year period of analysis resulted double at Zwielauf compared to Schirmkögel (Table 2), teleconnection between mean standardized (50-year spline) ring width PIAB chronologies showed a common climatic signal with high correlation values (Table 3b).

Contrary to spruce populations, silver fir populations showed similar productivity trends between Zwielauf and Schirmkögel (Figure4). Silver fir mean BAI chronologies over the last common 100-year showed a stable initial phase with higher mean BAI values in Schirmkögel, followed by an increasing trend and still ongoing phase that began in the early 1980s (Figure 4b).

Increasing productivity trends resulted much more sudden at Zwielauf with currently higher mean BAI values compared to Schirmkögel (Table 2), which instead showed a constant increasing trend.

Larch mean BAI temporal variation at Schirmkögel showed an initial increasing phase followed by a decreasing period (1860–1900; Figure5). An increasing trend started at the beginning of the 1900s, culminating at the end of the 1980s, when a decreasing phase began and still ongoing (Figure 5b).

Comparing raw BAI chronologies of the different species by site, a divergent trend was observed between silver fir and other species both at Schirmkögel and Zwielauf stand (Figure7).

At Zwielauf spruce showed an initial increasing trend culminated at the beginning of 1990s, followed by a decreasing phase which stabilized in the mid-2000s. On the contrary showed an increasing trend with a steeper phase until 1960s.

Silver fir in Zwielauf showed an initial stable trend until the end of 1960s followed by an increasing trend still ongoing with higher mean BAI values compared to other species (Figure7a). Despite these different trends, interspecific teleconnection showed higher correlation value between silver fir and spruce, while beech displayed a lower value both with spruce and silver fir (Table 4a).

Table 3. Intraspecific teleconnection between mean standardized (50–year spline) ring width chronologies of the study sites referred to the common 50–year period (1972–2021). Different colors were used to identify different species: a) FASY = green; b) PIAB = red; c) ABAL = black.

a) SITE	Hütberg	Kholersgraben	Schirmkögel	Zwielauf	Gamskitzgraben	Geisslucke
Hütberg		0.73	0.45	0.52	0.52	0.54
Kholersgraben	0.73		0.79	0.81	0.81	0.83
Schirmkögel	0.45	0.79		0.89	0.88	0.83
Zwielauf	0.52	0.81	0.89		0.94	0.91
Gamskitzgraben	0.52	0.81	0.88	0.94		0.92
Geisslucke	0.54	0.83	0.83	0.91	0.92	

b) SITE	Schirmkögel	Zwielauf
Schirmkögel		0.74
Zwielauf	0.74	

c) SITE	Schirmkögel	Zwielauf
Schirmkögel		0.74
Zwielauf	0.74	

Table 4. Interspecific teleconnection between mean standardized (50–year spline) ring width chronologies referred to the common 50–year period (1972–2021): a) Zwielauf; b) Schirmkögel (italic). Different colors were used to identify different species: FASY= green; PIAB = red; ABAL = black; LADE = orange.

a) Zwielauf	FASY	ABAL	PIAB
FASY		0.25	0.21
ABAL	0.25		0.61
PIAB	0.21	0.61	

b) *Schirmkögel*	FASY	ABAL	PIAB	LADE
FASY		0.32	0.23	0.19
ABAL	0.32		0.61	0.33
PIAB	0.23	0.61		0.72
LADE	0.19	0.33	0.72	

At Schirmkögel all studied species (ABAL, PIAB, FASY and LADE) showed an initial stable trend ended at the beginning of 1990s, followed by a decreasing trend for spruce, beech and larch and an increasing trend for silver fir with higher mean BAI values compared to the other species (Figure7b).

Spruce and larch in Schirmkögel stand, showed both a common growth pattern over the last 100–year period and higher interspecific teleconnections correlation value (0.72), between studied species (Table 4b).

Growth histories related to the oldest dated trees of each species by site (Figure 8), showed a common initial phase with reduced growth levels for all studied trees, with the exception of the beech found in Hütberg (Figure 8a) and the spruce found in Schirmkögel (Figure 8a), followed by a wide multi-decadal variation in growth levels of each tree.

Multi decadal variation showed similar pattern between beech of different sites and similar trend in all species in two different multi-decade intervals, that between the early 1800s and the early 1900s and the one between the early 1900s and the early 2000.

In recent decades silver fir trees, both for Schirmkögel and Zwielauf stand (Figg. 8g-8h), showed an opposite increasing growth trend compared to other tree species that instead displayed a constant decreasing trend.

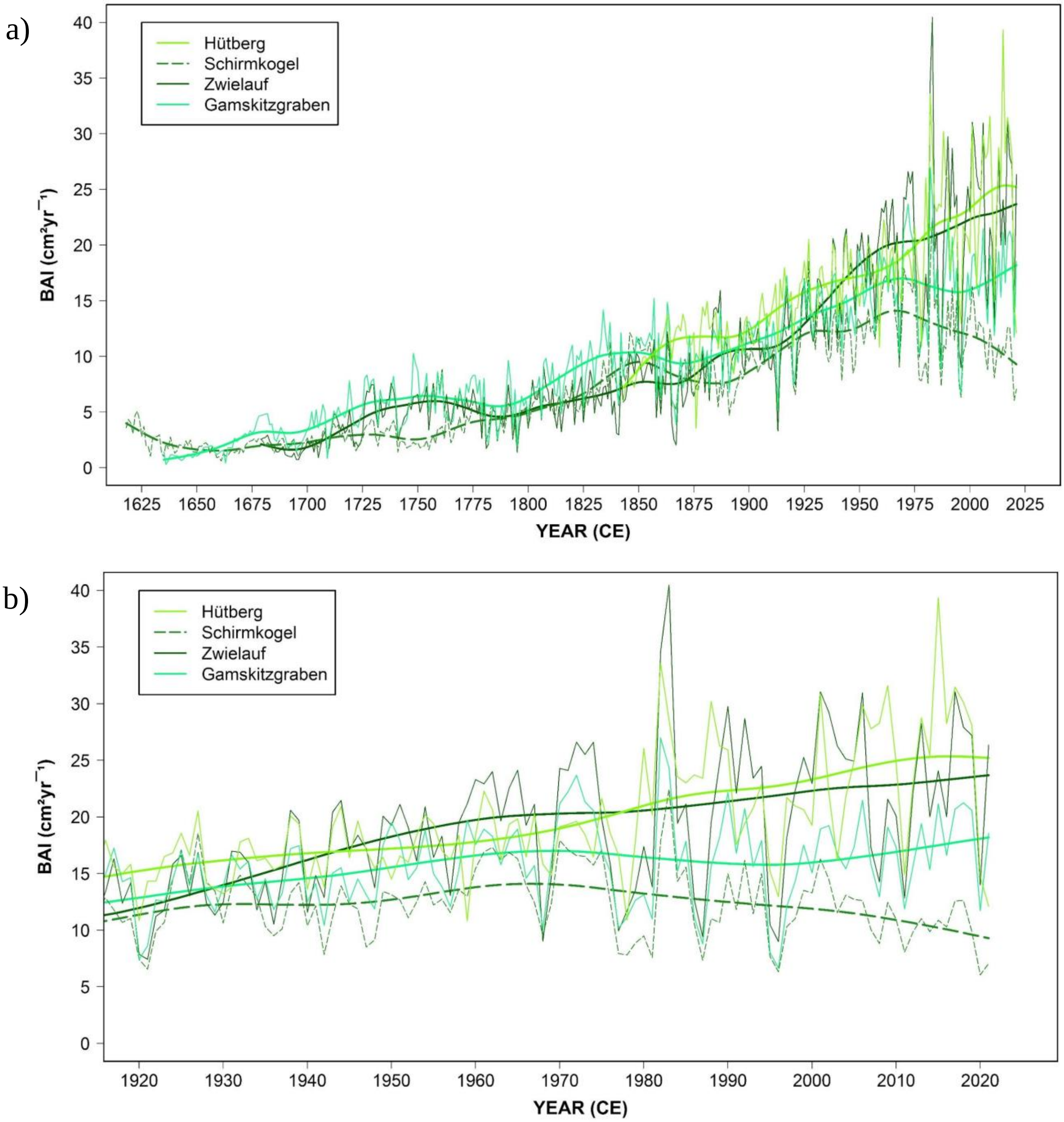


Figure 3. Comparison between mean beech BAI chronologies fitted by 50-year cubic smoothing spline, validated according to their EPS (a) and to the common 100–year period (b).

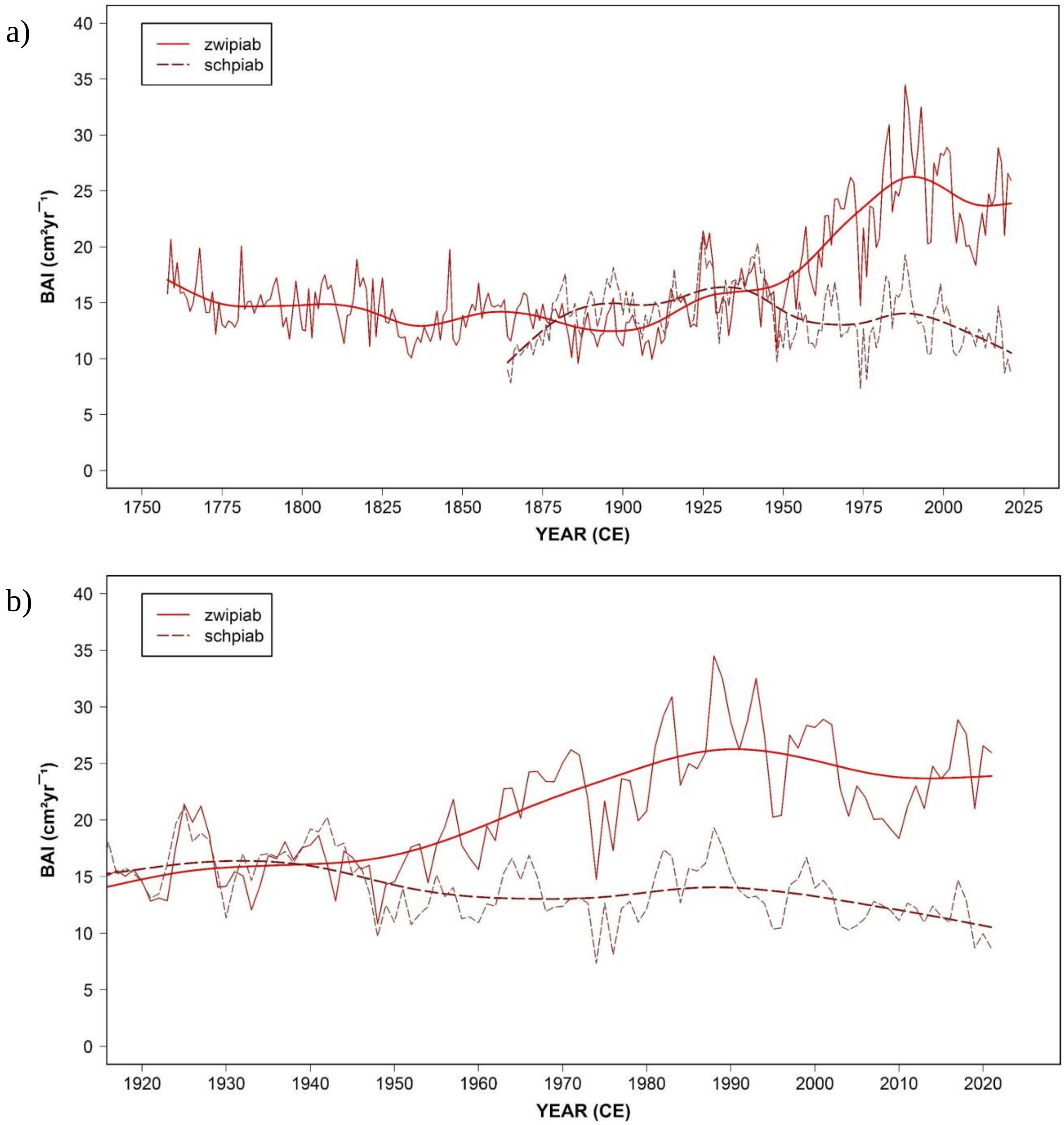


Figure 4. Comparison between mean spruce BAI chronologies fitted by 50-year cubic smoothing spline, validated according to their EPS (a) and to the common 100–year period (b).

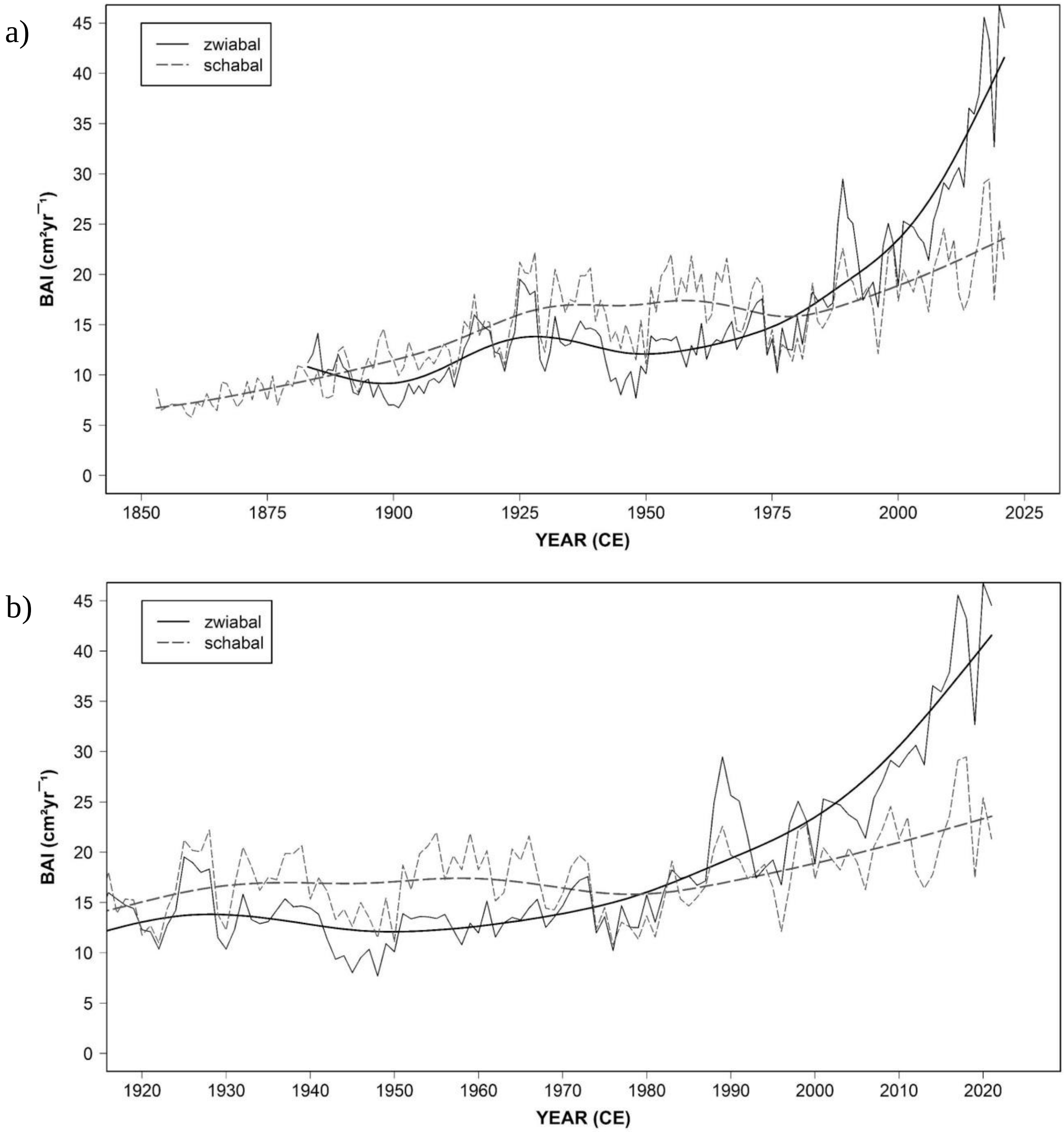


Figure 5. Comparison between mean silver fir BAI chronologies fitted by 50-year cubic smoothing spline, validated according to their EPS (a) and to the common 100–year period (b).

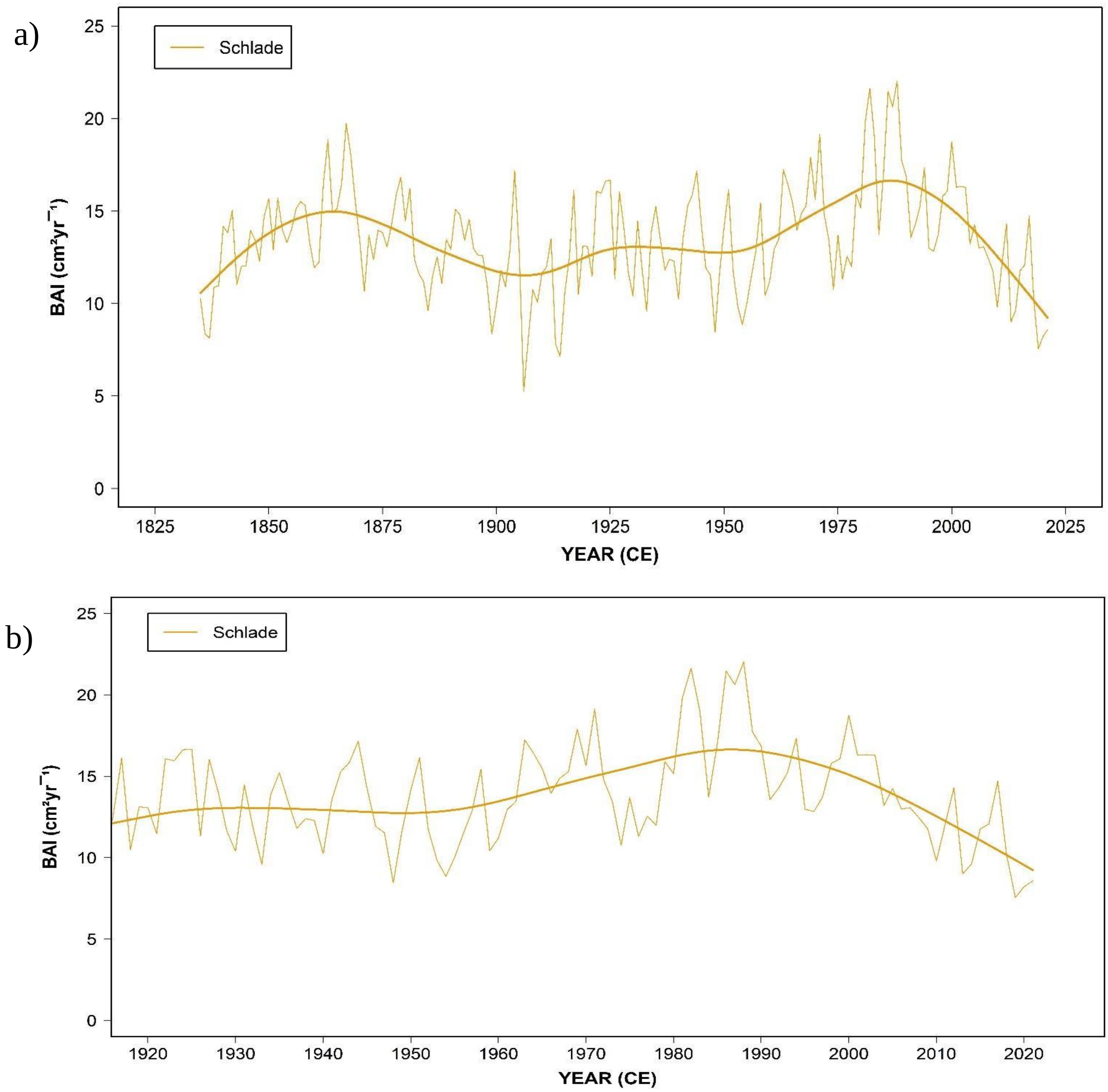
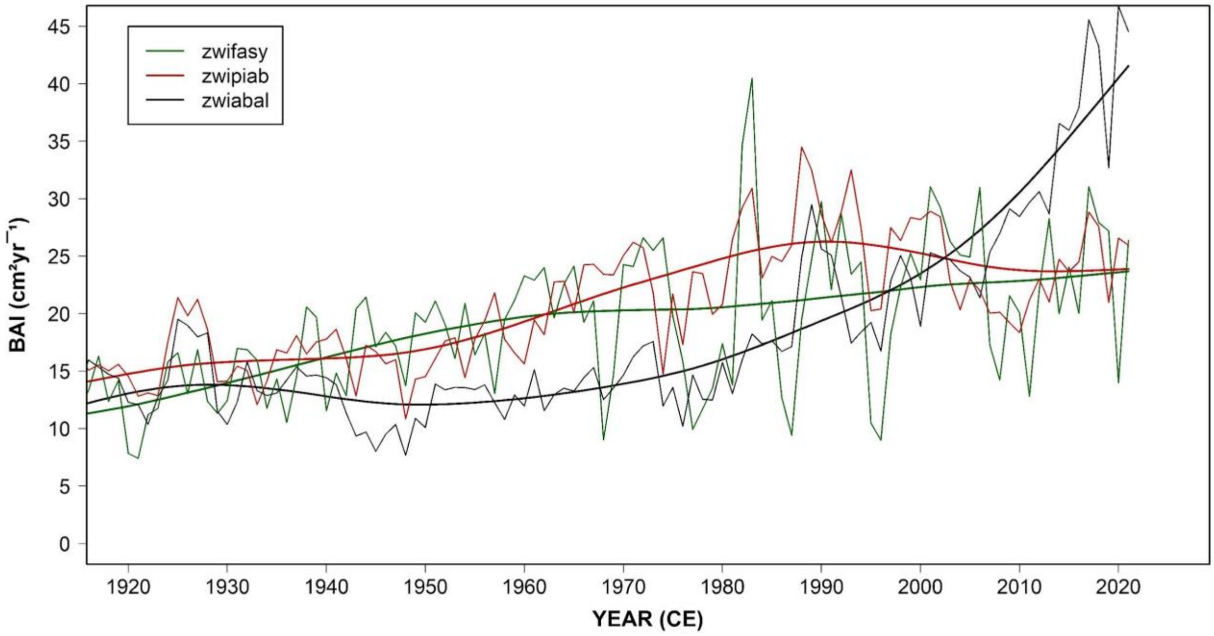


Figure 6. Larch mean BAI chronology fitted by 50-year cubic smoothing spline, validated according to their EPS (a) and to the common 100–year period (b).

a)



b)

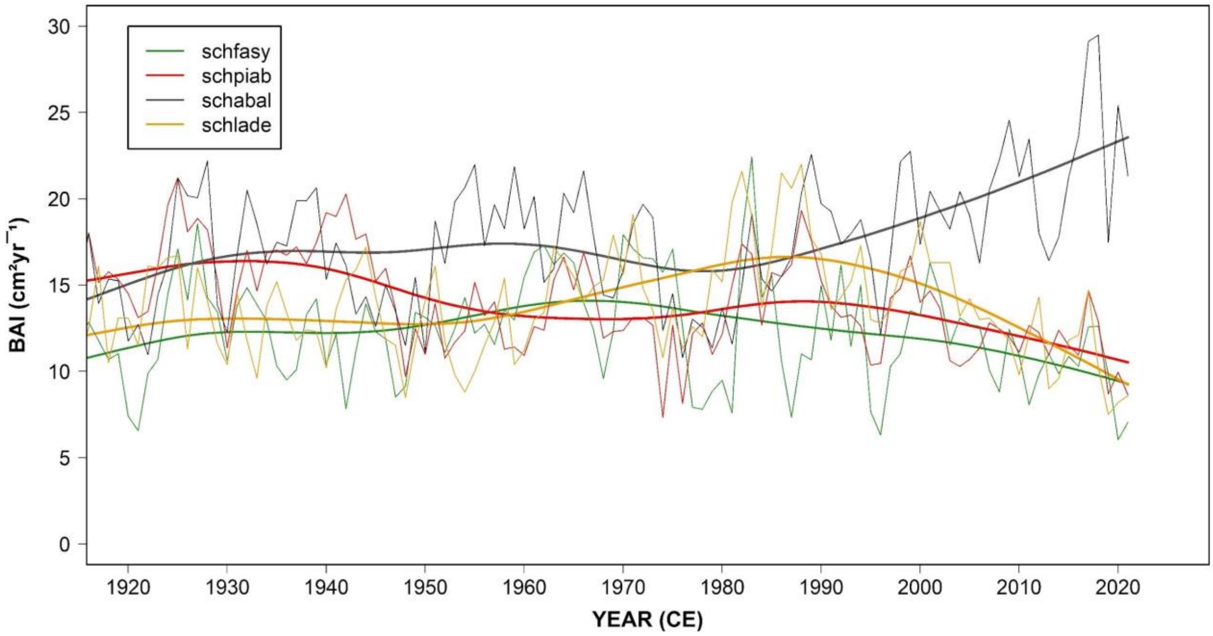
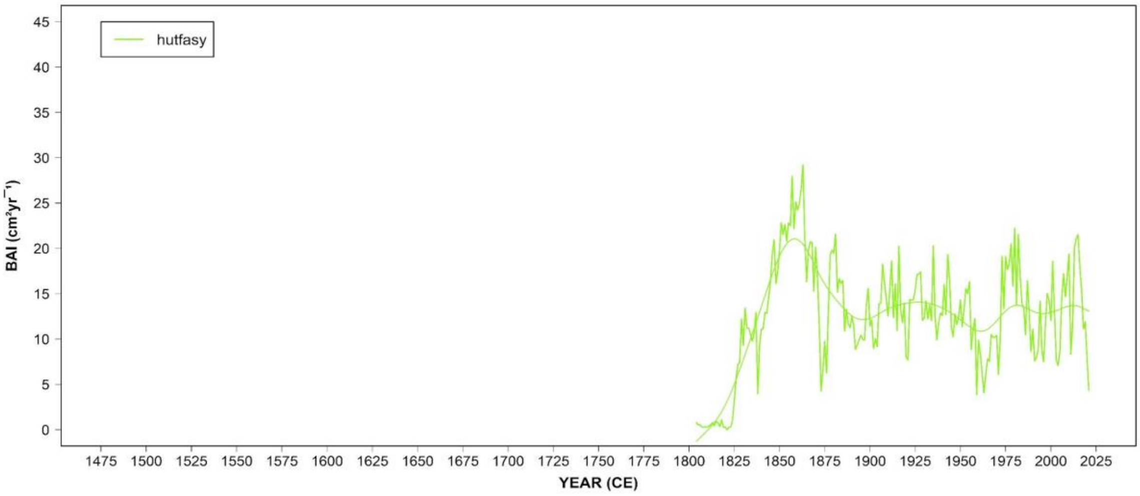


Figure 7. Comparison between mean site BAI chronologies fitted by 50-year cubic smoothing spline: a) Zwielauf; b) Schirmkögel. Different colors were used to identify different species: Beech= green; Spruce = red; silver fir = black; Larch = orange.

a)


hutfasy
BAI (cm²yr⁻¹)
YEAR (CE)
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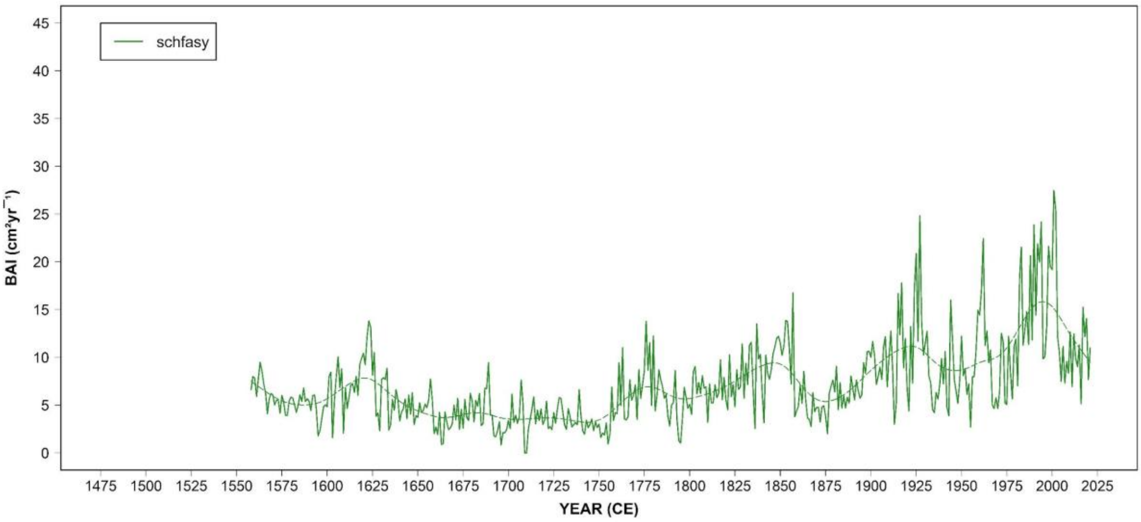
1475 1500 1525 1550 1575 1600 1625 1650 1675 1700 1725 1750 1775 1800 1825 1850 1875 1900 1925 1950 1975 2000 2025

b)


schfasy
BAI (cm²yr⁻¹)
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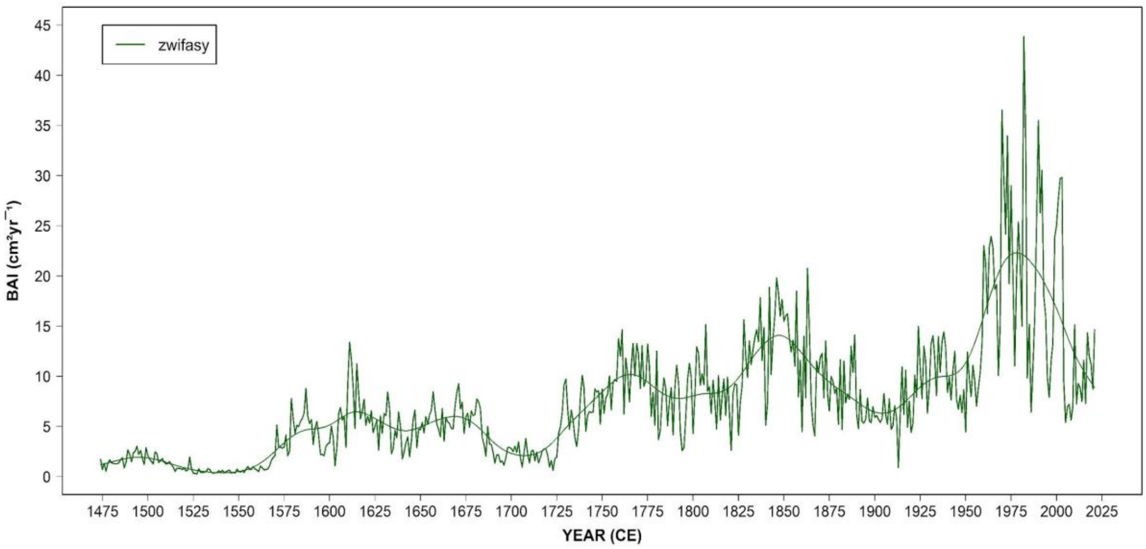
c)


zwifasy
BAI (cm²yr⁻¹)
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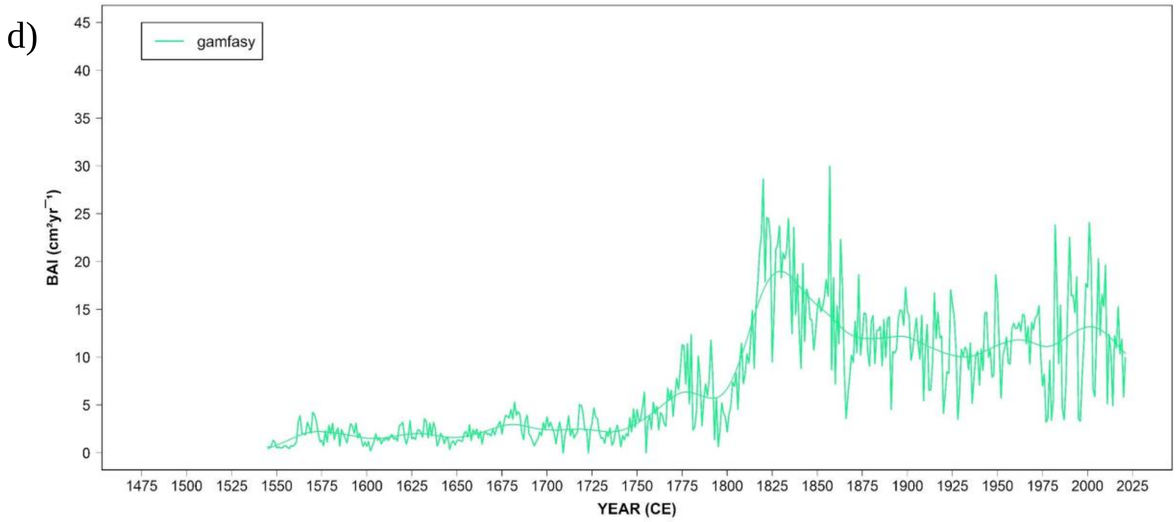
d)
gamfasy
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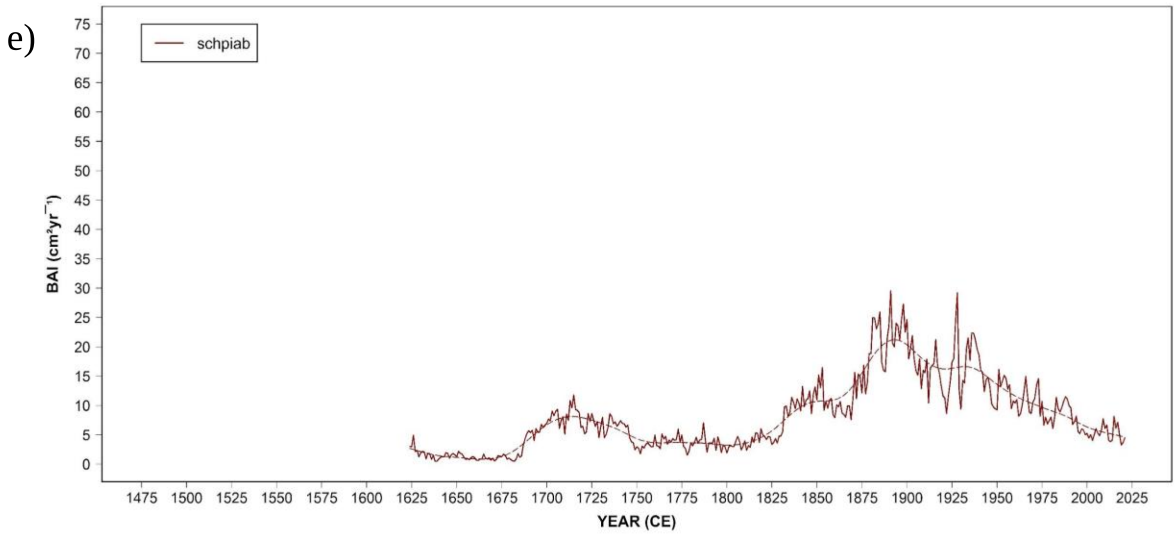
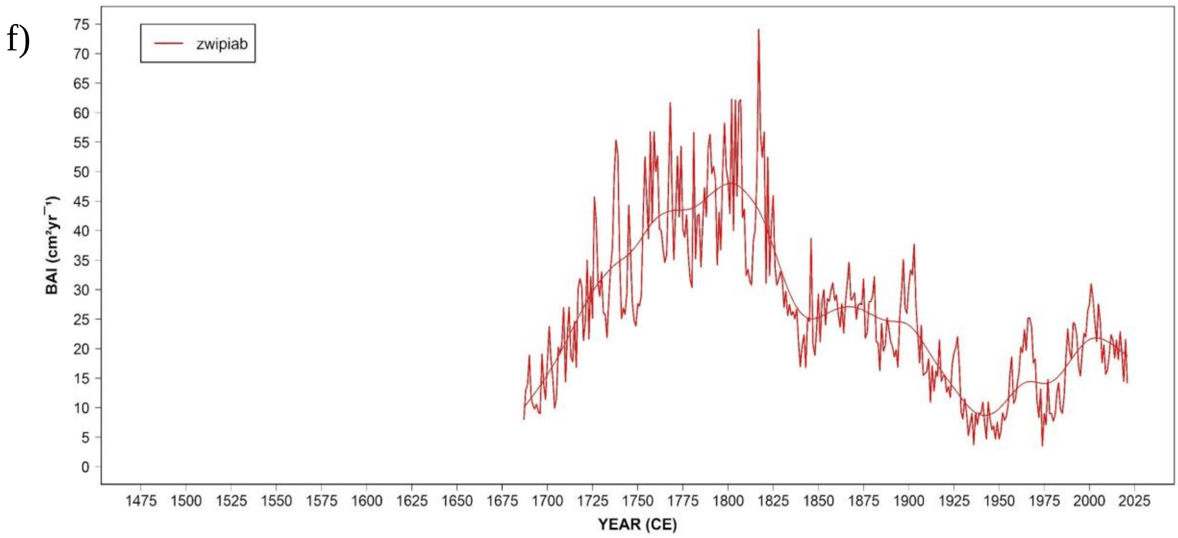
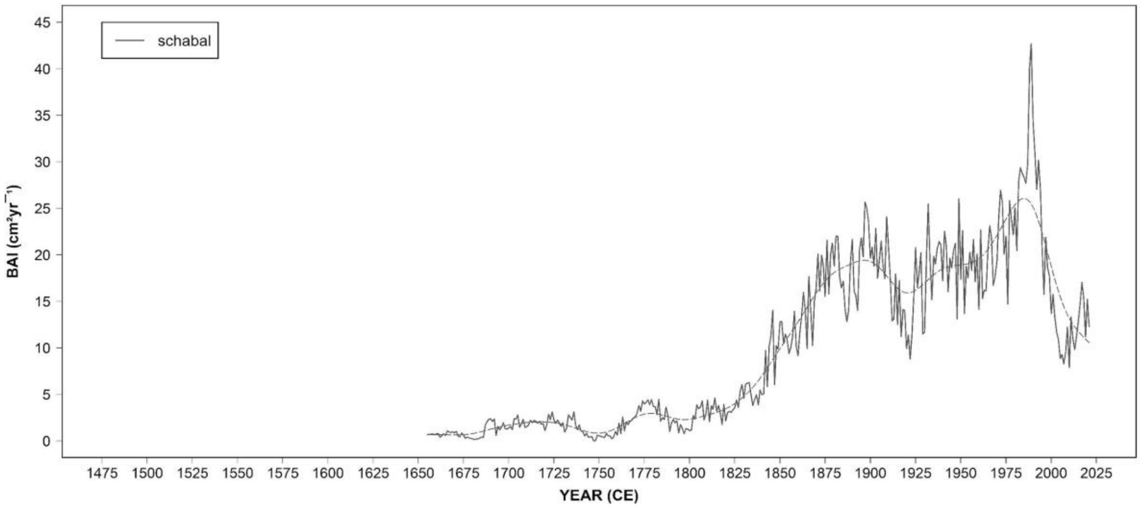
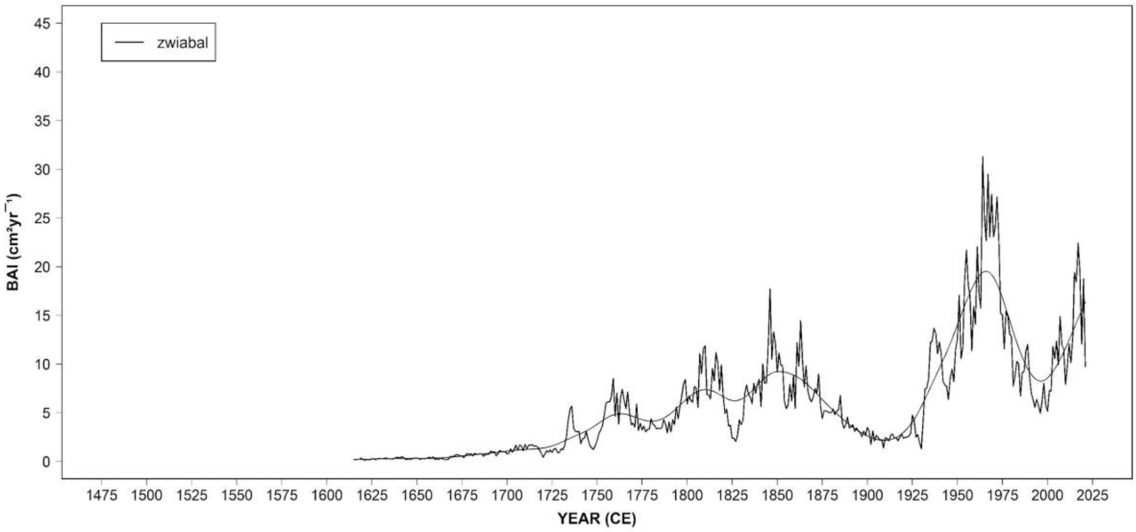

e)
schpiab
BAI (cm²yr⁻¹)
YEAR (CE)


f)
zwipiab
BAI (cm²yr⁻¹)
YEAR (CE)

g)



h)



i)

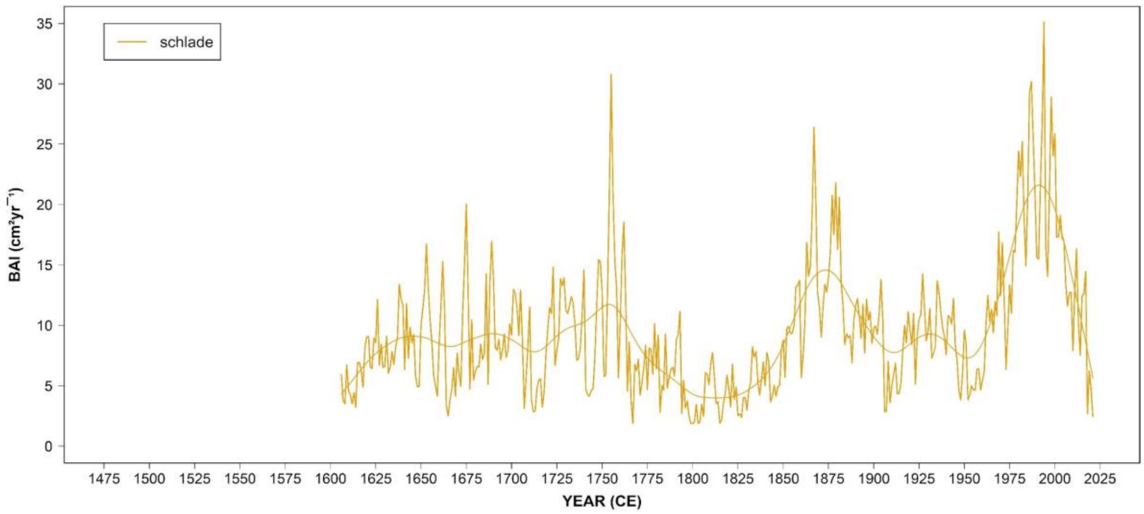


Figure 8. Raw BAI chronologies of the oldest dated trees per site, fitted by 50-year cubic smoothing spline: a) Beech; b) Beech; c) Beech; d) Beech; e) Spruce; f) Spruce; g) Silver fir; h) Silver fir; i) Larch.

Materials and Methods

3.1. Study sites

Kalkalpen National Park (Limestone Alps National Park) was established in 1997, within the Northern Limestone Alps Mountain range, in the state of Upper Austria (AT). It is relatively densely covered by shrublands and forests (81%), where mainly beech (*Fagus sylvatica* L.), spruce (*Picea abies* L.) and silver fir (*Abies alba* Mill.) form pure or mixed forests still actively managed or unmanaged due their inaccessibility (Mayrhofer et al., 2015). Forest cover spans the lower elevation areas (~350 m a.s.l.) up to ~ 1500 m a.s.l., while the highest peak reaches almost the 2000 m a.s.l. Although the elevation range is not excessively high, the area morphology is particularly complex, with a succession of large valleys surrounded by smaller and deeper valleys and high cliffs.

In this context, four different sites were selected covering a high environmental gradient from low- to high-elevation forests, chosen among the most intact ones (Table 1): Zwielauf (ZWI), Schirmkögel (SCH), Gamskitzgraben (GAM), and Hütberg (HUT). Overall, four different tree species were sampled: *Fagus sylvatica* L. (FASY), *Picea abies* L. (PIAB), *Abies alba* Mill. (ABAL) and *Larix decidua* Mill. (LADE). Additionally, two more stands sampled in 2013AD, Geisslücke (GEI) and Kholersgraben (KHO), were included to better define intra/inter–specific relations and investigate climatic common signals between sites and species at different elevation.

3.2. *Tree–Ring Data Collection and Analysis*

Using a dendroecological approach, each sampled trees was cored using an increment borer, collecting an associated set of metadata: Diameter at breast height (DBH), GPS coordinates and elevation. At least 15 trees per site were cored taking one sample at breast height (about 1.3 m from the ground; Fritts, 1976), on the uphill side of the stem. The beech trees sampled in ZWI updated the existent chronology developed during the previous field campaign in 2013, which also interested Geisslücke and Kholersgraben sites, where 28 and 21 trees were sampled respectively.

In the laboratory, all increment cores were mounted, sanded, and surfaced with scalpels and tree–ring chronologies were developed from wood samples using standard dendrochronological procedures (Stokes and Smiley, 1968). Tree–ring widths were measured to the nearest 0.01mm using a Computer Controlled Tree Ring Measuring Device (CCTRMD) interfaced with the software CATRAS (Aniol, 1983 and 1987). For conifer species (*Picea abies*, *Abies alba* and *Larix decidua*) we also measured earlywood and latewood widths, subjectively distinguished according to the sharp transition between large thin–walled earlywood cells and the small thick–walled latewood cells.

Each measure was cross–dated and checked both visually and statistically (via CATRAS). Cross-dating accuracy was checked using the COFECHA software (Holmes, 1983) and statistical parameters commonly used in dendrochronology were used to investigate sensitivity of the species to environmental factors: 1) the mean sensitivity (MS), defined as the mean percent change from each measured yearly ring value to the next; 2) the first order autocorrelation (AC1), the correlation of each value in a time series with the previous one using thus a time lag of one year (Fritts, 1976).

The reliability of each chronology was quantified using the Expressed Population Signal (EPS), a measure of how the mean chronology derived from the sampled trees represents a hypothetical infinitely replicated chronology. A chronology was considered reliable and then used for the following analyses starting from the year when the EPS was higher than 0.85.

Intraspecific teleconnection (correlation of chronologies from distant sites) and interspecific teleconnection (correlation of chronologies from different species within the same site), were performed to investigate common climatic signal with a focus on a common 50-year period (1972-2021). To remove the high-frequency variability connected to non-climatic factors, each ring-width chronology was standardized fitting a 50 years-frequency spline.

Tree–ring width time series were used to calculate basal area increment (BAI; a proxy for annual biomass production) using the dplR package in R (R Core Team, 2021). Compared to ring width, BAI is less influenced by the increase of the stem size over time (Biondi and Qeadan, 2008). Individual raw BAI series were averaged to produce a raw BAI site chronology to explore productivity trends. We analyzed the relationships between the individual BAI and tree age at each site and for each species. All calculations were performed using the R software.

2. References

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