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Synopsis and climatological interpretation of Central European tree-ring sequences

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Abstract

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The basis for a computation of yearly weather patterns, tree-ring width and maximum density is provided by chronologies from a number of sites with oak, beech, fir and spruce: Chronologies of maximum density include several sites with fir and spruce, all in the temperate region of southern Central Europe, at elevations between 250 and 1600 m a.s.l. The range of chronologies includes all ecological sites in which the four species widely occur. A uniform statistical analysis of the chronologies allows synoptic evaluation of annual extreme values (pointer values) within an altitudinal gradient in relation to climatic factors. A phenological approach allows year-by-year comparison of similar patterns of extreme values with weather diagrams. Pointer value patterns are usually specific to tree-ring parameters or sometimes to species, sites or regions. The most influential factor for maximum density of latewood in conifers on sites above 500 m a.s.l. are the mean daily temperatures in summer. Therefore many pointer value patterns are similar over large areas. The effects of weather on tree-ring width are much more specific. Some growth patterns result from very cold periods in winter, some from low precipitation in early summer. The relationship between late frosts and growth patterns is detectable but often can not be verified due to lack of local meteorological data. This heterogeneity explains why ring width patterns do not cross date so well and why pointer value patterns of ring width usually occur only over quite small areas.

Extensive geographical pointer value patterns can only be explained climatologically under three assumptions: 1. That living trees have become very well adapted to their sites, all trees unable to adapt sufficiently being eliminated during stand development; 2. that their inter annual reactions are an expression of a deviation from mean climatological conditions at the specific sites and 3. that latewood tracheids in conifers live several months so that general weather patterns are expressed in pointer year patterns.

Key words: Dendroclimatology, pointer values, ring width, maximum density, Central Europe, transects, *Picea abies*, *Abies alba*, *Fagus sylvatica*, *Quercus robur*, *Quercus petraea.*

Introduction

Since Zittwitz (1939) and Wittke (1940) published their diploma theses numerous studies concerning dendroecological questions have been conducted on trees growing in Central Europe with a temperate, humid climate. Time series analysis (response functions) in low land areas in Central Europe have not produced conclusive results about the annual relationship between growth ring development and climate (Wellenhofer 1948; Eckstein 1969; Spiecker 1990). Consequently, studies turned to the dendroclimatological analysis of single years. All the studies mentioned below aimed particularly at finding dendroclimatological explanations for the most exceptional tree rings, usually the narrowest. The question of climatic influence is often difficult to resolve through a synoptic approach to their findings, because different authors used different definitions of the term "extreme values". These definitions were influenced by the factors listed below.

Bronzini et al. 1989, Neuwirth 1998, and Schweingruber et al. 1991 used visual identification of extreme values. Z-transformations according to Cropper (1979) were applied by Bräuning 1998, Kienast 1985, Rolland et al. 2000, Z'Graggen 1992. Mean curves were studied e.g. by Becker 1987, Peticolas 1998 and others, but the authors standardized the curves differently. Often, the interval trends (termed pointer years in the original publications) were also computed (Desplanque 1997; Kelly et al. 1989; Peticolas 1998). In a critical study of the various procedures for pinpointing extreme values, Meyer 1998/99 came to the conclusion that, on the whole, visual identification and Z-transformations (pointer values according to Cropper 1979) furnish the most reliable results for the computation of growth/climate relationships.

A synoptic dendroclimatological interpretation is almost impossible when we consider the heterogeneity of sampling strategies of the mentioned authors e.g. Schweingruber et al. 1991, von Lührte 1991.

The origin of historical material requires attention. Very often, builders and craftsmen obtained their wood not only locally but also from distant sources (Vogel et al. 1996). Different reactions of species are evident in all the studies mentioned above.

All cited authors investigated ring width, some of them also maximum density (Kienast 1985; Lingg 1986), but only a few studied long-term increment changes beginning abruptly (Schweingruber et al. 1986; Worbes 1989) or the frequency of missing rings (Elling 1993).

The heterogeneity of the tree ring date base does not allow a dendroecological synopsis. Consequently, we set ourselves the following goals:

- to relate the extensive dendrochronological data recently collected (Tab. 1) to the climate on a year-by-year basis for the period 1901–1980 through the graphical representation of extreme values (single year analysis);
- to investigate the modifying effects of different weather conditions and site factors on radial increment (ring width) and cell wall growth in latewood (maximum density) of various tree species growing within an altitudinal band embracing all forest belts (250–1600 m a. s. l. in Central Europe).

Overall, this study aims at demonstrating how the documentation of pointer values can be used to reconstruct seasonal relationships between tree growth rings and climate.

Material and Methods

The study includes 53 ring width chronologies and 35 latewood chronologies (maximum density) from four tree species growing in southern Central European regions of Germany, France, and Switzerland (details are given in Table 1 and Fig. 1).

A large part of the material issued from the project "Dendrochronological analysis of climate-growth relations of five important European tree species along an east-west transect across the European Union: Vosges Mountains-Black Forest-Lorraine". We used the chronologies for the Swiss Central Plateau of Lenz et al. 1986. The chronologies for high elevations in the Jura (Chasseral) and the northern Pre-Alps (Rigi) form part of the sampling network for the Northern Hemisphere (Briffa et al. 1998). The sampling sites in France and Germany were situated within an altitudinal band from 248 to 1500 m a.s.l. (Fig. 1) and comprising three belts: low (> 500 m a.s.l.), medium (500–1000 m a.s.l.) and high (> 1000 m a.s.l.). Material from the Swiss Central Plateau belongs to the medium belt and that from the Jura and the northern Pre-Alps the high elevation belt. The sites of this last class lay 200–300 m below the upper forest limit imposed by low temperature; in the northern Pre-Alps at 1900 m, in the Jura at 1700 m and in the Black Forest at 1600 m a.s.l.

All the stands examined are or once were under management.

From each site within the east-west transect, five stem discs were taken at breast height from each of five dominant trees. Ring widths were measured in 8 radii from each disc, density (by radiodensitometry) in 4 radii. In the studies by Lenz et al. 1986 and Briffa et al. 1998, 10 to 15 trees were analysed, but only 2 radii from each stem. Most of the trees had germinated in the 19th century (Tab. 1). Only for 11 of the 53 ring width chronologies was the juvenile growth phase (after 1890) included. The annual diagrams of mean daily temperatures and mean daily precipitation are based on data from the meteorological station at Basle, Switzerland (300 m a.s.l.).

For Central European conditions, the climatic differences between the lowest and the highest sites are very distinct. According to Walther and Lieth (1963), precipitation during the decisive period for ring width growth (April to June) totals around 180 mm in the lowlands, around 270 mm at medium elevations and around 330 mm at high altitudes. The mean daily temperatures in July vary from 15 °C in the lowlands to 10 °C at high elevations, while the mean vegetation period lasts approximately 7 months in the lowlands but only some 5 months at high elevations.

For ring width measurements, stem discs from the sampling sites along the east-west transect were polished with a sanding machine, using belts with grain size 220. Ring width was measured by means of device developed at the Institute for Forest Growth of the University of Freiburg. Maximum density was measured by means of radiodensitometry (Eschbach et al. 1995). As only conifers furnish density measurements, which can be interpreted climatologically, maximum densities were not measured in beech and oak. For statistical analysis of ring width and maximum density (latewood) cross dated pointer values (Schweingruber 1996) were recorded. The term is defined after Cropper 1979 (Z-values):

The mean value (x) and standard deviation (STD) for windows of five years in the chronology were computed. The value closest to the middle of the window (x) was

Tab. 1. Site characteristics, time span in years of chronologies, replication, mean values and standard deviation of the chronologies analysed. Into the altitudinal groups high H (> 1000 m a.s.l.), middle M (500–1000 m a.s.l.) and low L (< 500 m a.s.l.). Species are summarized in groups of countries (D = Germany, F = France, CH = Switzerland). The term Logo mention chronologies in Fig. 1, 3 and 4. The abbreviations of the species names are: PCAB = spruce (*Picea abies*), ABAL = fir (*Abies alba*), FASY = beech (*Fagus sylvatica*), QUPE = oak (*Quercus robur* and *Quercus petraea*). X (Maximum density) and R (ring width) mention the number of used radii and trees incorporated in a chronology.

logo	site	spec.	alt. a.s.l.	coordinates lat.	long.	exp.	slope	total length of chronology	analysed period	no. of years	no. of trees X	R	no. of radii X	R	mean value X g/cm3	R 1/100mm	standard deviation X g/cm3	R 1/100mm
FI_FD_H4	**F/D-spruce high**																	
BSH	Seehalde (D)	PCAB	1250	47°51'N	8°02'E	NNW	19%	1756 - 1995	1900 - 1995	96	5	5	20	40	0.811	134.04	0.070	25.16
BFB	Feldberg (D)	PCAB	1330	47°51'N	8°01'E	SSW	48%	1851 - 1995	1900 - 1995	96	5	5	20	40	0.828	154.06	0.080	25.89
BSB	Silberberg (D)	PCAB	1320	47°50'N	7°59'E	NE	56%	1871 - 1995	1900 - 1995	96	5	5	20	40	0.775	191.62	0.084	75.60
BSS	Schluchsee (D)	PCAB	1200	47°48'N	8°05'E	NE	30%	1932 - 1992	1932 - 1992	61	5	5	15	40	0.803	303.66	0.084	104.16
FI_CH_H4	**CH-spruce high**																	
CHAS_N	Chasseral (CH)	PCAB	1500	47°08'N	7°04'E	N	18%	1839 - 1974	1900 - 1974	75	15	15	16	16	0.768	115.43	0.061	23.78
CHAS_S	Chasseral (CH)	PCAB	1400	47°07'N	7°05'E	S	36%	1845 - 1975	1900 - 1975	76	13	13	13	13	0.789	112.57	0.082	28.98
RIGI_K	Rigi Klösterli (CH)	PCAB	1400	47°02'N	8°29'E	N	36%	1805 - 1975	1900 - 1975	76	14	14	14	14	0.787	130.21	0.077	29.69
RIGI_S	Rigi Staffel (CH)	PCAB	1600	47°03'N	8°29'E	SW	47%	1840 - 1975	1900 - 1975	76	13	13	13	13	0.752	158.15	0.074	30.57
BU_FD_H2	**F/D-beech high**																	
BFB	Feldberg (D)	FASY	1330	47°51'N	8°01'E	SSW	48%	1840 - 1995	1900 - 1995	96	–	5	–	40	–	132.75	–	51.00
BSB	Silberberg (D)	FASY	1320	47°50'N	7°59'E	NE	56%	1822 - 1995	1900 - 1995	96	–	5	–	40	–	92.24	–	42.86
FI_FD_M4	**F/D-spruce middle**																	
VAB	Aubure (F)	PCAB	1080	53°34'N	8°00'E	S	30%	1904 - 1994	1904 - 1994	91	5	5	20	40	0.840	221.74	0.088	93.68
BSIS	Sirnitz SW (D)	PCAB	930	47°48'N	7°45'E	SW	25%	1844 - 1995	1900 - 1995	96	5	5	20	40	0.912	183.92	0.070	54.48
BSIW	Sirnitz NE (D)	PCAB	940	47°47'N	7°45'E	NE	50%	1867 - 1995	1900 - 1995	96	5	5	20	40	0.830	231.76	0.089	49.85
BVS	Villingen-S. (D)	PCAB	880	48°02'N	8°21'E	NE	6%	1897 - 1994	1900 - 1994	95	5	5	20	40	0.888	259.53	0.070	80.62
FI_CH_M6	**CH-spruce middle**																	
LIW	Lindenwald (CH)	PCAB	560	47°02'N	7°24'E	NWE	18%	1882 - 1979	1900 - 1979	80	14	14	28	28	0.919	228.10	0.061	56.47
RUE	Rüti b.B. (CH)	PCAB	555	47°09'N	7°26'E	–	0%	1917 - 1979	1917 - 1979	63	13	13	26	26	0.833	399.35	0.069	98.11
WYW	Wylewald (CH)	PCAB	570	47°01'N	7°29'E	–	0%	1904 - 1979	1904 - 1979	76	12	12	24	24	0.860	254.63	0.066	87.42
TOW	Toppwald (CH)	PCAB	875	46°52'N	7°41'E	WNW	9%	1841 - 1979	1900 - 1979	80	13	13	26	26	0.895	176.84	0.054	26.27
MAD	Madiswil (CH)	PCAB	675	47°09'N	7°48'E	E	5%	1808 - 1977	1900 - 1977	78	10	10	20	20	0.910	153.67	0.057	42.52
ROG	Roggwil (CH)	PCAB	535	47°15'N	7°50'E	–	0%	1843 - 1977	1900 - 1977	78	12	12	24	24	0.909	188.39	0.048	47.62
TA_FD_M3	**F/D-fir middle**																	
BSIS	Sirnitz SW (D)	ABAL	930	47°48'N	7°45'E	SW	25%	1844 - 1995	1900 - 1995	96	5	5	20	40	0.860	249.24	0.055	63.93
BSIW	Sirnitz NE (D)	ABAL	940	47°47'N	7°45'E	NE	50%	1841 - 1995	1900 - 1995	96	5	5	20	40	0.831	231.53	0.057	50.13
BVS	Villingen-S. (D)	ABAL	880	48°02'N	8°21'E	NE	6%	1898 - 1994	1900 - 1994	95	5	5	20	40	0.863	189.12	0.050	103.97
TA_CH_M6	**CH-fir middle**																	
LIW	Lindenwald (CH)	ABAL	560	47°02'N	7°24'E	NWE	18%	1877 - 1979	1900 - 1979	80	13	13	26	26	0.897	233.30	0.046	45.82
RUE	Rüti b.B. (CH)	ABAL	555	47°09'N	7°26'E	–	0%	1899 - 1979	1900 - 1979	80	13	13	26	26	0.869	316.74	0.043	90.95
WYW	Wylewald (CH)	ABAL	570	47°01'N	7°29'E	–	0%	1885 - 1979	1900 - 1979	80	13	13	26	26	0.855	270.74	0.047	46.74
TOW	Toppwald (CH)	ABAL	875	46°52'N	7°41'E	WNW	9%	1796 - 1979	1900 - 1979	80	13	13	26	26	0.881	193.38	0.048	31.62
MAD	Madiswil (CH)	ABAL	675	47°09'N	7°48'E	E	5%	1770 - 1977	1900 - 1977	78	10	10	20	20	0.835	147.36	0.044	33.74
ROG	Roggwil (CH)	ABAL	535	47°15'N	7°50'E	–	0%	1874 - 1977	1900 - 1977	78	12	12	24	24	0.871	258.46	0.049	59.65

X = Maximum density, R = Ring width

logo	site	spec.	alt. a.s.l.	coordinates lat.	long.	exp.	slope	total length of chronology	analysed period	no. of years	no. of trees X	R	no. of radii X	R	mean value X g/cm3	R 1/100mm	standard deviation X g/cm3	R 1/100mm
BU_FD_M5	**F/D-beech middle**																	
VAB	Aubure (F) *	FASY	1080	53°33'N	7°59'E	S	30%	1860 - 1994	1900 - 1994	95	–	5	–	40	–	105.51	–	37.11
BSPS	Spirzen SW (D)	FASY	640	47°58'N	8°03'E	SW	45%	1871 - 1995	1900 - 1993	94	–	5	–	40	–	79.53	–	17.14
BSPW	Spirzen NE (D)	FASY	840	48°02'N	8°02'E	NE	20%	1862 - 1995	1900 - 1993	94	–	5	–	40	–	188.06	–	53.63
BSIS	Sirnitz SW (D)	FASY	930	47°48'N	7°45'E	SW	25%	1823 - 1995	1900 - 1995	96	–	5	–	40	–	155.41	–	45.95
BSIW	Sirnitz NE (D)	FASY	940	47°47'N	7°45'E	NE	50%	1827 - 1995	1900 - 1995	96	–	5	–	40	–	146.81	–	45.82
EI_FD_M1	**F/D-oak middle**																	
BSPS	Spirzen SW (D)	QUPE	640	47°58'N	8°03'E	SW	45%	1871 - 1993	1900 - 1993	94	–	5	–	40	–	97.32	–	14.49
FI_FD_T4	**F/D-spruce low**																	
LVT	Vitrimont (F)	PCAB	230	53°59'N	7°05'E	–	0%	1930 - 1994	1930 - 1994	65	5	5	20	40	0.874	294.29	0.075	84.86
RKS	Kaiserstuhl (D)	PCAB	270	48°03'N	7°40'E	SE	15%	1903 - 1995	1903 - 1995	93	5	5	20	40	0.941	298.68	0.093	88.69
BMTS	Münstertal (D)	PCAB	490	47°51'N	7°47'E	SW	42%	1881 - 1995	1900 - 1995	96	5	5	20	30	1.013	184.93	0.044	65.53
BSTW	Sulzbach-Tal (D)	PCAB	390	47°50'N	7°42'E	NE	43%	1890 - 1995	1900 - 1995	96	5	5	20	40	0.858	278.33	0.062	84.95
FI_CH_T1	**CH-spruce low**																	
PIE	Pieterlen (CH)	PCAB	450	47°10'N	7°20'E	N	9%	1905 - 1979	1905 - 1979	75	12	12	24	24	0.891	270.05	0.074	112.23
TA_FD_T3	**F/D-fir low**																	
RKS	Kaiserstuhl (D)	ABAL	440	48°05'N	7°41'E	NE	28%	1927 - 1995	1927 - 1995	69	5	5	20	40	0.903	320.12	0.053	76.92
BMTS	Münstertal (D)	ABAL	460	47°51'N	7°46'E	SW	34%	1864 - 1995	1900 - 1995	96	5	5	20	40	0.910	233.91	0.056	68.16
BSTW	Sulzbach-Tal (D)	ABAL	390	47°50'N	7°42'E	NE	43%	1894 - 1995	1900 - 1995	96	5	5	20	40	0.865	305.26	0.060	101.32
BU_FD_T5	**F/D-beech low**																	
LVT	Vitrimont (F)	FASY	230	53°59'N	7°05'E	–	0%	1904 - 1994	1904 - 1994	91	–	5	–	40	–	226.84	–	91.72
LAM	Amance (F)	FASY	250	54°10'N	7°02'E	–	0%	1888 - 1994	1900 - 1994	95	–	5	–	40	–	191.65	–	85.02
RKS	Kaiserstuhl (D)	FASY	270	48°03'N	7°40'E	SSE	41%	1919 - 1995	1919 - 1995	77	–	5	–	40	–	278.34	–	123.72
BMTS	Münstertal (D)	FASY	460	47°51'N	7°46'E	SW	34%	1863 - 1995	1900 - 1995	96	–	5	–	40	–	260.60	–	76.61
BMTW	Münstertal (D)	FASY	450	47°51'N	7°43'E	NE	48%	1899 - 1995	1900 - 1995	96	–	5	–	40	–	283.40	–	61.49
EI_FD_T5	**F/D-oak low**																	
LAM	Amance (F)	QUPE	250	54°10'N	7°02'E	–	0%	1911 - 1994	1911 - 1994	84	–	5	–	40	–	190.119	–	64.675
RHF	Hardt Forest (F) living	QUPE	248	52°59'N	8°16'E	–	0%	1871 - 1994	1900 - 1994	95	–	5	–	40	–	148.895	–	65.637
RHF	Hardt Forest (F) dead	QUPE	248	52°59'N	8°16'E	–	0%	1871 - 1994	1900 - 1994	95	–	5	–	40	–	154.032	–	79.247
RKS	Kaiserstuhl (D)	QUPE	380	48°05'N	7°42'E	SW	21%	1858 - 1995	1900 - 1995	96	–	5	–	40	–	159.510	–	37.838
BMTS	Münstertal (D)	QUPE	690	47°52'N	7°46'E	SW	45%	1848 - 1995	1900 - 1995	96	–	5	–	40	–	167.313	–	45.418

X = Maximum density, R = Ring width

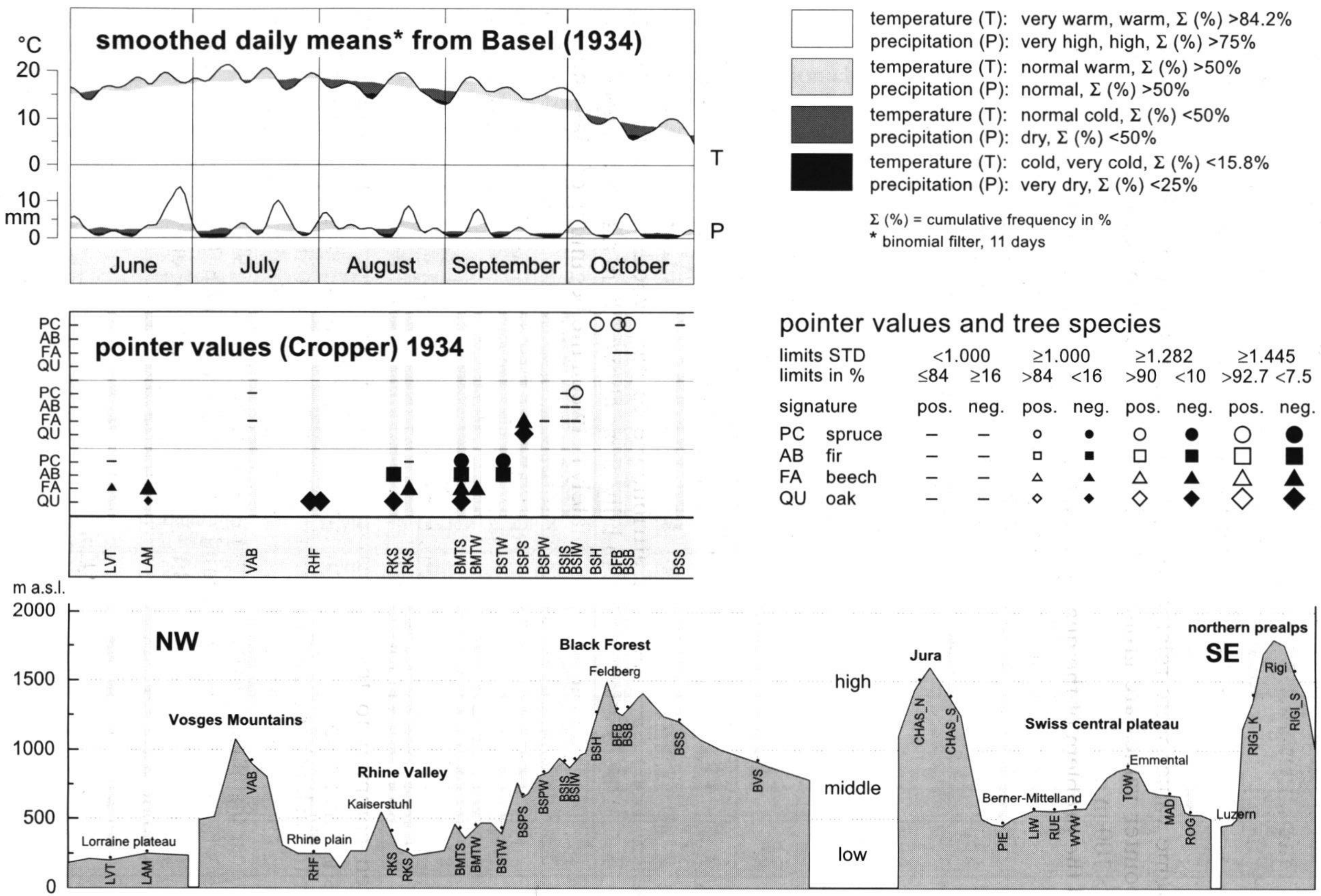


Fig. 1. Location of sites and explanation of signatures, shown for the year 1934. Presented are the climatological profile (Lenz et al. 1986), the extrem values (pointer values) in the three altitudinal zones and the position of the chronologies along the transects. Explained are the signatures used in Fig. 3 and 4 and their statistical meaning.

divided by the standard deviation (x–x) to give the pointer value, also termed Z-value. To identify the pointer values in the chronology, the synchronous values in the chronologies were summed and divided by their number.

The dendroecological interpretation of continuous sequences (Fig. 2) is based on Gleichläufigkeits-values for 1901–1980.

To present the data graphically, the annual values in chronologies have been clustered into classes; these are shown in Figure 1. If a value was statistically significant it was termed a pointer value.

The extreme values were related to a profile of elevation (Fig. 1). The classes of trend and pointer values are grouped to three 500 m spans of elevation: > 500 m, 500–100 m, > 100 m a.s.l.

To avoid the problem of the quality of meteorological records in the dendroclimatological analysis, we related all the single years of the chronologies to the verified records of the meteorological station at Basle. In this study, the term "growth" refers not to absolute ring width or maximum density but to an interval between two yearly values (pointer intervals based on Gleichläufigkeit) or an index value (pointer value).

Results

Dendroecological interpretation of continuous sequences – general remarks

The synoptic characteristics of different tree species and different parameters are shown in Figure 2. The greatest differences occur between various ring parameters. Ring width reflects weather conditions during a relatively short time at the beginning of the growth period. The time-span attributable to earlywood cells is very short, because they only live for a few weeks. In hilly areas above 500 m a.s.l. the rings develop some 80% of their total width approximately between the beginning of May and the end of June; This development takes place within only one month (approximately July) in of the upper tree line, between 1400 and 1800 m a.s.l. (Kern and Moll 1960). Consequently, the ring width chronologies from high elevations rarely or never correlate with those from lowland areas.

The maximum density of conifers is an expression of cell wall growth. It occurs during the second half of the vegetation period. The period over which climatic conditions are integrated common to the species studied is longer than for ring width. The chronologies of maximum density from the network of sampling sites are therefore more similar to each other than those of ring width (Fig. 2a and 2b).

We confirm all observations that elevation influences ring width more strongly than the geographical distance between sampling sites (Desplanque 1997).

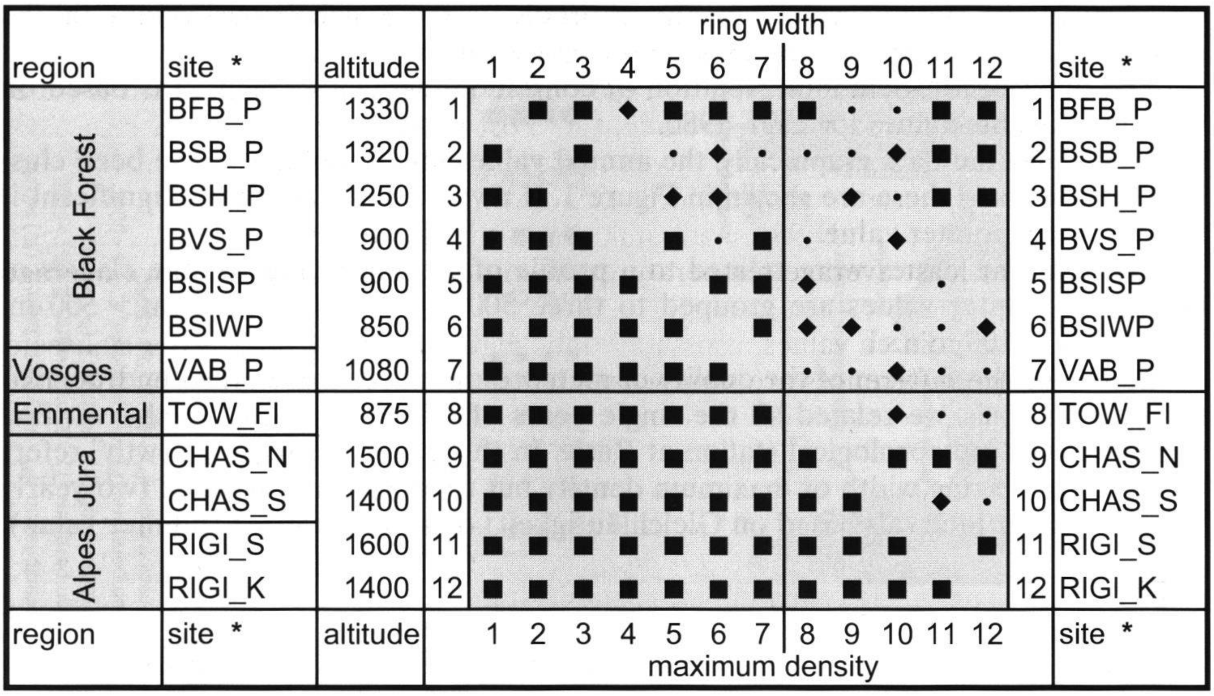
Differences between species are mainly evident in ring width. Differences in maximum densities of conifers are only slight. Beeches of the Swiss Central Plateau exhibit almost twice as many pointer values as spruce (Schweingruber et al. 1991).

Differences in site conditions are not reflected in curves of maximum density. Regional climatic factors have a stronger influence than local factors.

Dendroecological interpretation of discontinuous sequences for maximum density (Fig. 3)

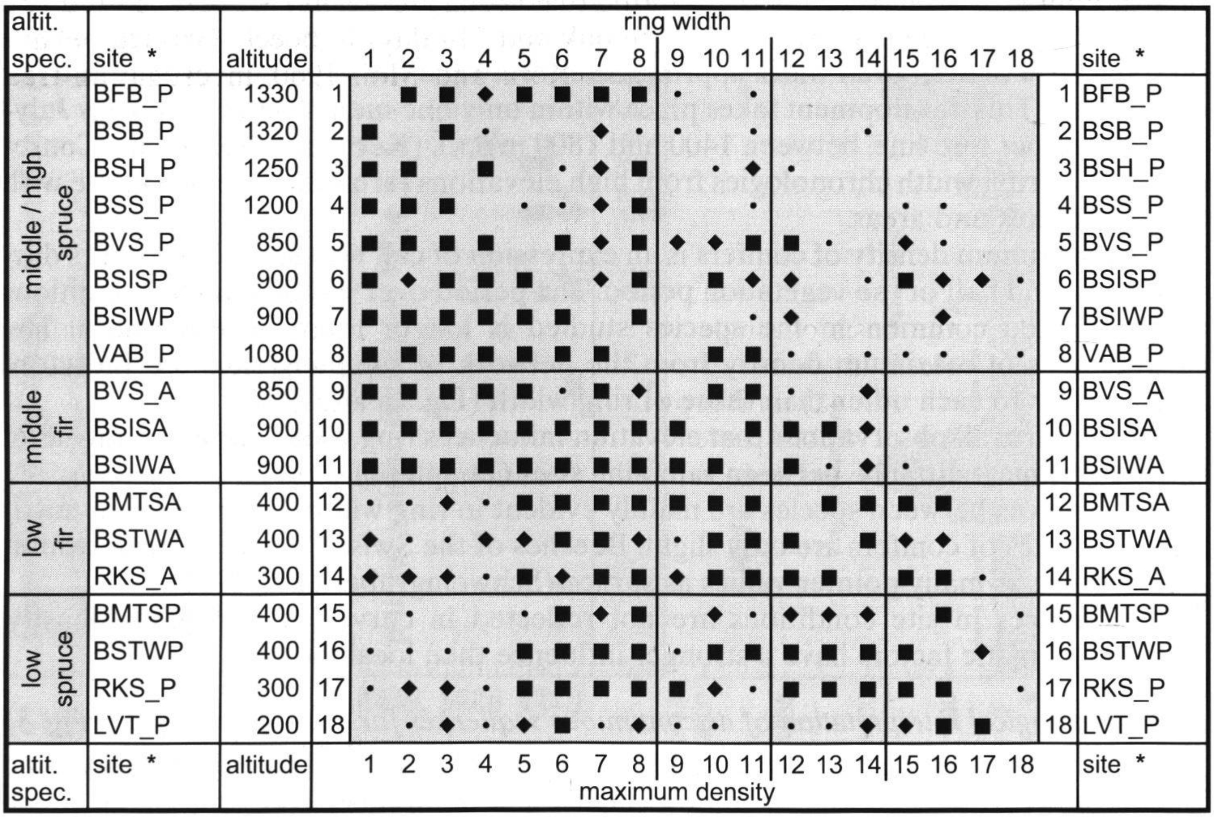
According to Schweingruber et al. 1978, latewood cell walls of trees in the subalpine belt of the Alps thicken mainly during August and September. The analysis of single years over the east-west and altitudinal transects shows clearly that the extreme nega-

Period 1904–1974 significance: 95.0% = • 99.0% = ◆ 99.9% = ■ **Fig. 2a**



* explanation see Table 1

Period 1932–1992 significance: 95.0% = • 99.0% = ◆ 99.9% = ■ **Fig. 2b**



* explanation see Table 1

tive (Fig. 3a) and extreme positive patterns of growth may occur in the whole region. Consequently, it can be assumed that at all sites cell wall growth in latewood occurs in most years in late summer. The most important growth factor is the mean daily temperature. From the fact that no obvious relationship between growth and extreme precipitation has been found, we conclude that in most years precipitation has very little influence. Increase in density probably demands less water than increase in ring width.

The positive patterns of growth differ little over the study area (Fig. 3c). Even for dry summers, e.g. 1947 and 1949, maximum density is above average on most sites. In all years with at least average temperatures, maximum density is also above average (Fig. 3c).

The negative pointer values also show only slight variations within the transects. Nevertheless, the differences are somewhat greater than those displayed by the positive values. In 11 of 20 years with negative pointer values, there are no recognizable differences over the altitudinal transect (Fig. 3a). Only in 1962 does a negative pointer value occur, and that only in spruce and only in the highest altitudinal belt (Fig. 3b). For many growth/climate relationships there seems to be no explanation. For instance, the temperatures in August and September of 1932, 1943 1958, 1961 and 1973 were clearly above average, but maximum densities did not reach extremely high values.

Dendroecological interpretation of discontinuous sequences for maximum ring width (Fig. 4)

The search for a relationship between the distribution of ring width pointer values and climate is fraught with problems from the beginning, because the onset, intensity and duration of radial growth in trees at the temperate zone of Central Europe are specific to tree species and in some cases even for individuals. After studying tree growth near Freiburg, Br., Henhappel 1965 reported that radial growth in 1960–1962 lasted 122 days in spruce, 137 days in fir, 133 days in oak and 114 days in beech. Growth behaviour is also strongly influenced by altitude. Kern and Moll 1960, investigating tree growth in southern Germany, found that in 1959 radial growth lasted a maximum of 146 days at 300 m a.s.l. but only 76 days at 1350 m a.s.l. Another point is that yearly growth is specific to site. The climatological interpretation of annual increment growth is also difficult because, of annual variation of the growth period (Henhappel 1965). The extent to which the weather of the preceding year and the trees' supply of remobilized reserves at the beginning of the vegetation period influence growth can not be reconstructed on the basis of single year analyzes. The high auto-correlation values between chronologies indicate that these factors exert an influence (Desplanque 1997).

Long dry periods (Fig. 4a) limit growth in 1934. The dry period lasted from November 1933 to mid-June 1934. All species below 1000 m a.s.l. exhibit negative pointer values because water supply was reduced at the beginning of the growing period. Spruces

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Fig. 2. Similarities between maximum density and ring width chronologies from spruces located above 850 m a.s.l. a) in the whole region analysed (Vosges, Black Forest, Jura, northern Préalps) and b) between spruces und firs located at low to high altitudes in Lorraine, Vosges and Black Forest. The similarities are expressed in percentages of Gleichläufigkeit for the period 1926 to 1975 for high altitude (< 1000 m a.s.l.) and 1900 to 1995 for the whole altitudinal transect shown in Figure 2b. The abbreviations are explained in Figure 1 and Table 1. the relationships are much stronger between maximum densities (Fig. 2a) than between ring width (Fig. 2b) into the three altitudinal zones.

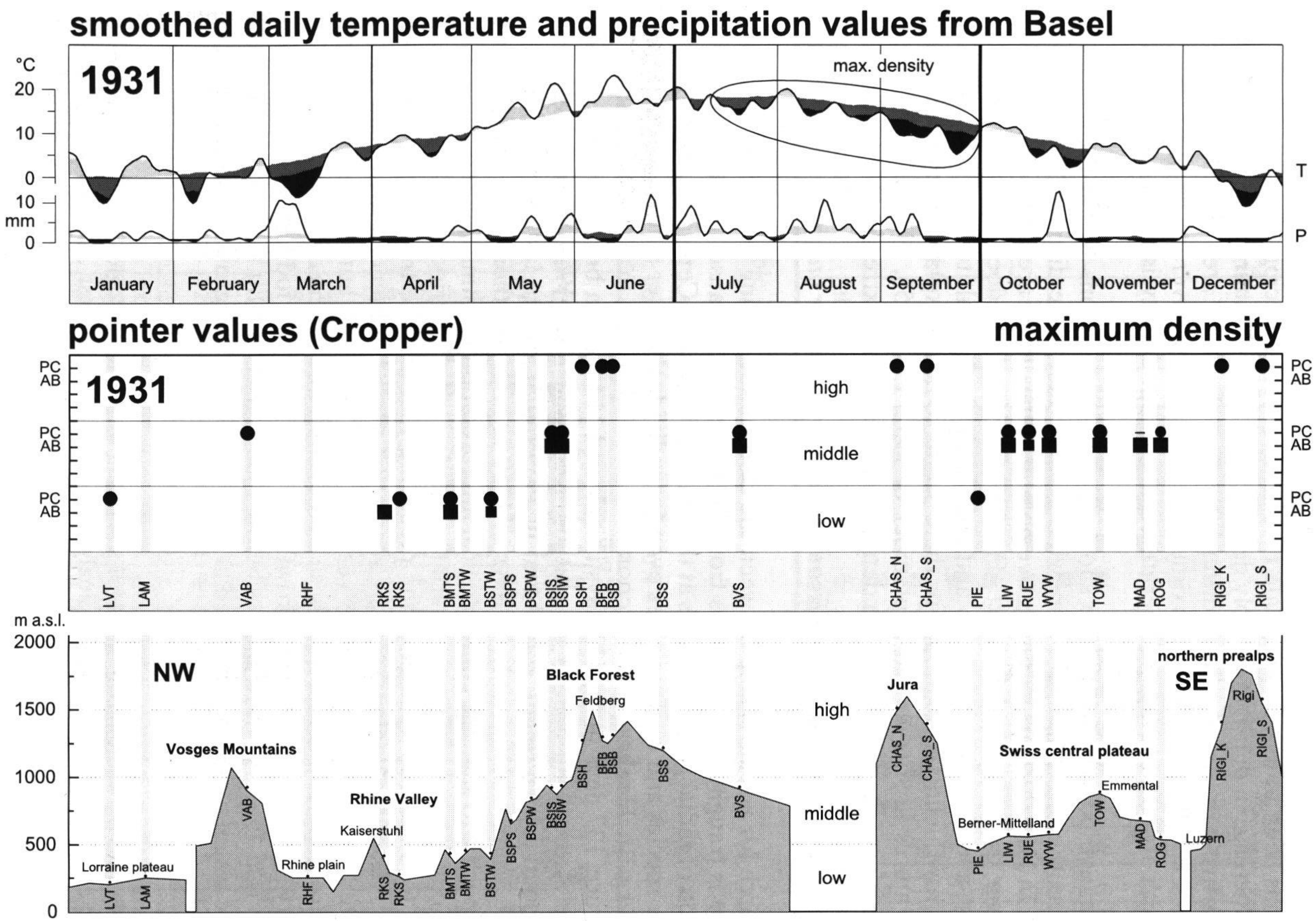

Fig. 3. Patterns of negative and positive pointer values from maximum density for spruce and fir in comparison with temperature and precipitation data from the meteorological station of Basle, Switzerland.
Fig. 3a. Negative pointer values along the whole altitudinal transect in 1931.

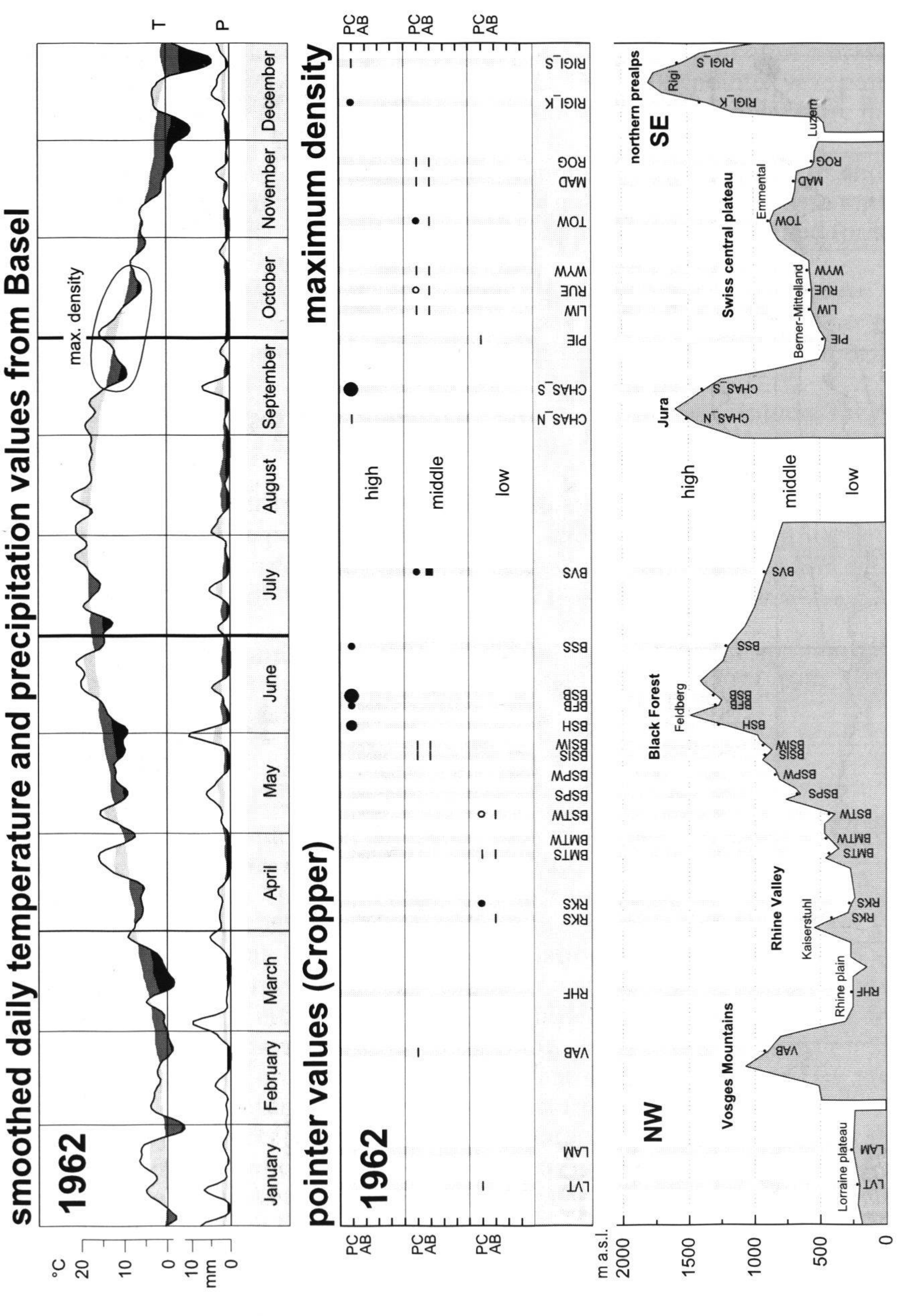

Fig. 3b. Negative pointer values above 500 m a.s.l. in 1962.

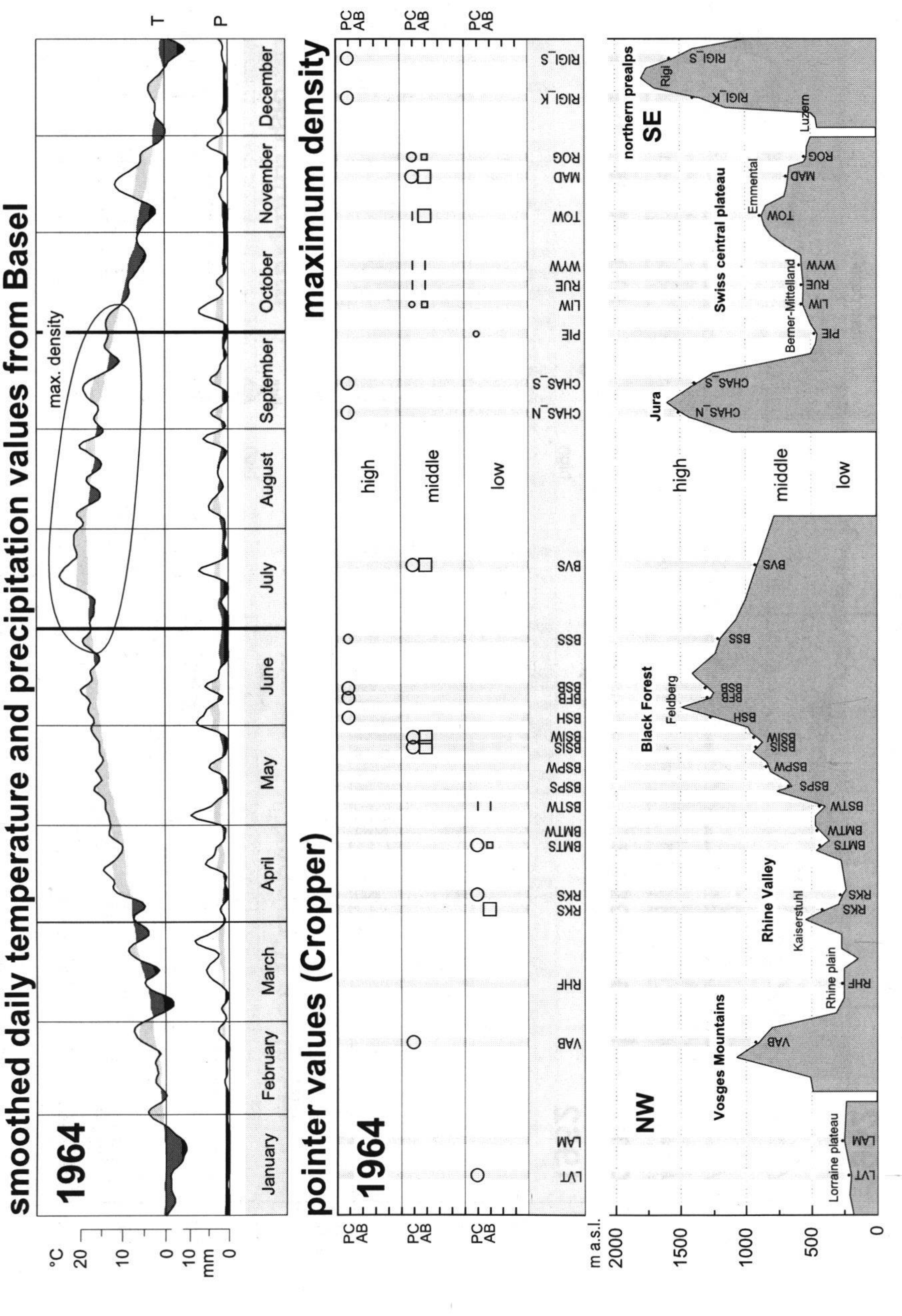

Fig. 3c. Positive pointer values along the whole altitudinal transect in 1964.

at higher altitudes have not been affected by water shortage because a rainy period occurred immediately at the beginning of radial growth in late June. Similar patterns can be seen for 1945, 1948, 1953 and 1976.

Extreme winter colds as in 1929 (Fig. 4b) cause negative pointer values in fir and possibly also in spruce. Physiological damage is most likely to occur after a drastic drop in temperature following a warm phase (Lenz et al. 1986). The pointer year patterns of the years listed below are to be attributed to a sudden drop in temperature in winter (frost).

1929: a sudden drop in temperature at the beginning of 1929 affected fir and spruce below 1000 m a.s.l. in particular. It was followed by an extremely cold phase until about mid-March. Similar effects occurred in high altitude for 1940 and 1963 and for low altitudes in 1907,1917 and 1956.

Late frosts are to some extent responsible for the patterns with negative pointer values. Combinations of winter frosts and late frosts in particular led to clear patterns of pointer values over fairly large areas e.g. in 1915 for spruces and 1928 for oak, beech and spruce below 500 m a.s.l.

1961: growth reductions are exhibited by spruce near at high altitude. They can be attributed to frost in May and June, after premature bud break due a preceding warm period.

Similar patterns occur for 1922, 1925, 1933, 1962, 1965, 1968 and 1980.

Patterns with positive pointer values e.g. 1927, 1939, and 1942 within the entire altitudinal span are evident only for years with abundant precipitation in late spring and early summer, but no frost occurred neither in the preceding winter or during the vegetation period.

It must however be emphasized that no climatological explanation can be found for many clearly marked patterns of pointer values, e.g. 1910, 1916, 1924, 1932, 1951, 1958.

Discussion

Research in forestry and especially wood biology (Larson 1994) has focused on the influence of climatic factors on single trees, but little attention has been given to their effects over larger areas. This is the focus of dendroclimatological research. Extensive sampling networks over climatically extreme areas e.g. in semi-arid (Fritts 1965) or boreal zones (Briffa et al. 1998) clearly show relationships between climate and tree growth, because each growth limitation is due to one particular factor. The multi-factorial aspect of climatic influence on tree growth is evident in our network from the temperate zone. As the present study demonstrates, patterns of tree growth in the temperate area of Central Europe can be dendroclimatologically explained for many single years of the 20th century. The ecological structure over the networks in temperate zones is in many respects heterogeneous. It embraces several tree species, different local and regional climatic areas and various soil conditions and phytosociological types. Theoretically, this heterogeneity precludes any dendroclimatological interpretation. As the findings show, however, patterns of growth which can only be explained by the governing influence of climate occur over large areas in Central Europe. 1976 is an example (Becker et al. 1990). Spring and summer were predominantly dry over all over Europe. In all species at all altitudes this led to growth reduction (ring width), although at higher altitudes both soil and air were moister than in lowland areas. During its life a tree adapts to the climate predominating at a given site. Poorly adapted trees wither

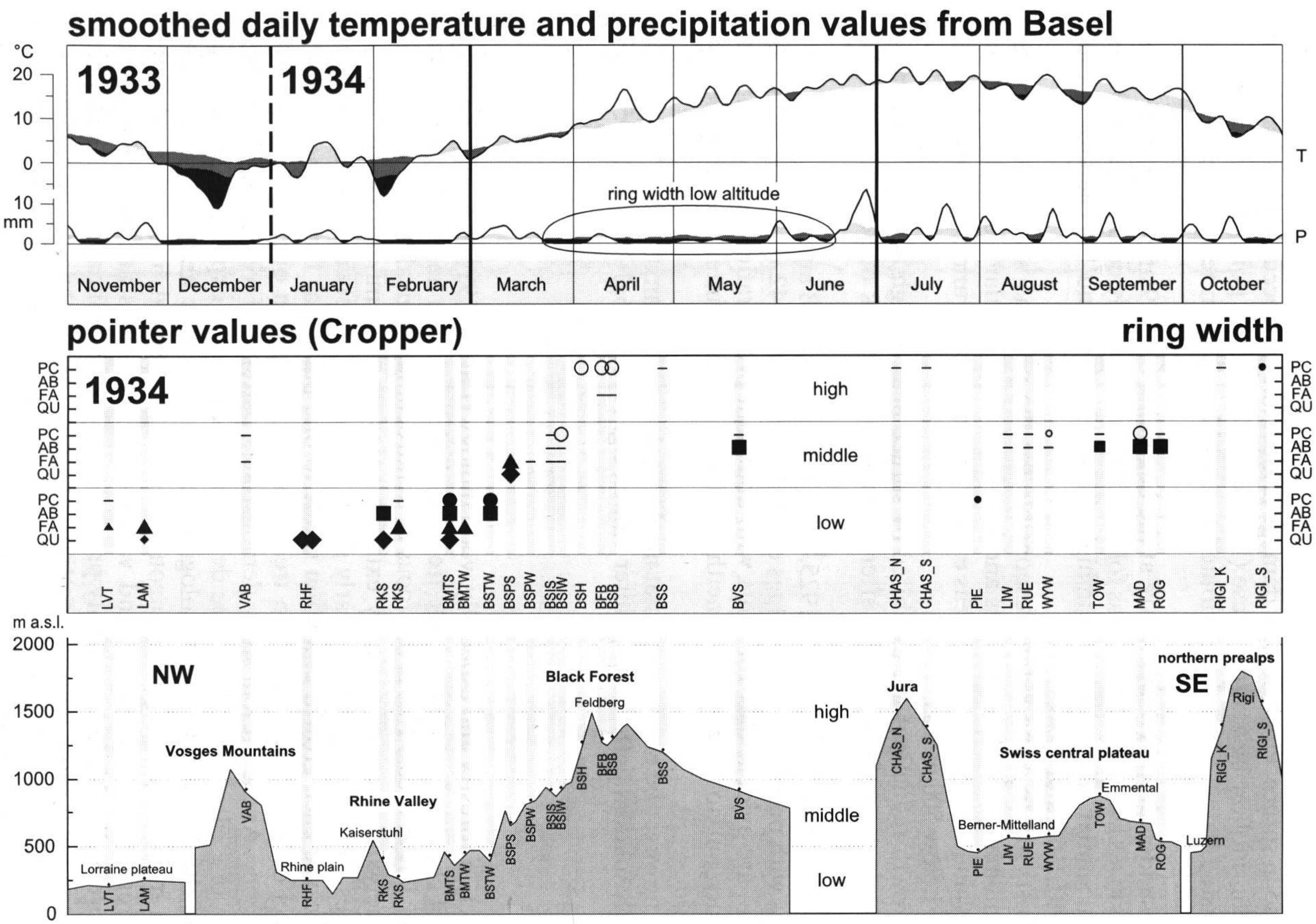

Fig. 4. Selection of ring-width patterns of negative and positive pointer years from spruce, fir, beech and oak in comparison with temperature and precipitation data (November and December of the previous year and all months of the current year) of the meteorological station of Basle, Switzerland.

Fig.4a. Patterns of negative pointer values below 1000 m a.s.l. which have been caused by long lasting droughts in spring and early summer in 1934.

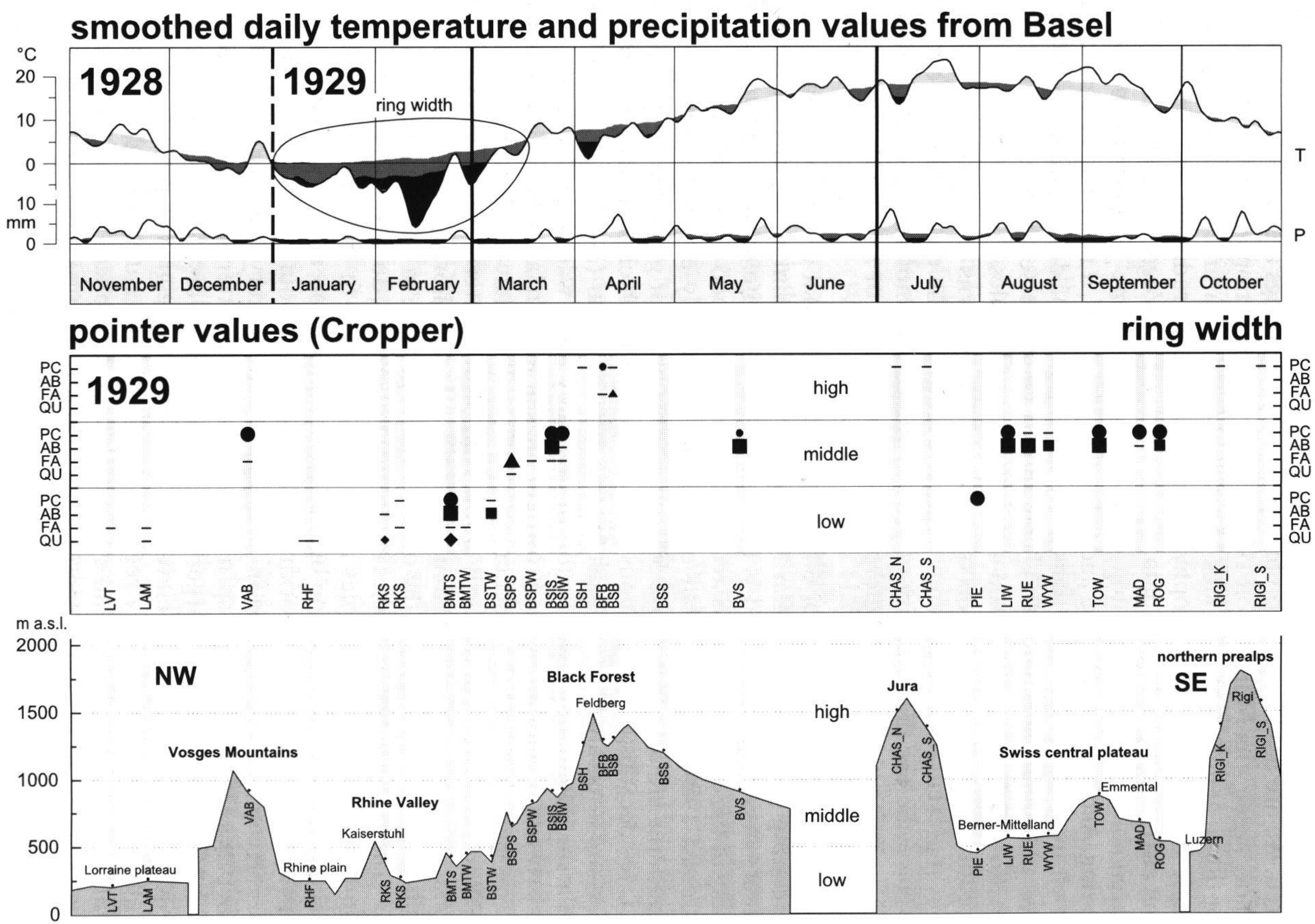

Fig. 4b. Patterns of negative pointer values below 1000 m a.s.l. which have been caused by a temperature drop in winter and a long lasting cold winter period in 1929. Especially firs are good indicators for such events.

during stand development and die. Selection of individuals is therefore also a selection by growth factors, and pointer values are the expression of similar (genetic) characteristics. Consequently, the synoptic diagrams of pointer values are understood as phenological maps. As in many other studies, tree rings which are "not characteristic" are not considered. We are not in a position to explain why such rings are "not characteristic". The authors agree with Müller-Stoll 1951 during ring formation no single environmental factor dominated growth. The lack of rational for ring parameters in extreme years may simply be due to lack of geophysical data, above all radiation and air humidity (mist) but also missing biological data, e.g. insect damage (Vogel and Keller 1998). It is also conceivable that a combination of several non-extreme factors may lead to an extreme ring. According to Rigling and Schweingruber 1997, it must also be considered that not all trees show the same sensitivity in all phases of development, as 'fitness' (Koukoui and Schweingruber 1995). This should be addressed in the climatological interpretation of chronologies based a low number of samples.

Theoretically, the interpretation of pointer value patterns should be based on an analogous representation of extreme weather events, but the meteorological data are lacking. Nevertheless, the relativity of growth values and monitoring of their annual and spatial occurrence allow an interpretation on the basis of a relatively low number of meteorological records.

The most important criteria for differentiation of regional growth patterns are different tree-ring parameters. Similarity of patterns of maximum density in conifers often occurs over large areas and is a result of the long life span of latewood cells. Thickening of the cell walls follows and is reflected in latewood density. Response functions (Kienast 1985, Schweingruber et al. 1986) of spatially extensive homogeneous growth patterns indicate that above 500 m a.s.l. this phase of growth ends in late September. Over decades, the continuous period through which climatic factors common to all trees are integrated lasts at least for two months a year (Briffa et al. 1998). Temperature is the dominant growth factor. In this study there was no evidence of a relationship between precipitation and growth of the cell walls in latewood in stands above 500 m. This indicates that the thickening of cell walls in latewood may require less water than cell elongation in the early wood. Ring-width patterns usually show a smaller area extension than maximum density. It is due to the short life span of the earlywood cells, and the differences in the onset of radial growth. In addition, there are considerable differences between species in the onset of growth, duration of growth or sensitivity to climatic factors. Examples are the sensitivity of fir to winter frosts and of beech to early frost. Even in the homogeneous subalpine zone, reactions of conifers are highly specific. Peticolas 1998, working in Briançonnais (south-west Alps), found 35 negative extreme values occurring in larch in the 20th century, but only 4 in arboreal mountain pines (*Pinus montana* ssp. *uncinata*). Negative patterns of pointer values for ring width are only common in larger regions when a long dry period or a short frost period was growth-limiting at all elevations during the same growth period.

The quality and validity of any regional dendroclimatic study depend on the sampling strategy and the technical and statistical methods applied. In terms of material, our network seems to be homogeneous only in terms of maximum density. It is ecologically too heterogeneous for the analysis of continuous ring width sequences. How far the heterogeneity of tree age affects quality and validity cannot be estimated. The findings from the shortest chronologies are definitely to be approached with caution because factors of stand dynamics exert a considerable influence on radial growth at least in the initial years of growth (Kahle 1994).

Despite all mentioned restrictions it is possible to reconstruct extreme climatic factors in the frame of networks from trees in temperate zones.

Biogeographical stratification of the chronologies is a prerequisite for comparisons with climatological and phenological sequences.

We thank Hanspeter Kahle and Heinrich Spiecker for providing the dendrochronological data and for valuable discussions and the European Union for financial support for the Project EV-5V-0437.

Zusammenfassung

Die Grundlage für die Berechnung der Beziehung zwischen der Witterung, der Jahrringbreite und der Maximalen Spätholzdichte bilden Jahrringbreiten-Chronologien von Eichen-, Buchen-, Tannen- und Fichtenstandorten sowie Chronologien Maximaler Dichten von Tannen- und Fichtenstandorten aus dem gemässigten Klimagebiet des südlichen Mitteleuropa aus Höhenlagen von 250 bis 1600 m ü.M. Das Standortspektrum umfasst alle weit verbreiteten Standorte der vier Baumarten. Dank einer einheitlichen statistischen Bearbeitung der Chronologien lassen sich jährliche Extremwerte (Weiserwerte) in einem Höhenprofil synoptisch nach klimatologischen Gesichtspunkten beurteilen. Mit einem phänologischen Erklärungsansatz werden ähnliche Verbreitungsmuster von Extremwerten zeitgleichen Witterungsprofilen gegenübergestellt. Weiserwertmuster sind meistens parameterspezifisch, manchmal art-, standorts- oder regionen-spezifisch. Die grossflächige Verbreitung der Weiserwerte ist auf die synchrone Wirkung des Klimas zurückzuführen. Wachstumswirksam für Maximale Dichten in Nadelhölzern sind in Höhenlagen über 500 m ü.M. vor allem die durchschnittlichen Tagestemperaturen in den Sommermonaten. Der Einfluss der Witterung auf die Jahrringbreiten ist sehr differenziert. Einige Wachstumsmuster sind auf Winterkälteperioden und einige auf Frühsommertrockenheit zurückzuführen. Ein Bezug der Wachstumsmuster zu Spätfrösten ist erkennbar aber oft mangels lokaler meteorologischer Daten nicht eindeutig beweisbar. Häufig müssen unterschiedliche Witterungsprofile ähnlichen Wachstumsmustern zugeordnet werden. Die grossflächigen Weiserwertmuster sind nur unter der Annahme erklärbar, dass die Bäume optimal an Standortsbedingungen angepasst sind und auf die jährlichen Veränderungen mit Relativwerten reagieren. In einem Trockenjahr entsteht sowohl in Tief- als auch in Hochlagen ein schmaler Jahrring, obwohl in der Höhe Boden- und Luftfeuchtigkeit absolut höher sind. Alle nicht optimal angepassten Individuen sind im Laufe der Ontogenese aus den Beständen ausgeschieden. Nur dank der Langlebigkeit der Nadelholz-Spätholztracheiden ist die stark synchonisierende Wirkung des Klimas auf die Maximale Dichte und die Entstehung geographisch grossflächiger Muster erklärbar. In jedem Jahr und an allen Standorten integrieren die Zellwände von Fichten und Tannen die täglichen Temperatursummen. Die weniger gute Synchronisierbarkeit und die meist begrenzte Ausdehnung der Weiserwertmuster beruht auf der saisonalen Asynchronität des radialen Wachstum bei Bäumen in verschiedenen Höhenlagen.

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