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Original article

Site ecological differences to the climatic forcing of spruce pointer years from the Lötschental, Switzerland

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Summary

Variations in ring width and ring coloration of 89 spruce trees from six sites in the Lötschental, Switzerland, are analyzed. Sites are located along an altitudinal transect spanning 1500 to 2000 m a. s. l. on a SSE- and a NNW-facing slope. Site ecology is further determined by local differences in micro relief, allowing differentiation into locally wet and dry sites. Growth reactions are classified as "site pointer years" representing extreme years common within a site, and as "valley pointer years" representing extreme years common between sites. These site and valley pointer years are classified and analyzed separately for ring width, light rings and dark rings. In so doing, 44 ring width and 9 light ring pointer years are reported for the 20th century. Dark rings do not crossdate within sites, so that no such pointer year is documented.

Comparisons with instrumental data show that May precipitation and temperatures are crucial for both negative and positive ring width pointer years. Climate variability in all other months only modifies the intensity of these pointer years. Light ring pointer years correlate with low temperatures recorded towards the end of the growing season, particularly in September. By further analyzing the climate response patterns of site and valley pointer years, a conceptual classification of six climate/pointer year groups is presented:

(1) Moderately cold and moist growing seasons cause wide rings at upper and lower sites.
(2) A cold May followed by moderately cool summers cause wide rings at lower sites.
(3) Warm (and moist) summers cause wide rings at upper sites.
(4) Warm and dry summers cause narrow rings at lower sites.
(5) Cold and moist summers cause narrow rings at upper sites.
(6) A cold September cause light rings at upper sites.

Keywords: Climate, tree ring, light ring, pointer year, site ecology, spruce, Switzerland

Introduction

To understand the complex forcing of climate on tree growth, correlation and response function analyses have been established (Fritts 1976; Cook, Kairiukstis 1990). Such techniques typically provide information about the average relationship between climate and ring width or ring density variation. The

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climatic forcing of single extreme years, however, is not revealed (Esper et al. 2001a; Krause, Eckstein 1992). A suitable approach to study such relationships and to further validate the temporal stability of climate/growth relationships is to compare extreme growth events with instrumental data (Schweingruber et al. 1990). If, in addition, ecological site conditions are considered, a comprehensive understanding of the growth-limiting factors may be developed (overview in Schweingruber 1996).

Here we analyze the climatic response of ring width, light ring, dark ring site and valley pointer years of subalpine spruce (*Picea abies* [L.] Karst.) from the Lötschental with respect to elevation, aspect, and moisture. These pointer years are compared between six tree ring sampling sites and related to monthly records of precipitation and temperature. In so doing, distinct patterns of site pointer years (e. g., wide rings recorded in sampling sites near the upper timberline) are discussed, and a conceptual classification of climate/pointer year groups is derived summarizing the most relevant and frequent response patterns seen in the Lötschental. Similar studies showed that site elevation and aspect (Esper et al. 2001b; Kienast 1985; Lingg 1986; Desplanque 1997), moisture and soil conditions (Z'Graggen 1992; Dittmar, Elling 1999), and species-specific differences (Schweingruber et al. 1991; Petitcolas 1998) might control the frequency and strength of pointer years. If we assume that the climate information of tree ring series, and particularly of certain extreme years of such records is modified by local site ecology, a detailed understanding of the differing climate response from trees growing in different settings is necessary to successfully reconstruct climate history over longer periods (Esper et al. 2002a, 2002b).

Material and Methods

Fourteen to sixteen dominant and subdominant spruce (*Picea abies*) trees were sampled at each of the six sites along a north-south running transect in the central alpine Lötschental (46°23′–25′ N/ 7°46′–48′ E). Four of these sites are located near the upper timberline between 1940 and 2020 m a. s. l., and two sites near the valley bottom between 1550 and 1650 m a. s. l. At each position – that is, high

Table 1. Settings and ecology of sampling sites.

Lötschental/Valais						
Position	**South**			**North**		
	Near timberline		**Valley bottom**		**Near timberline**	
Humidity	**dry**	**wet**	**dry**	**wet**	**dry**	**wet**
Site	**1**	**2**	**3**	**4**	**5**	**6**
Lat./Lon.	**46°25′40″/ 7°46′15″**	**46°25′30″/ 7°48′55″**	**46°25′15″/ 7°48′45″**	**46°24′05″/ 7°47′40″**	**46°23′30″/ 7°46′45″**	**46°23′25″/ 7°47′10″**
Elevation (m)	**2000–2020**	**1950–1960**	**1550–1560**	**1460–1480**	**1940–1960**	**1980–2000**
Exp./Incl. (°)	**SSE/45**	**SE/20–30**	**SSE/35–40**	**NNW/45**	**NNW/35–40**	**NNW/35–40**
Shrub and herb cover (%)	**30**	**70**	**20**	**50**	**45**	**95**
Leading shrubs and herbs	Deschampsia flexuosa, Hieracium murorum	Calamagrostis arundinacea, Vaccinium myrtillus	Deschampsia flexuosa, Hieracium murorum	Hieracium murorum, Oxalis acetosella, Vaccinium myrtillus	Deschampsia flexuosa, Hieracium murorum, Oxalis acetosella, Vaccinium myrtillus	Calamagrostis villosa, Adenostyles alliariae, Veratrum album
Soil	Slightly podsolic brown soil	Podsolic brown soil	Slightly podsolic brown soil	Ferric podsol	Podsol	Podsol
Number of trees	15	15	14	16	14	15
Mean age of 10 oldest trees (yr.)	267	164	135	151	210	300
Mean ring width (mm/yr.)	0.96	1.11	1.24	1.30	1.13	1.14

and north-facing, high and south-facing, and valley bottom – locally wet and locally dry sites were selected. This was done by considering the micro relief and analyzing the shrub and herb cover (Tab. 1).

Ring width, light ring and dark ring event years per tree (sensu Schweingruber et al. 1990) were dated using the skeleton plot method (Douglass 1941). Here we applied a five-tiered hierarchical classification system from "weak" to "extreme" (Weber 1993) according to the intensity of a single growth deviation relative to the neighboring 5 years. For example, the maximum intensity class, "extreme", is reached if a ring is at least 85 % narrower (lighter) or 400 % wider (darker) than the mean of the neighboring rings. The resulting weighted event years were then classified into site pointer years, I, where:

$$I = \frac{100}{k \cdot n} \sum_{j=1}^{k} h_j \cdot i_j \quad [\%]$$

with: k: = number of event year intensity classes (here five)
n: = total number of trees
h: = number of trees with event
i: = intensity class of event year

The maximum intensity of a site pointer year (I = 100 %) is achieved if all sampled trees show an extreme (here, i = 5) positive (or negative) event in a given year. If, for example, 40 % of the sampled trees show an event year i = 3 the resulting site pointer year would have an intensity of I = 24 %. This value was used as a threshold to classify "weak" site pointer years (I = 24–40 %). Accordingly, "median" site pointer years range from I = 41–60 %, and "strong" pointer years from I > 60 %. Valley pointer years are calculated with the same equation, but with respect to the numbers of trees sampled in the valley (not a site).

To calibrate site and valley pointer years, we used monthly temperature and precipitation data from Ried (46°25′ N/7°49′ E; 1480 m a. s. l.), Leukerbad (46°23′ N/7°38′ E; 1397 m a. s. l.), Montana (46°22′ N/7°31 ′E; 1508 m a. s. l.), Zermatt (46°05′ N/7°51′ E; 1638 m a. s. l.), and Kippel (46°24′ N/7°46′ E; 1375 m a. s. l., precipitation only). Due to the length of nearby observational station records the period of investigation is restricted to 1900–1995. Residuals from the monthly 96-year means (period 1900–1995) were calculated and expressed in standard deviation units (σ). For the comparison with pointer years, positive and negative thresholds of 0.6 σ are

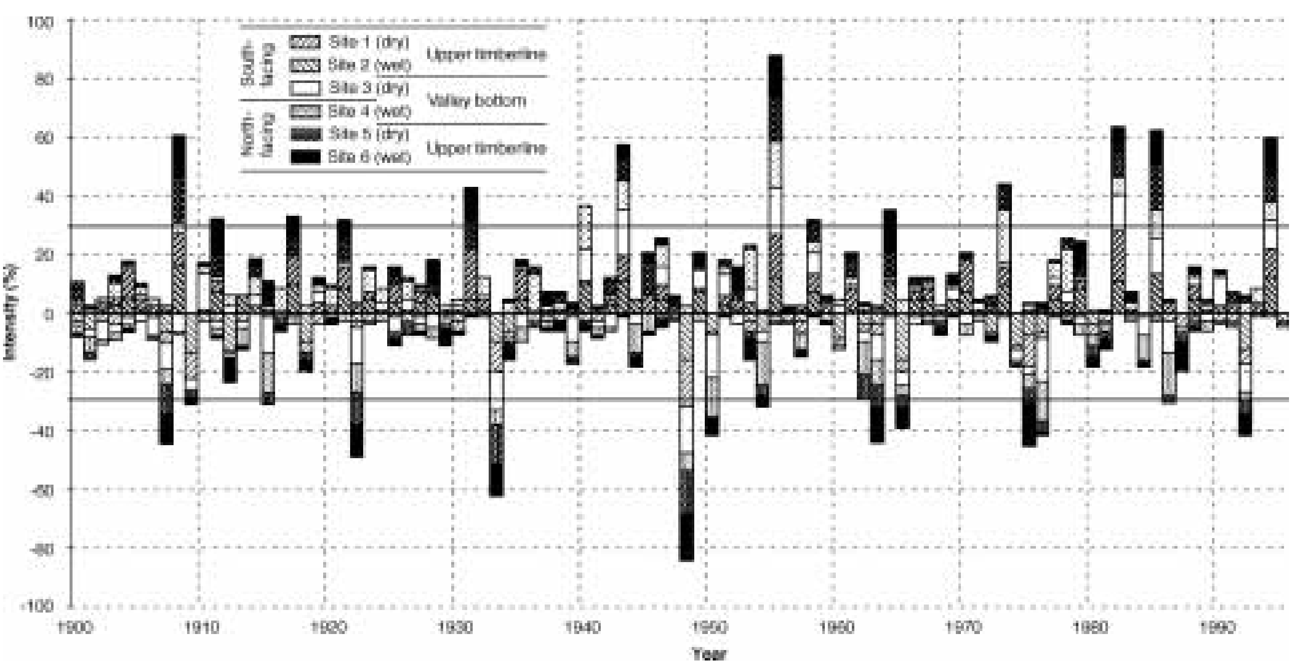

Figure 1. Lötschental ring width valley pointer years since 1900. Black lines indicate the I = ±24 % thresholds for positive and negative valley pointer years.

Table 2. 44 years with ring width and 9 years with light ring site pointer years. Two years (1972, 1995) of the total of 46 years listed left do not represent ring width pointer years (but light ring pointer years). In 1931 and 1953 both positive and negative ring width site pointer years are recorded.

	Ring width						**Light rings**					
	Upper-S		**Lower**		**Upper-N**		**Upper-S**		**Lower**		**Upper-N**	
Year	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**
1905		++										
1907	–		– –		– –	– –						
1908	+++	++			+++	+++						
1909	– – –	– –										
1910			+++	+								
1911	++					++						
1912	– –					–	– – –	– –			– – –	– – –
1915			– –	– – –								
1917	++	++			++							
1918	– –	– –										
1921	++				++							
1922			– –	–	– –	– –	– – –		– –			
1924				+			– – –	–			– –	– –
1928		+ –				+						
1931	–	+++			++	+ –	–					
1933	– –		– –		– – –	– –						
1936				++								
1939			– –	–								
1940	++		+	+++								
1943	++	+	+++	+								
1944				– –								
1948	– – –	– – –	– – –	–	– – –	– – –						
1950	–		– – –	– –				–				
1953			++	+ –								
1954				– – –								
1955	++	+++	++	++	+++	+++						
1958	+++				+							
1962				– –	–							
1963			– – –			– – –						
1964	++				++	+						
1965	– – –			–		– –	– – –	– –			–	– –
1970	++	+										
1972							– – –				–	– – –
1973	+		+++	++								
1974	– –											
1975	– –	– –				– – –						
1976	–		– – –	– – –								
1978			+	+++								
1979	++					++						
1982	++	+++	++		++	+						
1984			–	– –			– –	– –			–	– – –
1985	+++		++	+	+++	++						
1986			– –	– –								
1992	– –		– –			–						
1994	++	++			++	+						
1995							–	– –				– –

With:
– / + Weak site pointer year
– – / ++ Medium site pointer year
– – – / +++ Strong site pointer year
(light grey) Negative valley pointer year
(dark grey) Positive valley pointer year

utilized to differentiate between "average" versus "cold", "warm", "dry", and "wet" months. In addition, daily temperature data from Ried and Montana from 1931–1995 are used to study possible impacts of frost events on tree growth.

Results

Ring width valley pointer years

In the Lötschental, 14 positive and 15 negative ring width valley pointer years that exceed the I = 24 % threshold are recorded since 1900 (Fig. 1). Extremely "Strong" pointer years are only obtained when broadly synchronous individual site point years, like in 1948 or 1955, occur. Positive valley pointer years are classified as strong in 1908, 1955, 1982, 1985, 1994 (5), median in 1931, 1943, 1973 (3), and weak in 1911, 1917, 1921, 1940, 1958, 1964 (6). Negative valley pointer years show a different distribution, with only 1933, 1948 (2) being strong, 1907, 1922, 1950, 1963, 1975, 1976, 1992 (7) median, and 1909, 1915, 1954, 1962, 1965, 1986 (6) weak. Comparable valley pointer years for light or dark ring years are not recorded, as none exceeds the I = 24 % threshold necessary for classification.

Ring width valley pointer years result from different combinations of site pointer years (see bar contours in Fig. 1). In 1975 and 1976, for example, more than 40 % of all trees show a negative event year. However, while in 1975 the four high elevation sites account for 38 %, in 1976 the two low elevation sites account for 26 %. Consequently, valley pointer years of comparable strength contain different geographic information. The composition of valley pointer years and, thus, the strength of site pointer years seems to be related to varying climatic stresses modified by elevation, exposure, and local moisture supply.

Site pointer years

A comparison of the frequency and strength of site pointer years shows that 44 ring width, 9 light ring and zero dark ring site pointer years are reported for the 20th century (Tab. 2). Synchronous dark rings occurred too infrequently to reach the level of a site pointer year. The number of years with ring width site pointer years exceeds the number of valley pointer years (n = 29) by 15. Interestingly, only the valley pointer years of 1948, 1955, 1982, and 1985 have corresponding site pointer years, recorded in at least five sites. All other valley pointer years are replicated in only four sites or less. On the other hand, there are six years (1905, 1924, 1936, 1944, 1954, 1974), when only one site recorded a pointer year. We assume, that the climatic forcing in these single-site pointer years was less severe, and that local, non-climatic limiting factors were more relevant. Consequently, these six years are not considered for the climate/growth analysis.

Climate/pointer year groups

The classification of climate/pointer year groups considers the parameter (ring width and light rings), the altitudinal position of sites (upper and lower) and the climatic patterns (precipitation and temperature). Analyses including the exposure (north- and south facing) and the local moisture supply of sites (wet and dry) revealed that these ecological settings have no significant explanatory power to the pointer years (not shown). Considering the parameter and the position of sites, Lötschental pointer years were classified as (1) wide rings at upper and lower sites, (2) wide rings at lower sites, (3) wide rings at upper sites, (4) narrow rings at lower sites, (5) narrow rings at upper sites, and (6) light rings at upper sites. These groups represent the most significant spatial patterns found in the 20th century. A selection of the years characteristic for the groups including the precipitation and temperature patterns is shown in Fig. 2. For a complete list of site pointer years including those not listed in Fig. 2 or not mentioned in the discussion below see Tab. 2.

(1) Wide rings at upper and lower sites (Fig. 2a): Years with wide rings at all (1955) or almost all sites (1982, 1985) are characterized by average to slightly below average temperatures and average to slightly above average rainfall during the growing season from May to September. Here "average" and "slightly below/above average" are used to specify temperatures and precipitation not exceeding the $\pm 0.6\ \sigma$ range. Note that the sites have different exposures, range from the valley bottom to the upper timberline, and are locally wet and dry. Considering all data (Tab. 2), the year 1955 might be a representative example for optimal climate conditions at all Lötschental spruce sites. The conditions at the beginning of the vegetation period in May and June are crucial to this group. If precipitation and tempera-

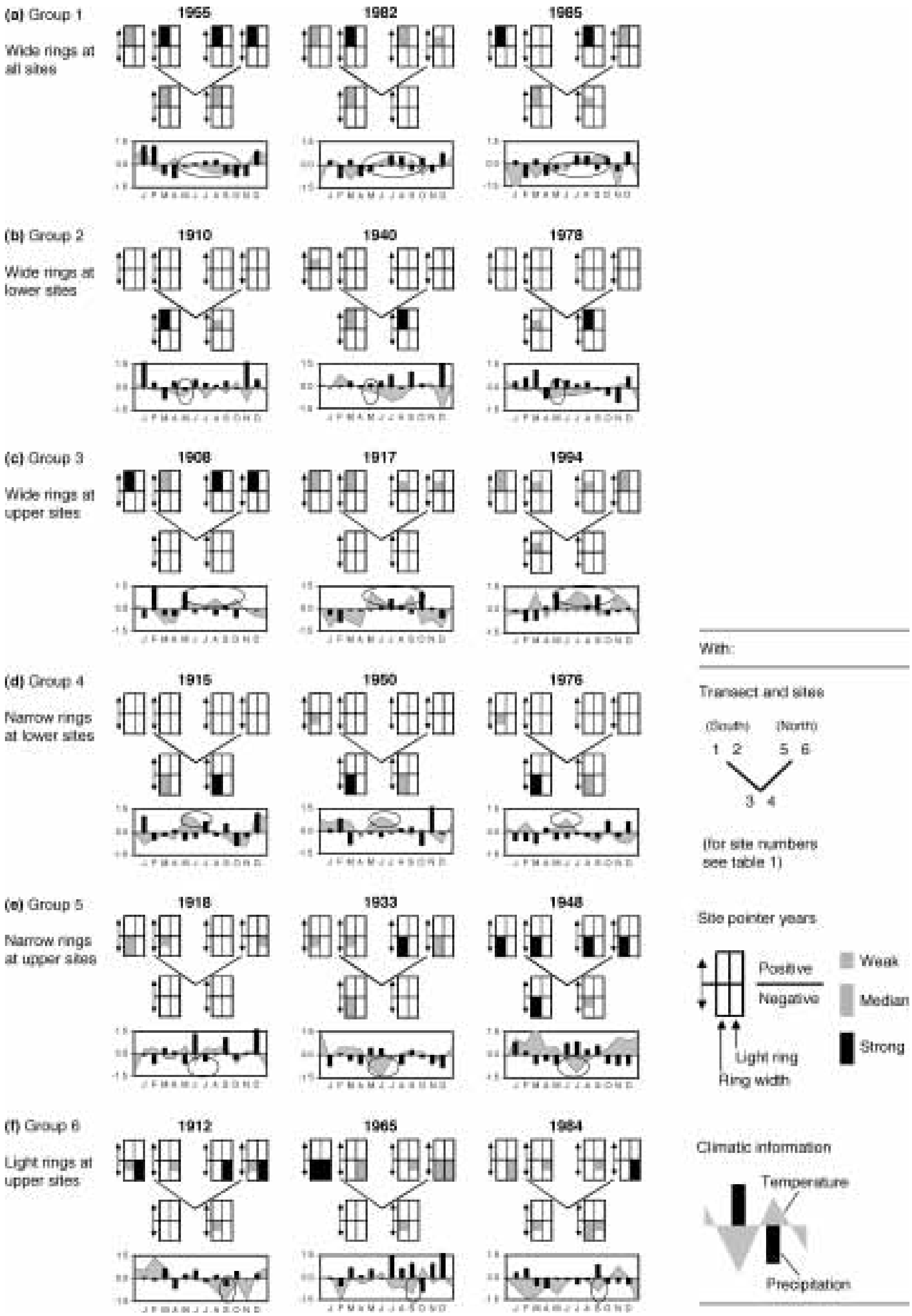

Figure 2. Selection of Lötschental pointer year patterns and associated climatic conditions. Temperature and precipitation anomalies are standardized with respect to the 1900–1995 mean, and expressed in standard deviation units (σ).

ture in these months are close to average, spruce trees develop a wide ring regardless of altitudinal differences. The following months only modify the magnitude of the wide ring, i. e., the ring will be exceptionally wide if the following months are moderately wet and average to moderately warm.

(2) Wide rings at lower sites (Fig. 2b): Years with wide rings at only lower (1910, 1978) or almost only lower sites (1940) are characterized by climate conditions similar to the ones of group 1. The only difference seems to be the colder conditions (at least one month colder than 0.6 σ) recorded at the beginning of the growing season that are crucial for the growth rate at lower sites. A cold May followed by moderately cool summers are the typical climatic pattern for this group. Upper sites are generally not affected by this pattern.

(3) Wide rings at upper sites (Fig. 2c): Years with wide rings only at upper (1908, 1917) or almost only at upper sites (1994) are characterized by temperatures above 0.6 σ in one or more months during the growing season, frequently combined with above average rainfall particularly at the beginning of the growing season. Again, May precipitation and temperatures need to be close to, or above, average conditions.

(4) Narrow rings at lower sites (Fig. 2d): Years with narrow rings only at lower sites (1915, 1950) or almost only at lower sites (1976) are characterized by warm to very warm conditions (temperature deviations even above 0.8 σ) in late spring (May) and especially early summer (June), and slightly below average precipitation during this period. Then the lower sites appear to be drought stressed. In 1976 the south-facing, locally dry upper timberline site also reacts. For all other years and upper sites, water from melting snow might help compensate for the lack of precipitation.

(5) Narrow rings at upper sites (Fig. 2e): The spatial pattern of this group is less homogenous. Years with narrow rings predominantly at upper sites (1918, 1933, 1948) are frequently characterized by either a warm and dry May and/or cold and wet June and July. If the temperature falls below –1.0 σ, lower elevation sites react with narrow rings too, such as in 1933 and 1948.

(6) Light rings at upper sites. (Fig. 2f): The spatial pattern of this group is again less homogenous and may include low elevation sites as well. Years with predominantly light rings at upper sites (1912, 1965, 1984) are characterized by a cold to very cold (even below –1.0 σ) September. In some of the years low temperatures are already recorded in August. This is the period of latewood cell develop, and cold conditions with an early end of the growing season limit the thickening of secondary walls and lighten the rings independent of the width.

A common feature to the positive ring width pointer years (groups 1–3) is the significance of the month of May. If the beginning of the growing season is exceptionally cool or moderately cool and sufficiently moist, the corresponding ring is generally wide. Temperature and precipitation variations during the months following May only modify the intensity of the positive growth reactions. On the other hand, groups 4 and 5 summarizing negative pointer years generally correlate with warm and dry conditions in May. Interestingly, even if the weather conditions in the following months were favorable the corresponding ring remains narrow.

In further abstracting the patterns of tree ring formation obtained and their corresponding weather conditions, six conceptual climate/pointer year groups are developed (Fig. 3). Note that this classification is of conceptual nature and remains to be statistically tested. Moderately cool and moist growing seasons are seen as optimal for the growth of spruce trees in the Lötschental. With these conditions the trees at upper and lower sites produce wide rings. If May temperatures were very cool, wide rings are limited to the lower sites, and if growing seasons were warmer and wetter, wide rings are limited to upper sites. Thus, narrow rings are either caused by drought stress in lower sites (Cook et al. 1999) related to a dry May and June and a warm growing season, or by temperature stress in upper sites related to a cold summer. Nevertheless, if a particular year was exceptionally cold, like 1948, narrow rings are recorded at all sites. Finally, cold conditions at the end of the growing season cause light rings predominantly at sites near the upper timberline.

Discussion

The modified skeleton plot method, including a hierarchical classification system of event years, applied here has proven useful for the analysis of extreme growth reactions of ecologically differing sites in the Lötschental. It enabled a detailed documentation

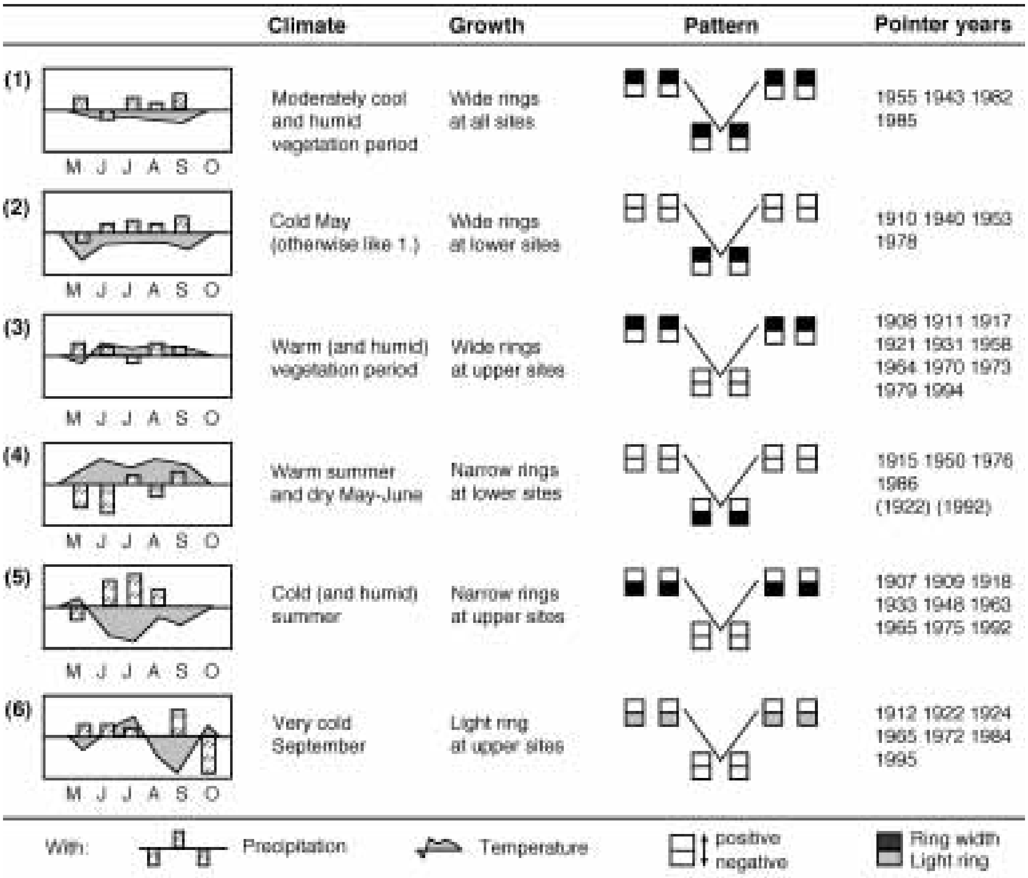

Figure 3. Conceptual spruce climate/pointer year groups for the Lötschental.

of positive and negative growth deviations, and an analysis of pointer years with respect to site ecology. Note that the sites were purposely chosen to maximize ecological differences within the Lötschental. This approach enabled a thorough analysis of climatic forcing of extreme years, and a classification of conceptual climate/growth relationships. The 14 positive and 15 negative ring width valley pointer years obtained for the 20th century (period 1900–1995) underline the high sensitivity of the investigated spruce trees. For ecologically similar spruce sites from comparable central alpine environments, two to three ring width pointer years per decade can be expected on average.

In comparison to ring width, the numbers for light and dark ring pointer years are low. These pointer years that were also derived using the skeleton plot method were thought to serve as a surrogate for labor-intensive densitometric measurements (Schweingruber et al. 1978). The latter are described as being a close estimator of summer and late summer temperature variations (Briffa et al. 1998, 2002; Bräker 1981; Schweingruber et al. 1988). However, light ring event years from Lötschental spruce only crossdate on the site-level, and dark ring event years do not crossdate at all. We, thus, assume that differing limiting factors control the densitometry-derived maximum latewood measurements in comparison to the skeleton-plot-derived light and dark ring pointer years. This conclusion is derived, even if the (infrequent) light ring site pointer years reported here correlate with cold temperatures at the end of the growing season, like in 1912 when the September was 2.9 °C colder than 1900–1995 mean.

Interestingly, many of the ring width valley pointer years obtained for the Lötschental do not crossdate with other reconstructions from spruce trees in the western and central Alps (Koukoui, Schweingruber 1994; Kienast 1985; Lingg 1986; Schweingruber 1986; Schweingruber et al. 1991; Hüsken 1994; Desplanque 1997; Petitcolas 1998; Grindl 1999; Meyer 2000). Desplanque (1997), when deriving some similar conclusions, argues that this spatial inhomogeneity of pointer years might at least partly be associated with differing assessment approaches applied in papers dealing with extreme years. Meyer (2000), however, additionally refers to the spatially differing weather situations repeatedly reported for this region in the Alps. This argument might be valid for observed precipitation patterns, but less applicable to temperature (Böhm et al. 2001). To further analyze the true reasoning for the obvious spatial inhomogeneity of extreme years, a systematic analysis of uniformly derived pointer years from a larger network of alpine tree ring sites is required (Frank, Esper, in prep.).

Lötschental negative ring width valley pointer years that are also reported in other work are 1922, 1933, 1948 and 1976. These interregional pointer years are described for the Valais (Kienast 1985; Koukoui, Schweingruber 1994; Lingg 1986; Schweingruber et al. 1991), Swiss Jura (Schweingruber 1986), French Alps (Desplanque 1997; Petitcolas 1998), Italian Alps (Hüsken 1994; Koukoui, Schweingruber 1994), and the nearby Grindelwald (Meyer 2000). The positive Lötschental pointer years 1955 and 1982 are confirmed by Desplanque (1997) and Meyer (2000), and 1955 again by Schweingruber et al. (1991). In general, the highest agreement is found with the subalpine spruce trees from the nearby Grindelwald (Meyer 2000), where at least sixteen 20th century pointer years crossdate with the data from the Lötschental.

A comparison of the pointer years reported here with $\delta^{13}C$ pointer years recorded from latewood samples of the same trees in the Lötschental over the period 1946–1995 (Treydte et al. 2001) shows no correlation. We conclude that ring width and $\delta^{13}C$ records are limited by differing forcing factors, or at least by seasonally differing climate variables (Treydte and Neuwirth, in prep.). The only year that matches using both methods is 1984 (light ring, low $\delta^{13}C$ value). However, whereas cold conditions at the very end of the growing season caused the light ring, the moist and cold conditions starting in July are reported responsible for the low $\delta^{13}C$-values (Treydte et al. 2001).

In general, our analysis suggests relevance of the weather conditions during May for the formation of both negative and positive ring width pointer years. Close to average temperatures and precipitation in May set the conditions for wide rings. Then, the rings are wide at all sites if the vegetation period was moist but not too cold. If, however, the vegetation period is moist and warm, then wide rings are recorded at upper sites only. A cold May results in wide rings at lower sites, nearly independent from the conditions in the following months. In negative ring width pointer years, May conditions were generally warmer and drier. Narrow rings are then limited to lower sites, if the summers were also warm (and dry). If, however, the summers were cold and humid, narrow rings are limited to the upper sites.

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