Use of false rings in Austrian pine to reconstruct early growing season precipitation

Rupert Wimmer, Giorgio Strumia, and Franz Holawe

Abstract: As a consequence of dry conditions, coniferous trees may produce radially smaller diameter tracheids within their tree rings before regular latewood formation starts. The resulting structures, which are commonly called false rings, have demonstrated utility as an environmental indicator. However, the climatic patterns behind false rings and their potential use in climate reconstruction models have been barely explored. The study is based on 313 Austrian pines (*Pinus nigra* Arn.) sampled at 29 sites in the Viennese basin, an area with low annual rainfall, extended dry periods during the growing season and usually severely cold winters. False rings relate significantly to May precipitation, and in years with higher false-ring proportions, a relationships with the combination of wet April, dry May, and wet June is often seen. In linear regressions, the presence–absence of false rings was used as a "dummy" variable and, together with earlywood width, explained 31% of variation in May precipitation. Years with high false-ring proportions were found when May precipitation was less than half its long-term average. False-ring trends during the past 100 years were closely associated with changing May rainfall pattern. Overall, false rings are shown to be a useful tree-ring feature and may be applied successfully in dendroclimatic studies, i.e., in the reconstruction of very low rainfall months in early growing seasons during pre-instrumental periods.

Résumé : Suite à une période de sécheresse, les conifères peuvent produire à l'intérieur des cernes annuels des trachéides dont le diamètre radial est plus petit avant que démarre la formation de bois d'été normal. Les structures qui en résultent, communément appelées faux-cernes, ont démontré leur utilité comme indicateur environnemental. Cependant, les conditions climatiques à l'origine des faux-cernes et la possibilité de les utiliser dans des modèles de reconstruction du climat ont été à peine explorées. Cette étude est basée sur 313 pins noirs d'Autriche (*Pinus nigra* Arn.) échantillonnés dans 29 stations situées dans le bassin viennois, une région avec une précipitation annuelle faible, de longues périodes de sécheresse pendant la saison de croissance et des hivers habituellement très froids. La présence de faux-cernes est significativement corrélée à la précipitation durant le mois de mai. Les années où il y a une plus forte proportion de faux-cernes, on observe souvent une relation avec une suite de conditions climatiques caractérisées par un mois d'avril humide, un mois de mai sec et un mois de juin humide. La présence ou l'absence de faux-cernes a été utilisée comme variable nominale dans des régressions linéaires. Cette variable, combinée à la largeur du bois de printemps, explique 31% de la variation dans la précipitation du mois de mai. Les années avec une forte proportion de faux-cernes sont caractérisées par une précipitation pendant le mois de mai inférieure à la moitié de la moyenne à long terme. Au cours des 100 dernières années, les variations dans la présence de faux-cernes ont été étroitement associées aux changements dans le patron de précipitation du mois de mai. Globalement, les faux-cernes s'avèrent être des caractéristiques utiles des cernes annuels et peuvent être utilisés avec succès dans les études dendroclimatologiques; en particulier pour détecter les mois avec de très faibles précipitations au début des saisons de croissance antérieurement à l'existence d'instruments de mesure.

[Traduit par la Rédaction]

Introduction

The activity of the vascular cambium is regulated by genetic and environmental factors. Anatomy of the xylem is species specific but also subject to modification by the environment (Telewski and Lynch 1991). The most visible change in anatomy regulated by the environment and mediated by plant growth regulators is the change in cell size. Normally, xylem of conifers produced early in the growing season is composed of cells with relatively large diameters and thin walls. Xylem produced late in the growing season is composed of cells with small diameter and thick cell walls. These characteristics may vary under severe conditions during the growing season such as shortage in water availability, shoot growth flushes (Larson 1969), tree injury (Kramer and Kozlowski 1979), or variations in temperature (Schweingruber 1980). As a consequence of dry conditions, radially smaller tracheids may be produced before regular latewood formation starts. When more favorable growing conditions return, subsequently formed cells are again larger with thinner walls (Fritts 1976, see Fig. 1). Zahner (1963) points out that the reason for the earlier small-tracheid formation is the same as for latewood formation, but in the former it is followed by a reversion to earlywood production. The resulting structures in tree rings are called growth

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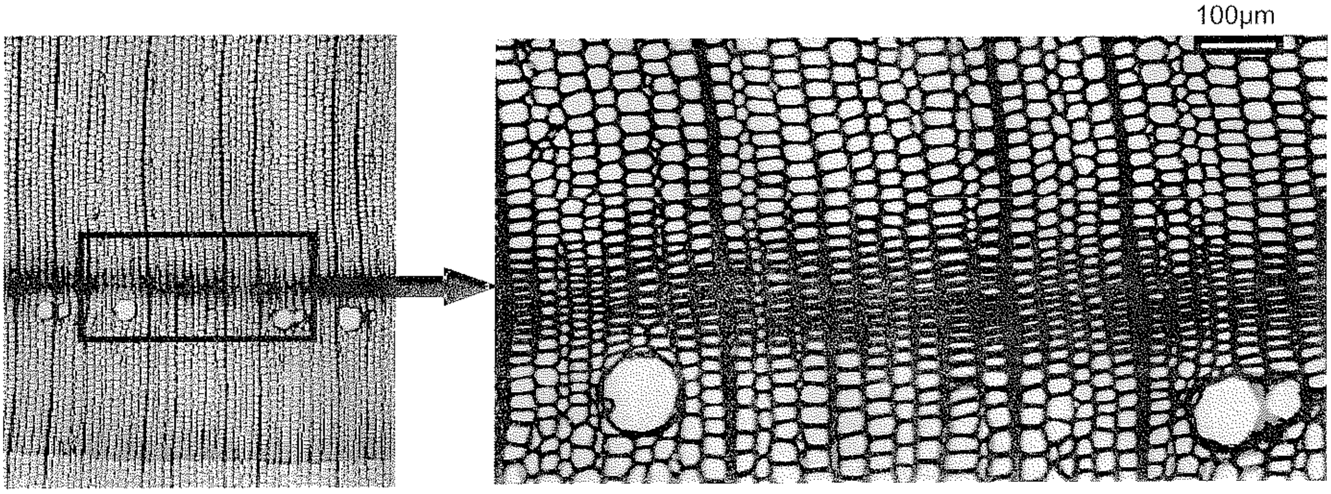
Fig. 1. Microscopic cross section of a *Pinus nigra* tree ring (left) including a false ring and a close-up of the false ring on the right side (scale bar = 100 μm); most false rings are located at a relative radial position of 0.6–0.7 within the tree-ring.



bands, double rings, multiple rings (Kramer and Kozlowski 1979), false rings, or intra-annual growth bands (Fritts 1976). In this paper the most common term "false ring" is used.

Pioneering work on false rings was first published by Schulman (1939) and Glock and Reed (1940) with the main emphasis on clear identification of tree rings for correct age determination and cross dating (Schultze-Dewitz 1968; Wendland 1975; Yamaguchi 1991; Van der Burgt 1997; Gruber 1998). Glock (1951) related "multiple growth layers" to frost injuries and emphasized the idea of using false rings as an environmental indicator. Schweingruber (1980) was apparently the first to utilize false rings in a climatic–ecological study. False rings in softwood tree rings have been successfully used in studies of flood regime (Young et al. 1993), air pollution (Kurczynaka et al. 1997), and as indicators of spring–summer drought (Villalba and Veblen 1996). Identification of false rings has also been considered in hardwoods. Zhang and Romane (1991) demonstrated a relationship between summer rainfall and false rings in *Quercus ilex* L., and Priya and Bhat (1998) used false rings in teak (*Tectona grandis* L.f.) to show a relationship to drought. False rings in teak have been also observed in association with insect defoliation (Priya and Bhat 1997). Leuschner and Schweingruber (1996) did a comparative study of several intra-tree-ring features including false rings for *Pinus sylvestris* L. and *Quercus*. While these studies have shown the utility of false rings as an ecological indicator, the climatic relationships with false rings and their potential use in climate reconstruction models have been little explored. Based on a large data set including 313 trees, this paper explores the use of false rings in climate reconstructions, including some issues on how do deal with non-continuous tree-ring variables.

Material and methods

Study area

The area sampled for this study is located at the eastern edge of the northern Alps, south of Vienna. It is the southern part of the Viennese Basin, a downfaulted lowland to a depth of 5500 m filled with sediments. The area extends about 52 km from Rodaun in the north to Rax-Schneeberg in the south (48°08′–47°40′N) and about 45 km from the Traisen river in the east to the foothills of the northeastern Alps in the west (15°45′–16°18′E). Approximately 50% of this region is covered by forests with European black pine or Austrian pine (*Pinus nigra* Arn.) as the dominant species. Wendelberger (1963) defined these Austrian pine forests as a Tertiary relict. However, it is unclear if this species migrated from the south after the last Ice Age or if the area was a refuge for this species during that time (Frank 1991). Austrian pine is most commonly found on limestone and dolomite bedrock and grows exceptionally well on gravel terraces where it was planted for pitch production, a former major economic endeavor in this region (Strumia et al. 1997). Austrian pines are long lived (up to 800 years) and often found on very poor soils or even cliff faces, with typically umbrella shaped crowns. The geographic distribution of *Pinus nigra* ranges from Anatolia, Cypress, across the Balkan region, southern Italy, Korsica to the Pyrenees. In Austria, *Pinus nigra* can be found in the Karavankes, a mountain range of the eastern Alps, extending eastward along the Slovenian–Austrian border for 80 km. The Viennese basin is at the northern range limit for this species.

Tree ring data

The study is based on the analysis of 313 trees sampled at 29 sites across the area covered with Austrian pine in the Viennese basin. Based on analysis of vegetation communities the sites were split into xeric and medium–mesic habitats. About half of the sites were xeric, and the other half were medium to mesic. Eight to 16 trees from each site were sampled, taking two cores from each tree. Cores were glued on wooden mounts and sanded until individual tracheids were clearly visible. All cores were cross-dated according to Swetnam et al. (1985), and ring widths were measured to the nearest 0.01 mm with an incremental measuring table. Cross-dating quality and measurement errors were evaluated using COFECHA (Holmes 1983). Correctly dated cores were visually examined for false rings. A sequence of earlywood cells – latewoodlike cells – earlywoodlike cells followed by normal latewood cells was recorded as a false ring (Fig. 1). With good surface preparation and magnification, false rings were easily distinguishable from annual tree-ring boundaries. The latter show an abrupt change in cell size between the last-formed cells of the previous ring and the first-produced cells of the current ring. In contrast to the abrupt annual ring boundaries, intra-annual growth bands were recognized by the gradual transition in cell size on both margins of the bands (Villalba and Veblen 1996). Because of the variability of false

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rings tangentially and vertically within tree rings (Kuo and McGinnes 1973), a false ring was identified only when both cores from a tree showed false-ring formation in an annual growth ring.

The proportion of false rings per year, F, was calculated as the ratio:

$$[1] \qquad F = \frac{N}{n}$$

where N is the number of trees that formed false rings in a given year (as evidenced on both increment cores) and n the number of trees that formed annual rings in a given year. The sample depth (n) is lower in the early part of the records and variance increases with reduced sample depths. To address this problem the adjustment proposed by Osborn et al. (1997) was used to calculate the adjusted false-ring proportion (f):

$$[2] \qquad f = F\sqrt{n}$$

The ring-width series of each increment core sampled at the sites were detrended and converted to dimensionless indices by fitting a cubic spline with 50% cutoff at a window equal to two thirds of the length of the series (67n criterion). Series were also modeled using Box and Jenkins (1976) to obtain residual white noise chronologies, i.e., a chronology with all persistence removed (Cook 1985).

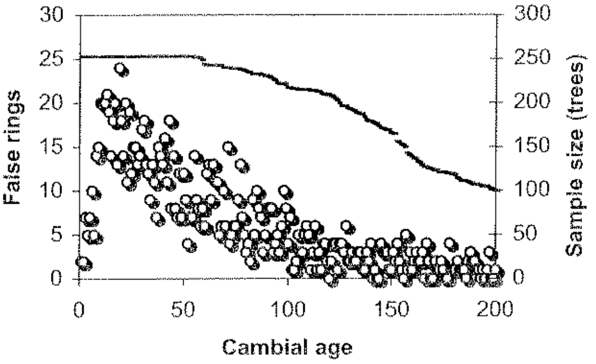
False-ring proportions (f) were converted to a 0–1 coded "binary variable" using a certain f value (eq. 2) as a cutoff point. Years with f values below the cutoff point were coded 0; otherwise, 1. The advantage of a "binary variable" is that even though it is a nominal-level variable it can be treated statistically like an interval-level variable. Different f values were tested and two cutoff values were used in the analysis. First, the median was used as a cutoff value (f = 0.17), which divided the observed 116 years in two equally sized groups. To find the rainfall pattern most responsible for false-ring formation the April, May, and June rainfall data were also coded in above-median ("wet") and below-median ("dry") years. This allowed a listing of all dry–wet combinations, which were subsequently cross tabulated with low and high false-ring years.

As a second cutoff point, f = 0.4, was chosen because it provided the most significant results relative to climate. The binary coded variable using the f = 0.4 cutoff point was further included as an explanatory variables in regression equations to predict climate. The presented results refer to the period 1880–1995 with sample depth of 250 trees at the year 1880, which went up to almost 300 trees at the year 1940.

Climatic data

Vienna is situated at the foothills at the east end of the northeastern Alps, at the border between the alpine and the pannonian region. There is an increasing gradient in annual rainfall from the city of Vienna (630 mm/year) to the west (up to 850 mm/year). Elevation of the sites ranged between 240 and 700 m a.s.l. Climatically the area is subcontinental with expressed pannonic character, with low annual rainfall, extended dry periods during the growing season, and severely cold winters. The regional average of precipitation is 620 mm/year, but locally this average can drop well below this value (Nobilis 1985). Dry winds coming mainly from the east may contribute to drought situations (Mayer and Tichy 1979). Monthly temperature and precipitation data used in this study were made available by the Central Institute for Meteorology and Geodynamics (ZAMG 1995). These data were measured at Hohe Warte located north of the city of Vienna and are representative for the entire area (Ehrendorfer 1987; Holawe and Dutter 1999).

Fig. 2. False-ring proportions and cambial age of trees at breast height. Sample size is plotted on the second ordinate.



Results

General properties of false rings

In total, 1443 of 56 367 (i.e., ~3%) tree rings showed false rings. In 26% of all trees (89 of 313), no false rings were found. Distribution of false rings is positively skewed (skewness = 4.77), while the ring-width data are close to normality. Tree age at breast height ranged between 52 and 575 years with a median of 162 years. The false-ring series were lined up with their cambial age, and Fig. 2 shows the number of counted false rings for the first 200 years of cambial growth along with the sample depth (trees). During the juvenile growth phase trees have an increased tendency to form false rings. This tendency levels off at a cambial age of around 80 years. Because of this, trees younger than 100 years (26 of 313 trees) were further excluded from the analysis.

Climatic conditions and false rings

The observed median of the false-ring proportion for each year (f = 0.17) was used as a cutoff point to assign the 116 years (1880–1995) with false rings values greater than the cutoff point to a "high" false-ring group and years with values less than the cut point to a "low" false-ring group. Both groups held 50% of the investigated years (58). The same procedure was performed with the April, May, and June rainfall data. The majority (72%) of all high false-ring years matched with a low-rainfall (below-median) May. While May rainfall appears to be essential in false-ring formation, the preceding conditions in April might also play a role. Two contour plots are presented; one uses the data from the xeric, and the other one, data from the medium–mesic sites (Fig. 3). Contour plots are projections of three-dimensional surfaces onto two-dimensional planes for different levels of the used variable. Each contour line represents a different false-ring f value (eq. 2). The xeric sites plot shows that higher false rings occur with dry May preferably combined with a wet April. There are also high false-ring "spots" that occur with a dry April.

In a next step, all combinations of wet and dry years for the months April, May, and June were listed and cross-tabulated with low and high false-ring years. This is a group of three (n) permutation with repetition from an two-element set (r), using the formula n^r. A f value of 0.4 was used as cutoff value instead of the median. From the 116 years, 30

Fig. 3. Contour plots presenting false-ring proportions relative to April and May rainfall for (*a*) xeric and (*b*) medium–mesic sites. Only years with *f* values (false-ring proportions) above 0.17 are plotted. Open areas indicate *f* values lower than 0.17 or lack of data. Higher *f* values are increasingly shaded. False rings occur with a dry May combined with a wet April.

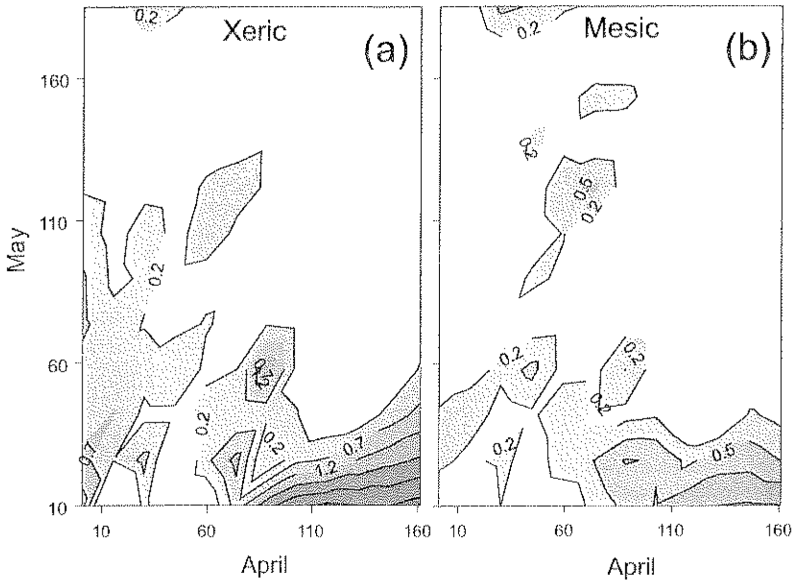
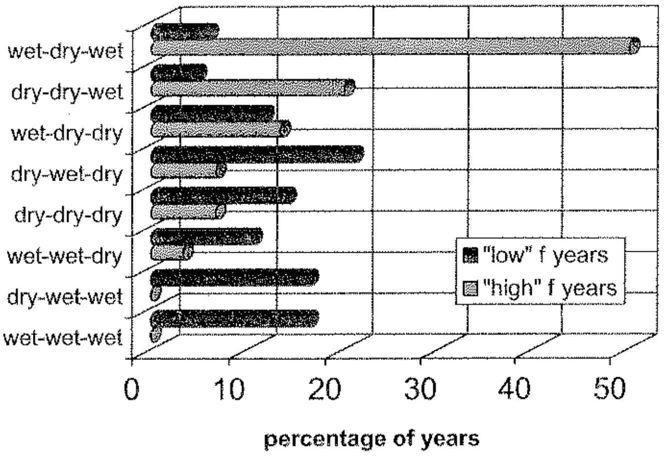


Table 1. Comparison of linear regression models using total ring widths (RW), earlywood widths (EW), and the false rings (FR_d) to predict May precipitation (MayP).

Linear regression	Variance explained, R^2
MayP = 1.74 + 66.5RW	7
MayP = 14.5 + 63.3RW − 38.4FR_d	25
MayP = −32.3 + 100.3EW	20
MayP = −11.5 + 87.8EW − 33.3FR_d	31
MayP = 78 − 39.4FR_d	17

Note: FR_d is a binary coded variable (dummy).

Fig. 4. Frequency of possible April–May–June rainfall combinations associated with high and low false-ring years. A cutoff value of *f* = 0.4 was used to split in high and low false-ring years.



years were assigned as "high" and 86 as "low" false-ring years. Figure 4 shows that 50% of all high false-ring years matched with a wet April, dry May, and wet June pattern. The second most frequent combination was dry–dry–wet (20%), and third most frequent was wet–dry–dry (13%). The chi-square value for the high false-ring years was 30.06 (df = 7), which is significant at the 1% level. On the other side, the combination dry–wet–dry was most associated with the low false-ring years (20%), but the χ^2 test was not significant.

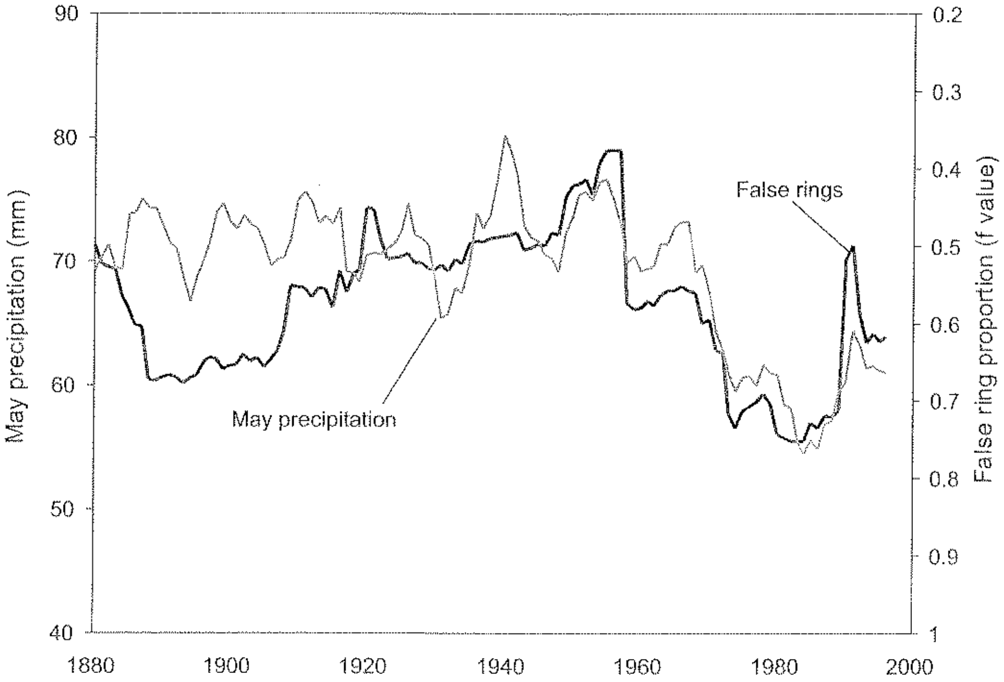
Using false rings in regression equations

Because of its non-normality, false rings cannot be used directly as a continuous variable in regression equations. Therefore, false-ring proportions were converted to a "dummy," which is a numerical variable to distinguish between the presence and the absence of false rings. False-ring proportions above the cutoff point of *f* = 0.4 were coded as 1, and below, as 0. The dummy variable enables its use in regression equations, where it acts like a "switch" that turns false rings on and off in the equation. The regression has the form of

$$[3] \qquad y_i = \beta_0 + \beta_1 Z_i + e_i$$

where y_i is May precipitation, β_0 is the coefficient for the intercept, β_1 is the coefficient for the slope, Z_i = 1 for below and 0 for above a false-ring proportion of 0.4, and e_i is the residual (error). In the equation, β_1 is the estimate of the difference between the groups with and without false rings. This means the coefficient β_1 indicates the change in May rainfall when false rings are switched on and off. The β_1 values are between −33 and −39 in the equation, which means that, in false-ring years ($f > 0.4$, $FR_d = 1$), May precipitation is less than a half of its long-term (1880–1995) average of 68 mm. Table 1 lists a comparison of different linear regression models that predict May precipitation. Total ring width explains less than 10% of the variation but with the added false-ring dummy the variation explained increased to 20%. Seventeen percent of the May precipitation is predicted by the false-ring dummy only, and a maximum of 31% is achieved with a combination of earlywood width and the

Fig. 5. Thirty-year running mean curves of false-ring proportion and May precipitation for 1880–1996; sample size was between 250 and 300 trees. Data prior to 1880 were included to calculate running means for the complete period. False-ring axis was inverted to more clearly show the negative relationship with May precipitation.



false-ring dummy. The variance explained by the regression models is greater (up to 36%) when using only the xeric sites data.

Recent false-ring trends in the Viennese basin

To demonstrate trends of the investigated parameters a 30-year running mean was used as a smoothing process for false-ring proportions and May precipitation to exclude some of the high-frequency variation. Figure 5 shows the trends from 1880 on, because the available rainfall data started in 1845. While the association between rainfall and false rings is loose during the first shown decades (1890–1910), it becomes closer afterwards. The most striking feature is the change in false rings from 1960 to present, at times where May rainfall drops below the long-term average. Around 1960, the false-ring proportion increases rapidly (shown inversely on the figure) and continues to rise during the 1970s and 1980s. Around 1990, a decrease in the false-ring proportion coincides with higher May precipitation.

Discussion

The results presented here provide evidence that rainfall in May is associated with false-ring proportions in Austrian pine. Years with false-ring proportions above the median occur most commonly with a wet April, dry May, and wet June combination. Villalba and Veblen (1996) investigating *Austrocedrus chilensis* (D. Don) Endl. growing at the steppe–forest border in northern Patagonia, also found a dry spring – wet summer type of pattern most likely to be correlated with the formation of false rings. It seems that the change of a wet April to a dry May followed again by a wet June is an important factor in the false-ring formation process. A possible explanation is that a favorable April reactivates cambial division early in the year and large-diameter, thin-walled tracheids are formed. After this initial growth period with optimum soil moisture, water stress increases rapidly during a subsequent dry period in May. Because of water stress cambial growth is affected resulting in false-ring-like structures. Cambial activity is not uniform in space and time and is very responsive to environmental stresses. It is known that diameter growth often stops during droughts and resumes after a rain and alternations of earlywood and latewood are repeated (Kramer and Kozlowski 1979). After phases of sufficient water supply, internal water deficits may have direct inhibitory effects on cambial activity, because high turgor is required for cell enlargement. Water stress reduces cell numbers in the expanding cambial zone with smaller tracheid diameters (Abe and Nakai 1999).

In the regression analysis, false rings were used as a switch and, together with earlywood width, explained 31% of May precipitation. While ring widths are known to be an integrative index of weather conditions over the growing season (Fritts 1976), false rings seem to be especially suitable to indicate selected periods within the growing season. The cutoff point of $f = 0.4$ for coding false-ring proportions into a present–absent variable was found to produce regression models that explained the most variance. Using eqs. 1 and 2 a f value of 0.4 is already reached when at least 7 of 300 trees show false rings in a given year. As with other tree-ring parameters, false rings showed an age-related pattern. The first 80 years of cambium activity showed increased tendency to form false rings, which led to the exclusion of young trees (<100 years) from the analysis. Juvenility of certain tree-ring features may differ greatly (Larson 1969). As an example, tracheid length in *Pinus radiata* leveled off at an age of 10 (Bisset et al. 1951), while

Baas (1986) found that tracheid length in *Pinus longaeva* D.K. Bailey steadily increased over the last 2200 years with no sign of leveling off. Therefore, the found period of false-ring juvenility could be very different across species and sites.

We have shown here that false rings have potential to improve regression models for estimating monthly precipitation. Because of its on–off behavior the regression might be especially suited to identify years with wet springs followed by very dry early summers. Because false-ring formation is related to a rather narrow climatic window within the growing season this tree-ring feature should be especially useful in the verification of other proxy climate records, including historical (or documentary data), which often focus on selected events within a year. Other tree-ring features with similar properties have been studied but little used to improve climate reconstruction models. Frost and light rings have been used in dendroecology to indicate severe events such as volcanic eruptions, insect-caused defoliation, or low temperature. (e.g., LaMarche and Hirschboeck 1984; Filion et al. 1986; Brunstein 1996; Szeicz 1996). Yamaguchi et al. (1993) report threshold temperatures for frequent light rings that could be used as a presence–absence trigger, similar to our findings. These authors further suggest that light rings could be used to verify temperature reconstructions based on transfer functions that use tree-ring width as an independent variable. Future studies should emphasize how these trigger variables in tree rings can be used to improve climate reconstruction models.

The last 150 years of climate records show that all of Austria has become warmer with increased and decreased precipitation in the west and east, respectively (Auer and Böhm 1994). Frequent droughts have been reported in Austria during the past several years. The Viennese basin aquifer represents an unique groundwater system, as it is the only drinking water resource for many local inhabitants. The local rain shortage therefore affects people and farm production, and severe drops of groundwater levels parallel to rain shortage were reported recently by Reitinger (1998) for numerous measuring stations in eastern Austria. The drop of the water table is even more pronounced, because in periods of rain shortage, local farmers are pumping proportionally more water for irrigation. It is shown that recent changes in rainfall coincide with measured false-ring proportions in Austrian pine which provides enough evidence that this noncontinuous tree-ring variable can be useful in multiple ways.

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