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TREE-RING CHRONOLOGIES OF DOWNY OAK (*QUERCUS PUBESCENS*), PEDUNCULATE OAK (*Q. ROBUR*) AND SESSILE OAK (*Q. PETRAEA*) IN THE BIELINEK NATURE RESERVE: COMPARISON OF THE CLIMATIC DETERMINANTS OF TREE-RING WIDTH

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Abstract: In 2004-2006, 50 trees of downy oak (*Quercus pubescens*), pedunculate oak (*Q. robur*) and sessile oak (*Q. petraea*) were sampled in the Bielinek Nature Reserve. The following chronologies were established from their tree-ring series: OMS of 212 years (1793-2004) for downy oaks well as D10 of 183 years (1817-1999) and D13 of 211 years (1789-1999) for the two indigenous oak species pedunculate and sessile oak, respectively. These chronologies were used for signature years and response function analyses. All three chronologies were highly similar, which points to identical responses to the ambient meteorological conditions. The radial increment of downy oak depends primarily on the amount of precipitation. A high annual sum of precipitation, copious rain in spring-summer in particular, results in wide tree rings. Precipitation in form of rain and snow in winter, too, enhance tree growth by raising the groundwater level and improving the water supply in the habitat during the subsequent spring. Droughts in spring and summer, coupled with high air temperature, result in narrow rings. The tree-ring width/climate relationships at the two indigenous oak species are very similar to those of downy oak. Responses are, however, more distinct and with a higher statistical significance.

Keywords: dendroclimatology, *Quercus pubescens*, *Q. robur* and *Q. petraea*, Bielinek Nature Reserve

1. INTRODUCTION

The Bielinek Nature Reserve is unique in Poland. The communities of xenothermic swards and thermophilous oak woods, along with rare plant species, have no equivalent in the country. The Reserve was established in 1927 under the name "Naturschutzgebiet Bellinchen a. d. Oder" [Odra Slopes near Bielinek] and later maintained by the Polish authorities. Since 1957, the Reserve has been featuring on the map of protected areas of Poland as a forest-steppe nature reserve (Ciaciura, 1997a, b; Sukopp, 1997; Rezerwat..., 2000).

The Reserve is located in the westernmost area of Poland. It covers steep (grading up to 50°) slopes of the Odra valley facing south and south-west and rising to 70 m altitude. The slopes, incised by 12 gullies, support a high diversity of relief, lithological, hydrological conditions and microclimate, thus constituting a mosaic of habitats and plant communities.

The microclimatic conditions were studied by Brzoska in 1930-1932 (cf. Celiński and Filipek, 1958; Rezerwat... 2000). He reported large differences in meteorological parameters between sun-bathed slopes and shaded gullies. The maximum and minimum temperature differences between these two habitats may reach 16 and 7°C, respectively; the daily temperature amplitude on sunny slopes and in shaded gullies is 27 and 13°C, respectively. These differences are caused by the strong heating of the S- and SW-facing slopes during sunny days, followed by a high nocturnal heat radiation. The high air temperatures are associated with a low air humidity and high evapotranspiration. On a sunny day, the air

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Fig. 1. *A downy oak in the Bielinek reserve.*

humidity on the slopes may drop below 30%, while evapotranspiration may increase 8-fold as compared to a shaded gully (cf. Celiński and Filipek, 1958, p. 28). This high microclimatic variability results in a close coupling between the slope exposure and type of plant communities. The sunny south-facing slopes are occupied by xenothermic vegetation containing sub-Mediterranean plant species, while the shaded gullies nearby support elm-ash woods.

The best-known and most valuable among the floristic peculiarities of the Reserve is the downy oak (*Quercus pubescens* Willd.). The Reserve is the only Polish site of this species and marks its north-easternmost occurrence boundary. A further, island-like occurrence is located 300 km south, near Jena - Germany, on the slopes of Mount Kunitzberg. The northern continous boundary of downy oak runs in Lorraine, Alsace, south Tirol, Slovenske Rudohorie in Slovakia, and northern Moldavia in Roumania (Sukopp, 1997; Rezerwat..., 2000).

Individuals of downy oak in the Reserve have grown to a height of 20-24 m and a circumference of 2-3 m (Boratyński, 1994 and 1995). The low-set canopy is very extensive (**Fig. 1**); the bark is ash-grey and finely and shallowly cracked. The leaves vary in size and shape; they are usually elliptic or inversely egg-shaped, and the top lobe is shorter than that of the indigenous oaks (Boratyński, 1994 and 1995). The trunks and leaves of one-year-old trees are strongly hirsute in early spring (**Fig. 2**).

The downy oak population in the Reserve is estimated to about 1900 individuals most of which are not particularly tall (up to 12 m in height and 75 cm in trunk circumference measured at the height of 1.3 m) (Ciaciura, 1997b). The leaf morphometry and other diagnostic characters of the species indicate a high proportion of hybrids in the populations. Downy oak is the closest relative of sessile oak (*Q. petraea*) with which it most frequently hybridises; however, hybrids of downy oak with pedun-

Fig. 2. *Leaves of downy oak (right) and of indigenous oak species (left) in early May.*

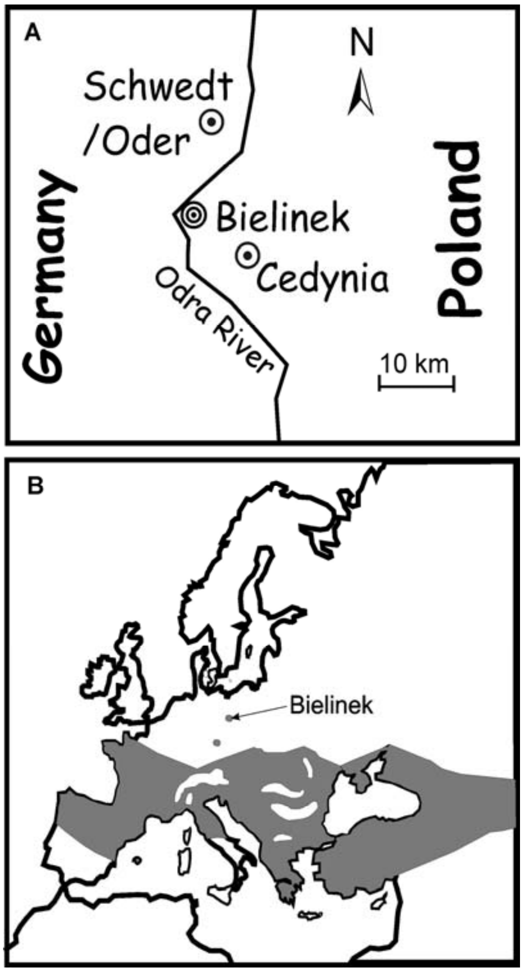

Fig. 3. *Location of the study area. A, central part of the Bielinek reserve: 52°55'25''N; 14°10'30''E (Rezerwat..., 2000); B, geographical range of Quercus pubescens in Europe.*

Table 1. *Statistical data for the tree-ring measurements and for the index chronologies of three oak species.*

Laboratory code	No. of years	Time span	No. of samples	Mean width ring (mm)	Std. Deviation (mm)	*Mean sensitivity*	1st order autocorrelation	Index chronology			
								Median	Mean sensitivity	Std. Deviation	1st order autocorrelation
OMS	212	1793 - 2004	16	1.09	0.41	0.27	0.51	0.97	0.26	0.22	0.08
D10	183	1817 - 1999	15	1.48	0.58	0.29	0.50	0.97	0.25	0.24	0.02
D13	211	1789 - 1999	11	1.20	0.49	0.26	0.54	0.98	0.19	0.17	-0.01

culate oak (*Q. robur*) and with *Q.* x*rosacea* are encountered as well (Staszkiewicz, 1977).

As indicated by its range, downy oak is physiologically well-adapted to drought conditions by a deep rooting system, xeromorphic leaves, osmotic adjustment, and stomatal closure during droughts (Weber *et al.*, 2005).

The present study is aimed at (1) constructing a downy oak tree-ring chronology, (2) correlate it with the tree-ring chronologies of pedunculate and sessile oak, (3) investigating the effects of climate on these three oak species and comparing their tree-ring width/climate relationships.

2. METHODS

Field studies were carried out in 2004-2006 in the forest-steppe Bielinek Nature Reserve managed by the Regional Directorate of State Forests in Szczecin. Due to a high proportion of hybrids in the downy oak population, the plots and trees to be examined were selected after consultations with botanists and foresters, and after reference to previous studies which involved, among others, identification of individuals representing the typical *Quercus pubescens*. A total of three plots were studied: two of them supported the indigenous oak species (*Q. robur* and *Q. petraea*) and one contained downy oak (*Q. pubescens* Willd.). A total of 50 trees were sampled by coring with 40 and 80 cm long Pressler borers. The cores were taken from two sides of the trunk to eliminate slope-related influences, at the height of 130 cm; the trunk circumference was measured at this height as well. The bore holes were protected by wooden pegs and treated with a fungi- and bacteriocide (Lac-Balsam).

The tree-ring widths were measured using a special equipment coupled with the DendroMeter software (Mindur, 2000). All measurements, taken to 0.01 mm, were performed twice from the part closest to the pith towards the bark. The occurrence of very narrow rings and of very wide or variable latewood was recorded, as was the number of rings in the sapwood. When the relevant statistics (linear correlation coefficient k, t statistics and the coefficient of convergence GI) reached high values and the dendrochronological curves, constructed using the TRRAD module of the TREE RINGS computer package (Krawczyk, 1995; Krawczyk and Krąpiec, 1995; Walanus, 2001) were concordant, the two measurements were averaged to obtain a tree-ring width series for a tree. Subsequently, local chronologies were assembled using the classical dendrochronological technique and tested with the COFECHA software (DPL program package, Holmes, 1983 and 1994). These local chronologies served as a basis for the analyses of signature years and response functions.

A signature year is a year in which the tree-ring width in most trees of a population is clearly wider or narrower than in previous and subsequent years (Huber and Giertz-Siebenlist, 1969, cf. Kaennel and Schweingruber, 1995). Signature years are important in dendrochronological dating as well as in identification and elimination of errors in individual samples. Anomalies in the tree-ring curves appear in years with favourable or detrimental environmental factors, among which meteorological conditions are most important and most variable. The signature year analysis was carried out using the TCS software (Walanus, 2002); signature years were identified from at least 10 trees, and the minimum convergence threshold was set at 90%.

In addition, relationships between climate and tree-ring width were explored using the response function analysis (Fritts, 1976; Fritts and Xiangding, 1986; Blasing *et al.*, 1984; Cook and Kairiukstis, 1990; Zielski and Krąpiec, 2004). The response functions were calculated with the aid of the DPL program package (RESPO module, Holmes 1983 and 1994). The technique involves multiple regression analysis in which the mean monthly air temperature and monthly sum of precipitation are the independent variables. RESPO calculates coefficients of linear correlation (k) and multiple regression (r) as well as the multiple regression coefficient of determination (r^2). The response function analysis was applied to follow the effects of climatic factors on the tree ring sequences in a 16-month period (from June of the year preceding the increment to September of the current growing year) over 57 years from 1948-2004. The study made use of climatic data collected by the nearest meteorological stations (Gorzów Wlkp. and Szczecin-Dąbie). Positive values of the linear correlation (k) and multiple regression coefficient (r) express a simultaneous increase of tree-ring width and the meteorological parameter. Negative values evidence a converse effect of a meteorological component on the tree-ring width. The value of r^2 expresses the strength of the relationship between the climatic components and the tree-ring width.

3. RESULTS

Chronologies

The chronology for downy oak (OMS) was produced by combining 16 tree-ring series and consists of 212 rings (1793-2004; **Fig. 4**); the mean ring width is 1.09 mm. The indigenous oak species produced two chronologies, denoted D10 and D13; D10 spans 183 years (1817-1999), while D13 spans 211 years (1789-1999; **Fig. 5**). The

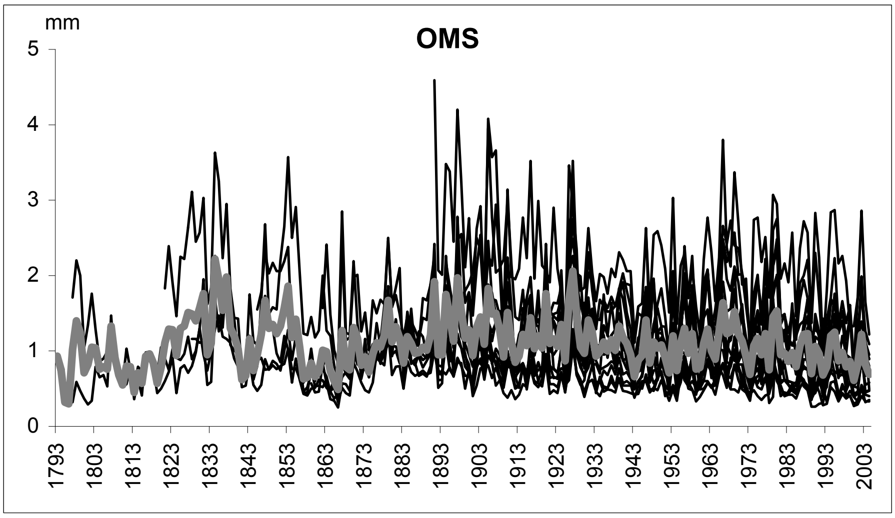

Fig. 4. *Tree-ring series of 16 downy oaks (black lines) and resulting local chronology (grey line).*

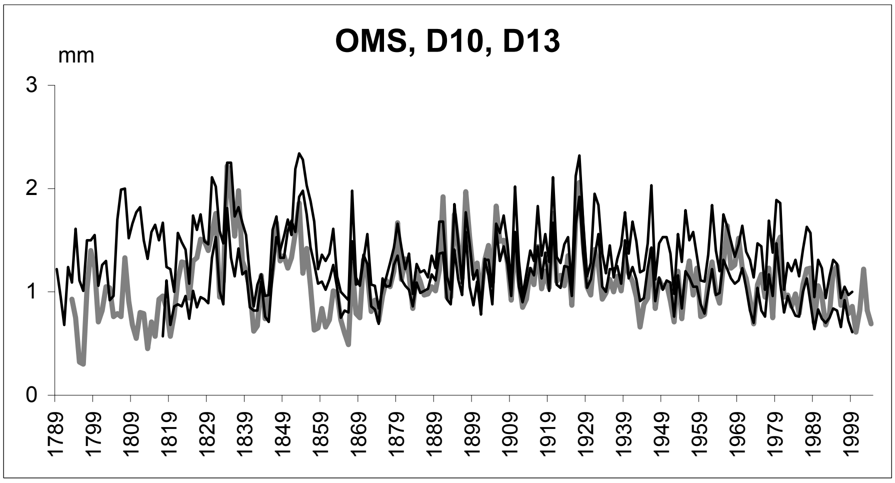

Fig. 5. *Chronologies of downy oak (OMS, grey line) and the two native oak species (D10 and D13, black lines).*

mean ring width in D10 and D13 is 1.48 and 1.2 mm, respectively (Cedro, 2004 and Cedro, in press; **Table 1**). The OMS, D10 and D13 chronologies show a very high agreement between each other and high values of the test statistics (t from 11-20 and GI from 77-79%). These values represent the upper part of the range found in Western Pomerania oak populations (Cedro, 2004).

Signature years

The local chronologies served as a basis for an analysis of signature years. For downy oak 55 signature years with an identical growth trend in at least 90% of the trees were identified (25 years with positive and 30 with negative trends; **Table 2**). Positive signature years were associated with a high annual sum of precipitation, copious precipitation in autumn-winter (prior to growth), and – primarily – with higher - than - average precipitation in spring-summer (May-July).

Let us consider the year 1965 as an example. The annual sum of precipitation was higher than the multi-annual average (Pma) both in Szczecin (1965 precipitation = 569 mm, Pma=532 mm) and in Gorzów (625 versus 541 mm); May and July of that year, too, showed high sums of precipitation. The mean annual temperature was lower than the multi-annual mean (Tma) (1965 in Szczecin = 7.5°C; Tma=8.5°C; 1965 in Gorzów=7.3°C; Tma=8.4°C); summer temperatures, too, was lower than the multi-annual mean.

Negative signature years occurred when the annual sum of precipitation was lower than the multi-annual mean and/or featured droughts and high summer temperatures. The year 1989 is taken as, exceptionally dry and warm. The annual sums of precipitation in Szczecin and Gorzów were 421 and 397 mm, respectively; in winter and spring (particularly in May precipitation was low), while precipitation in summer was at or below the multi-annual mean. The mean annual temperature was very high; it was the warmest year within the period analysed (Szczecin: t=10.1°C; Gorzów: t=9.9°C); the winter-spring period was very warm and the summer very hot.

Similar relationships between signature years and climate were revealed for the indigenous oak species (Cedro, 2004). Depressed growth was primarily associated with annual of precipitation lower than the multi-annual mean and with droughts in summer, while positive trends reflected sufficient water supply in the habitat, particularly in summer. Like for downy oak, an additional factor limiting tree-ring width of the indigenous oak spe-

YEAR	OMS	D10	D13
1884		+	+
1885			-
1890		+	+
1892		-	-
1894	+	+	+
1895	-		-
1896	-	-	
1897	+	+	+
1898	-		-
1899	-		
1901	-	-	
1902	+		+
1903			
1904	-	-	-
1905	+	+	+
1906	-		-
1909	-	-	
1910	+	+	+
1911	-	-	-
1912	-	-	-
1913		+	
1914	+		
1916	+	+	+
1917	-	-	-
1918			+
1919			-
1920	+	+	+
1921	-	-	-
1924	+		
1925	-	-	
1926	+	+	+
1927	+		+
1928	-		-
1929	-	-	-
1931	+	+	+
1932			+
1933	-	-	-
1934			
1935			+
1939	+		+
1940			-
1943	-		
1944	+		
1945			
1946	+		
1947	-		-
1952			-
1953	+		+
1954	-		-
1955	+		+
1957	-		
1959	-		
1962	+		+
1963	-		-
1965	+		
1967	-		
1970	-		
1973	-		
1974	+		
1977		+	+
1978	-		
1979	+		+
1980			-
1981	-	-	
1986	+		
1989	-		
1990	+		+
1992		-	
1994	+		
1996	-	-	
1998	-		
2002	+		

Table 2. *Signature years (+ positive years; - negative years) in oak chronologies: OMS, D10, and D13. Negative years for the Western Pomeranian oaks marked light grey; positive years marked dark grey.*

cies may be a high summer temperature resulting in excessive evapotranspiration and water deficiency.

Response function analysis

The response function analysis described the tree-ring width/climate relationships **(Fig. 6)** which were very similar to those described for the signature years. The high coefficients of determination (particularly for the downy oak: OMS r^2=79%, but also for the indigenous oak species: D10 r^2=50% and D13 r^2=55%) demonstrated a very strong relationship between tree-ring width and meteorological conditions. T correlation and regression coefficients were higher and more frequently significant for precipitation, than for temperature. In addition, they were positive, which means that high sums of precipitation in different months corresponded to wide tree rings. At all sites October and December of the year preceding the growing period and April of the current period were of influence; the relationships were extremely strong in February and June with respect to both correlation and regression. The coefficients for temperature were usually negative, particularly for July and August of the preceding year (at all sites) as well as for May and July of the actual growth year.

4. DISCUSSION AND CONCLUSIONS

In the Bielinek Reserve the downy oaks studied are approximately of the same age as the two indigenous oak species. Contrary to previous estimates of about 100 years (Rezerwat..., 2000), the trees are older than 200 years. The chronologies reconstructed for the native oaks and for the downy oak are very similar, as are changes in the tree-ring widths, which demonstrates identical responses to the changing meteorological conditions. The tree-ring width of *Quercus pubescens* depends mainly on the magnitude of atmospheric precipitation. A high annual sum of precipitation, particularly a copious rainfall in spring-summer, results in wider annual rings. Spring-summer droughts coupled with high air temperatures depress the tree ring growth. Moreover, the amount of snowfall and the duration of snow cover are additional factors affecting the tree-ring width of the oaks growing on the Odra valley slopes studied. A snow cover on south-facing slopes insulates the ground and prevents its heating; water from the melting snow supplies moisture to the roots. Winter rainfalls, too, enhance tree ring width by elevating the groundwater level and increasing the habitat's water supply in spring. The relationships between tree-ring width and climate for the indigenous oak species proved very similar, but the growth responses displayed by *Quercus pubescens* are more distinct and show a higher statistical significance.

The co-occurrence of the downy oak with other xenothermic species typical of the Mediterranean region as well as results of the dendrochronological and dendroclimatological analyses suggest the natural origins of the downy oak's site at Bielinek.

Polish literature features a discussion on the origin of downy oak in Poland. Some authors (Czubiński, 1950; Celiński and Filipek, 1958; Rezerwat..., 2000) favour the hypothesis of a natural origin of the *Lithospermo-Quercetum subboreale* community as a result of an early holocene migration of the xenothermic component and the relict nature of the site. Others (Schwarz 1937, in Celiński and Filipek, 1958 p. 10; Boratyński, 1995; Baryła, 2001) invoke a possibility of the downy oak being introduced accidentally (e.g. in Middle Ages acorns were used as fodder for farm animals), or purposefully (e.g. by Cistercian monks as wood for wine barrels; wine was produced by the monks on the gentler slopes of the Odra valley). However, the absence of any written evidence preclude a verification of either hypothesis.

Downy oaks occurring in Moravia (a location closest to the study site) within the continuous range of the species, grow in very similar habitats, i.e. on steep slopes facing south, with calcium carbonate-rich soil (Chytry, 1997a, b). Aggregations of downy oak (frequently in the form of shrubs) co-occur there – like in Bielinek – with the sessile oak. They are also accompanied by numerous species of plants typical of the Mediterranean region (Chytry, 1997a, b).

A tree-ring width/climate relationship was explored also in downy oak in dry Alpine valleys (e.g., the Valais region in Switzerland), characterised by major climatic factors similar to those in Bielinek Natural Reserve (mean annual temperature 8.6°C; sum of annual precipi-

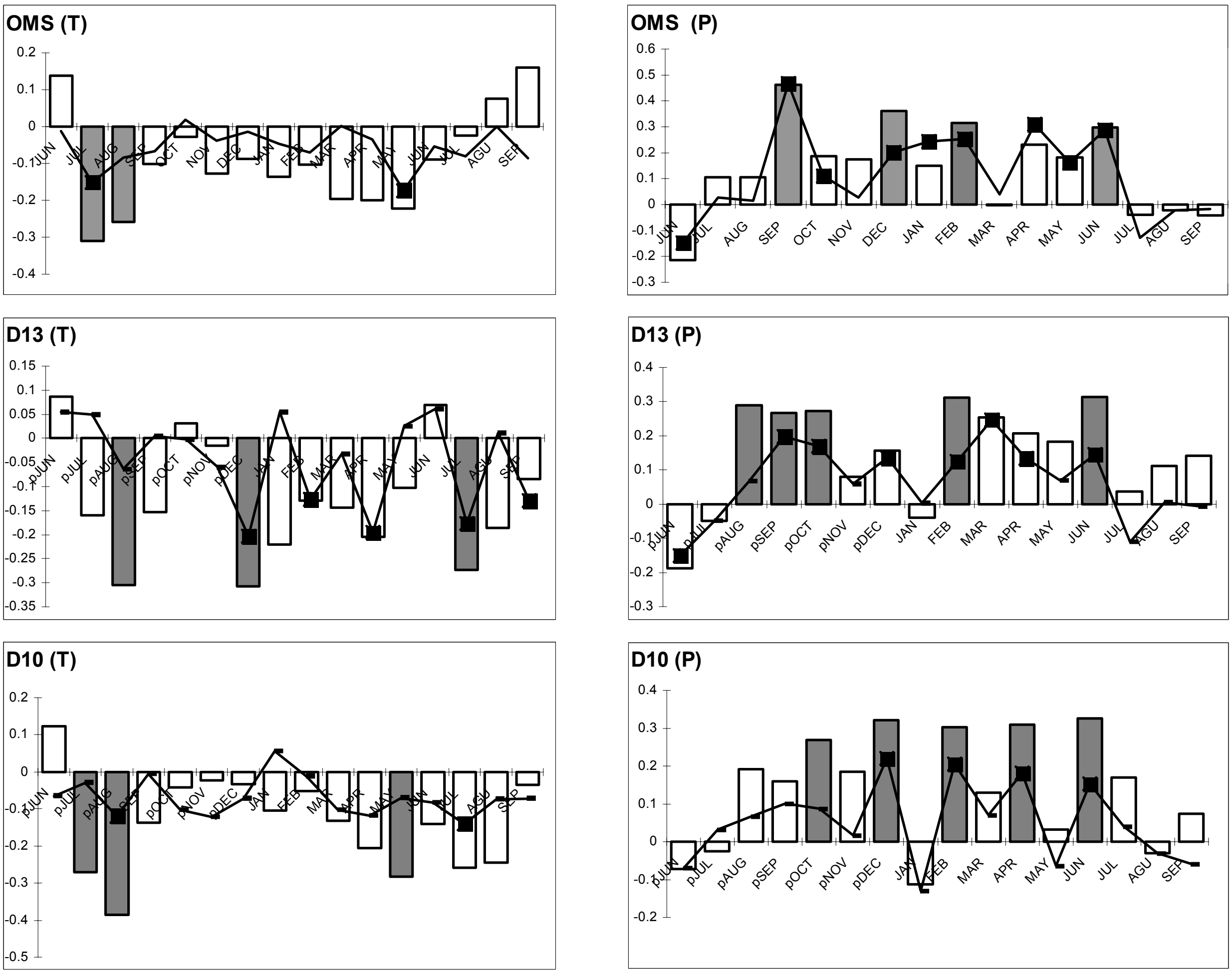

Fig. 6. *Response function analysis for T, air temperature, and P, precipitation. Bars depict correlation coefficients; lines show regression coefficients; significant values are indicated by grey bars and solid black squares. Coefficients of determination: OMS r^2 = 79%; D13 r^2 = 55%; D10 r^2 = 50%.*

tation 599 mm; summer precipitation 123 mm; Weber *et al.*, 2005; Eilmann *et al.*, 2006). The thirteen chronologies were 42-109 years long; the climatic conditions were summarised as a moisture index (Ppot) reflecting water availability in the soil and calculated as a difference between the sum of precipitation and potential evapotranspiration (Weber *et al.*, 2005). The downy oak was found to be highly sensitive to variable meteorological conditions, particularly to moisture deficiency in the soil. Positive relationships were revealed for autumn (August-September) of the year preceding the growing season, and for spring (March-June, with a maximum in April) of that year (Weber *et al.*, 2005; Eilmann *et al.*, 2006).

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