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THE INFLUENCE OF TEMPERATURE AND PRECIPITATION ON RING WIDTHS OF OAK (*QUERCUS ROBUR* L.) IN THE NIEPOLOMICE FOREST NEAR CRACOW, SOUTHERN POLAND

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ABSTRACT

Analysis of the relationship between ring-width indices of pedunculate oaks (*Quercus robur* L.) in the Niepołomice Forest with average monthly air temperatures (1826-1980) and total monthly precipitation (1881-1985) in Cracow revealed a strict relationship between tree-growth and the precipitation of June-July, May-July, and June-August. These relationships are described by a high percentage of agreement, at or around 70%, and coefficients of correlation (r_{xy}) of 0.40 (June-July), 0.36 (May-July) and 0.30 (June-August). The group of 10 oaks with the highest coefficients between growth and precipitation yielded still higher correlations: 0.50, 0.50, and 0.41, respectively. High total monthly precipitation in June and July favors radial growth, while low precipitation reduces radial growth. The influence of air temperature on oak ring-width indices is less significant. The highest positive correlation occurs for January to April of the preceding year. Correlations for the years of radial growth have values close to or below (June) zero except for August.

Es wurden die Beziehungen zwischen den Jahrring-Indices von Stieleiche (*Quercus robur* L.) im Niepołomic-Forst und der mittleren Monatstemperatur (1826-1980) und den Monatssummen der Niederschläge (1881-1985) im Krakau untersucht. Dabai ergaben sich deutliche Zusammenhänge zwischen Wachtstum und Niederschlag von Juni bis Juli, Mai bis Juli und Juni bis August. Diese Zusammenhänge werden belegt mit einer Gleichläufigkeit von ca. 70% und Korrelationskoeffizienten von 0,40 (Juni-Juli), 0,36 (Mai-Juli), und 0,30 (Juni-August). Das Kollektiv der zehn Eichen mit den höchsten Koeffizienten zwischen Wachstum und Niederschlag brachte sogar Korrelationen von 0,50 bzw., 0,50 und 0,41. Hohe Juni- und Juli-Niederschläge fördern das Dicken-Wachstum, geringe Niederschläge hemmen es. Der Einfluß der Lufttemperatur auf die Jahrringbildung der Eiche ist weniger stark. Die höchste positive Korrelation besteht für die Zeit von Januar bis April des Vorjahres. Im Jahr des Wachstums sind die Korrelationen nahe Null oder darunter (Juni), mit Ausnahme im August.

L'analyse des relations existant entre les indices d'épaisseur des cernes de chênes pédonculés (*Quercus robur* L.) provenant de la forêt de Niepołomice, la moyenne mensuelle des températures (1826-1980), et les précipitations mensuelles totales (1881-1985) relevées à Cracow, montrent une relation stricte entre la croissance des arbres et les précipitations de Juin-Juillet, Mai-Juillet, Juin-Août. Ces relations montre un pourcentage de concordance élevé (aux environs de 70%) et des coefficients de corrélation (r_{xy}) de 0.40 (Juin-Juillet,) 0.36 (Mai-Juillet), et 0.30 (Juin-Août). Le groupe de 10 chénes présentant les plus hauts coefficients entre coissance et précipitations, montre même des correlations plus élevées, soit 0.50, 0.50, et 0.41. Des précipitations totales fortes en Juin et Juillet favorisent la croissance radiale tandis que de basses précipitations la réduisent. L'influence de la température de l'air sur les indices est moins significative. La plus haute corrélation positive apparait de Janvier à Avril de l'année précédente. Les corrélations pour l'année même de croissance ont des valeurs proches ou sous (Juin) zéro, excepté pour Août.

INTRODUCTION

The most useful trees for dendroclimatological investigations in Poland are those that occur in the extreme site conditions of high altitudes. Among these are the coniferous stone pine (*Pinus cembra* L.), Norway spruce (*Picea abies* [L.] Karst), and dwarf mountain pine (*Pinus mugo v. mughus* Zenari) and the deciduous sycamore maple (*Acer pseudoplatanus* L.) (Bednarz 1981). The strong dependence of ring width in these species on the air temperatures of the summer months, especially June and July, creates the possibility of reconstructing thermal conditions prevailing in the past (Bednarz 1984). Such reconstructions, however, extend no more than 250 years back into the past. Elaboration of longer reconstructions encounters difficulties resulting from the absence among the above-mentioned trees of long-lived species as well as the lack of ancient building timber and subfossil wood. It is for this reason that investigating the influence of climate on the radial growth of lowland trees, especially pedunculate and sessile oak (*Quercus robur* L. and *Q. sessilis* Ehrh.), is so important. In Poland and other European countries, these trees are some of the most useful to dendrochronology (Eckstein and Pilcher 1982; Leuschner et al. 1987; Pilcher and Baillie 1980a, 1980b; Pilcher et al. 1984; Ważny 1987). Investigations of the effects of climate on radial growth in oaks and the possibility of utilizing their rings for climatic reconstruction indicate that oaks are less promising than trees from high mountain sites and the northern forest border (Eckstein and Schmidt 1974; Gray and Pilcher 1983; Hughes et al. 1978; Pilcher and Gray 1982). However, these studies pertain to oaks growing in the milder Atlantic climatic conditions of western Europe. It is difficult to say whether these investigations also apply to Poland, whose climate is transitional between maritime in the western part and continental in the eastern part, because such studies are lacking. One of the few relevant studies is by Ermich (1959) on cambium activity in the Niepołomice Forest near Cracow. It was carried out with the aim of determining the dates when cambium activity begins and ends, and the connection of this activity with air temperature and precipitation. The method used was microscopic analysis of wood samples collected with a steel tube of hole-puncher type from oak trunks during two consecutive growing seasons. Ermich found that the growth processes in the oak depend significantly on precipitation during the growing season but not on air temperature. Ermich (1953) also noted that the diameter increment of oaks depends chiefly on total June precipitation as well as on the relative humidity of June-August of the current year. To support these results and to obtain information concerning the possibility of utilizing oak wood for dendroclimatological reconstructions, analyses were made of the relationship between ring widths of 27 oaks (*Quercus robur* L.) from the Gibiel reserve in the Niepołomice Forest and mean monthly air temperatures and total precipitation in Cracow. A description of the standardized tree-ring chronology, spanning 225 years, was presented in an earlier publication (Bednarz 1987). The ring width data for 27 trees used in the chronology will be deposited in the International Tree-Ring Data Bank.

STUDY AREA

The Gibiel reserve in the Niepołomice Forest is situated in the southwestern part of the Sandomierz Basin (Lat. 50° 03' N, 20° 22' E) at an altitude of about 186 m and about 20 km east of Cracow (Figure 1). The area of the reserve slopes slightly northward, toward the broad valley of the Vistula River. Along the northern margins of the reserve runs the Drwinka stream, and about 5 km away the Vistula flows. The Traczówka stream, a tributary of the Drwinka, cuts across the southern margins of the reserve. At high water levels in the Vistula, the Drwinka inundates the northern margins of the reserve where, during thaws and heavy precipitation, water stagnates on the surface, filling local depressions in the land.

The entire Gibiel reserve lies on a Holocene floodplain terrace of the Vistula. Intensive accumulation of sediments from the Vistula and its tributaries took place until the Middle Ages, resulting in the formation of warp soils of considerable depth. These processes came to an end when the Vistula and its tributaries were fully embanked, which was not accomplished until the 1920's. Concurrently with the regulation of the channel of the Vistula, extensive drainage was also

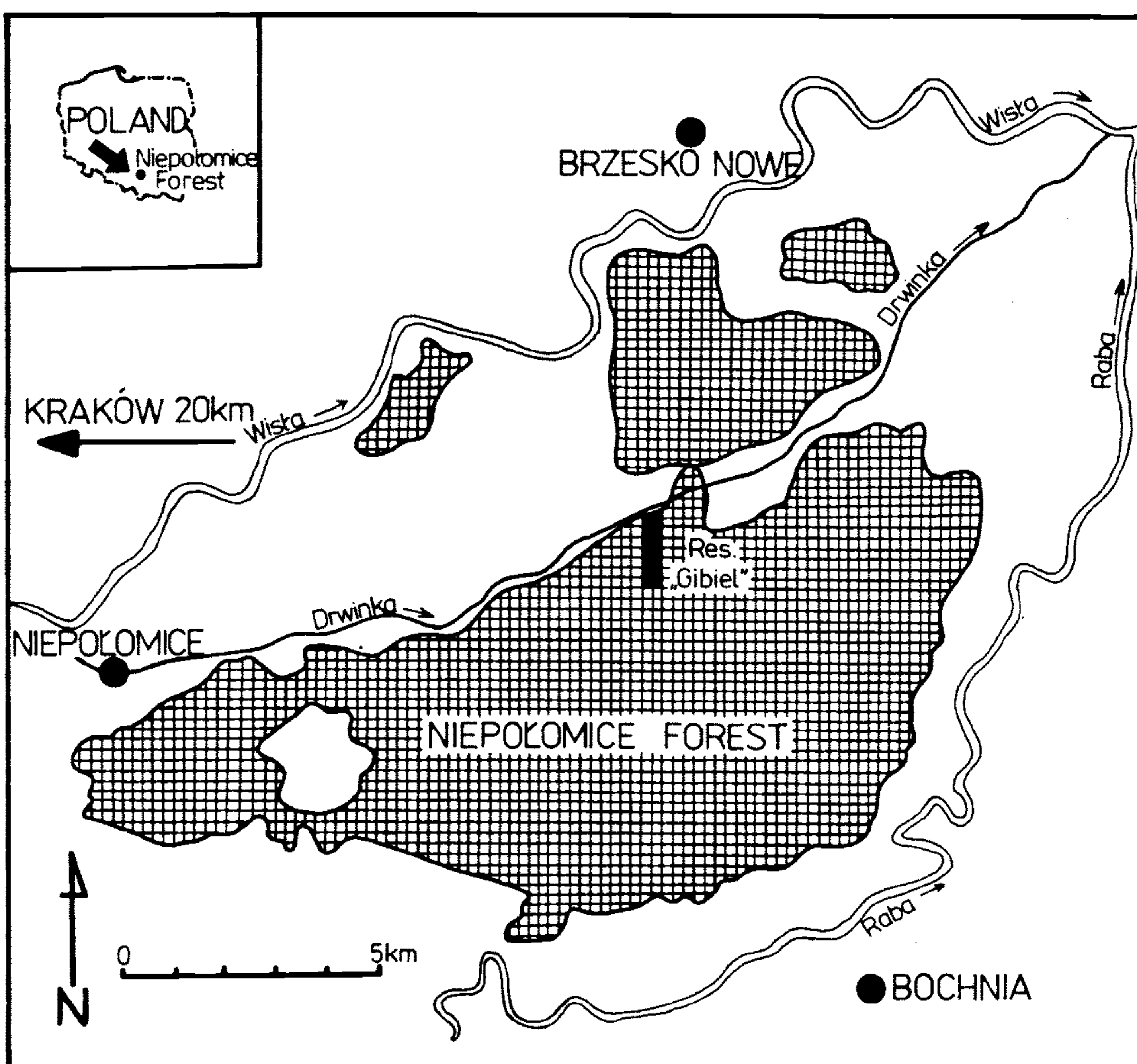

Figure 1. Location of the Gibiel reserve in the Niepołomice Forest.

carried out in the Niepołomice Forest itself. This work was begun in the second decade of the previous century, with the most important drainage work being carried out in the period 1904-1932.

During the last few decades the Niepołomice Forest has been exposed to air pollution, chiefly sulfur dioxide, heavy metals, and fluoride emitted from coal combustion mainly from the metallurgical plant at Nowa Huta. The species most sensitive to industrial emissions in the Niepołomice Forest is Scots pine. Pedunculate oak is relatively tolerant of sulfur dioxide and other airborne pollutants (Grodziński et al. 1984).

SOILS

Natural soil formation processes and human activity have produced in the reserve brown, weakly leached gleyed and muck-gley soils with podzolic peat-muck soils in the southern part (Adamczyk 1984). These soils are very fertile and have a high moisture content all year round. Loamy and sandy loam, intercalated with loam and gravel, predominate. Notable is the low pH of these soils, varying from 3.0 to 4.5.

FOREST COMMUNITIES

The moist oak-hornbeam community (*Tilio-Carpinetum stachyetosum*) occupies most of the Gibiel reserve. Its tree layer consists of oaks (*Quercus robur* L.) with a small admixture of Scots pine (*Pinus sylvestris* L.) and European hornbeam (*Carpinus betulus* L.) in the secondary treestand. Second with respect to coverage is alder-elm forest (*Circaeo-Alnetum*), which is associated with the wettest stands of the reserve. In addition to oak, black alder (*Alnus glutinosa* Gaertn.) occurs in the tree layer of this community. The remaining communities -- lowland elm forest (*Ficario-Ulmetum campestris*), mesic oak-hornbeam (*Tilio-Carpinetum*), and mixed oak-pine forest (*Pino-Quercetum*) -- are limited to fairly small areas. Oaks, on which the tree-ring chronology is based, occur chiefly in the alder-elm forest and moist oak-hornbeam, i.e. in the wettest habitats of the reserve.

CLIMATE

In the southwestern part of the Sandomierz Basin, in which the Niepołomice Forest lies, the transitional character of Poland's climate -- between maritime and continental -- is most apparent. Large fluctuations in temperature, precipitation, and the timing of the seasons are characteristic of this region. Gaussen-Walter's diagram contains the basic climatic data for the area studied (Figure 2).

Access to long-term meteorological information as close as possible to the trees used for study is vital for dendroclimatological investigation. In this study, the meteorological station at Cracow, 20 km away, met these conditions. It has had uninterrupted observations on air temperature from 1826, and precipitation from 1881. These are some of the longest meteorological observations in Europe (Trepińska 1971).

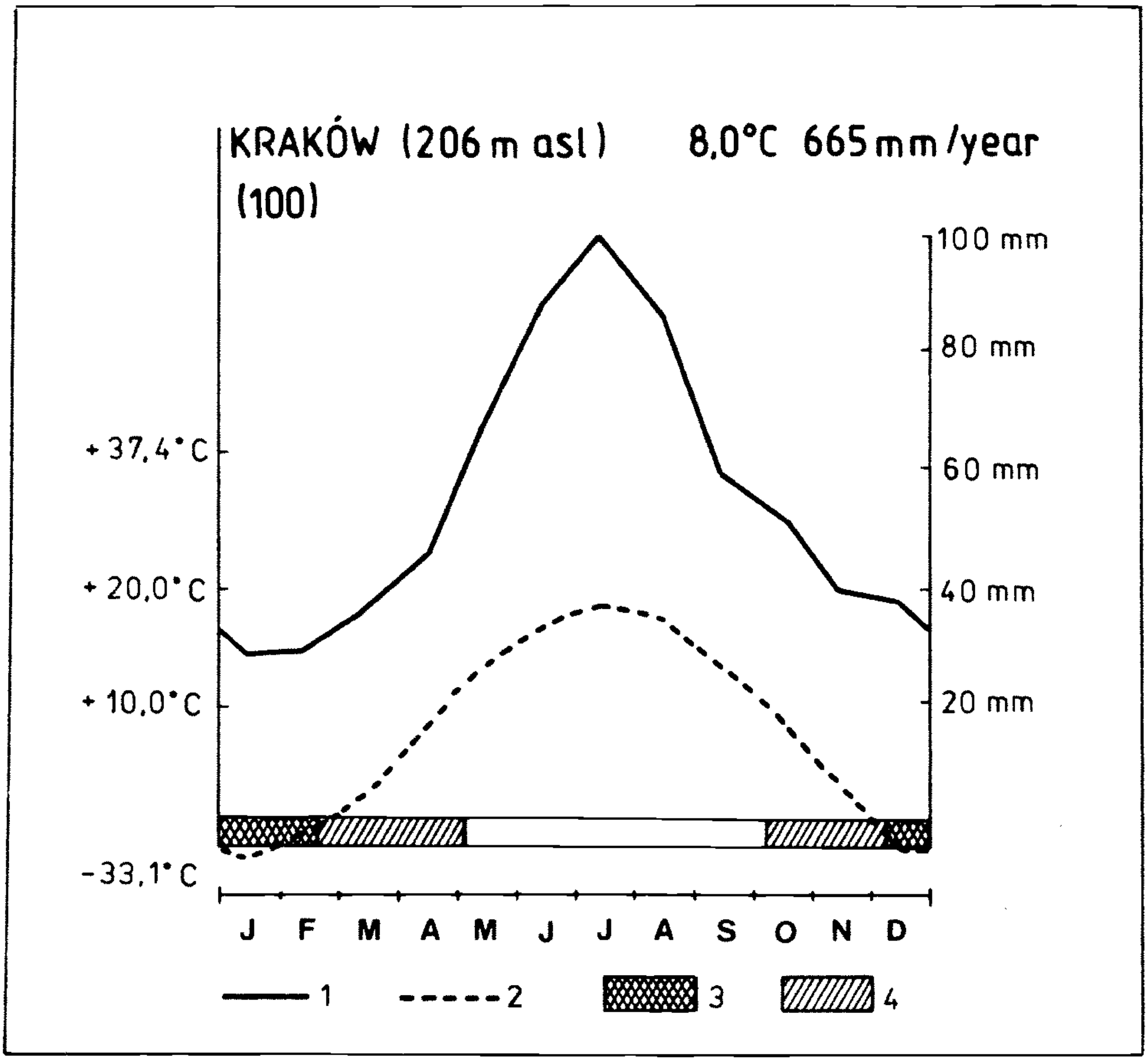

Figure 2. Climatic diagram for Cracow compiled using Gaussen-Walter's method. 1= mean monthly precipitation 2= mean monthly air temperatures, 3= period with mean diurnal temperatures below 0°C, 4= period with occurrence of frost (minimum air temperature below 0°C).

RESULTS AND DISCUSSION

In examining the relationship between oak growth, mean monthly air temperatures, and total precipitation, we have used the percentage of agreement and coefficient of correlation. These relationships were determined for the year of tree-ring formation (January to August) and for the year preceding it (January to December). Correlations were also calculated between tree-ring width, temperature, and precipitation in winter, spring, summer, autumn, and the June-July period. The long term tree-ring chronology was compared with meteorological data from the Cracow station. The data spanned 155 years in the case of air temperature and 105 years for precipitation. The analyses yielded a surprisingly strong relationship -- despite considerable site moisture in the Gibiel reserve -- of tree-ring widths and precipitation in June-July of the year of growth (Figure

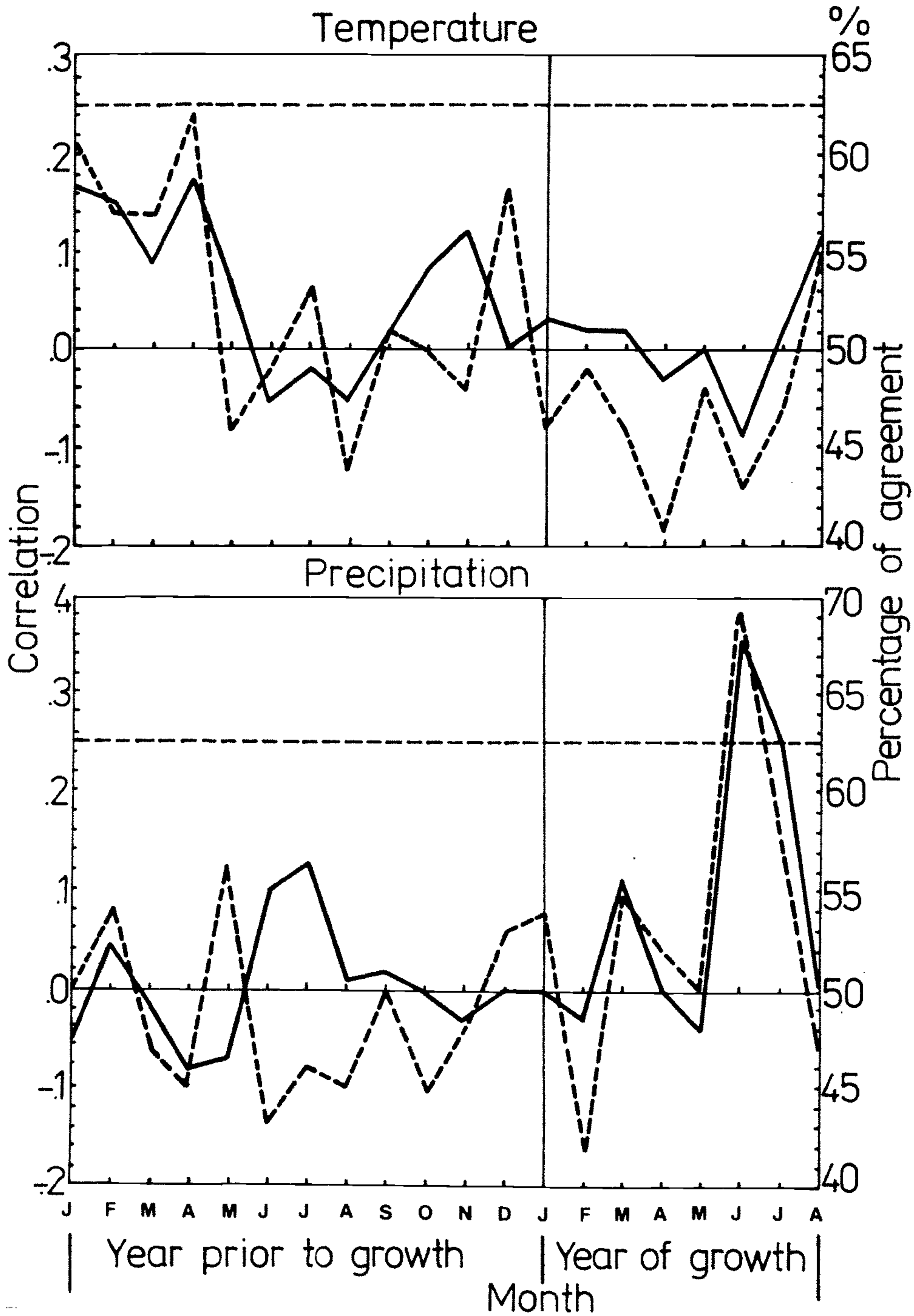

Figure 3. Relationship of mean ring-width indices in *Quercus robur* from the Gibiel reserve in the Niepołomice Forest with mean monthly air temperature (1826-1980) and monthly precipitation (1881-1985), expressed by the coefficient of correlation (solid line) and the percentage of agreement (dashed line). The horizontal dashed lines indicate the 0.01 significance level for correlation.

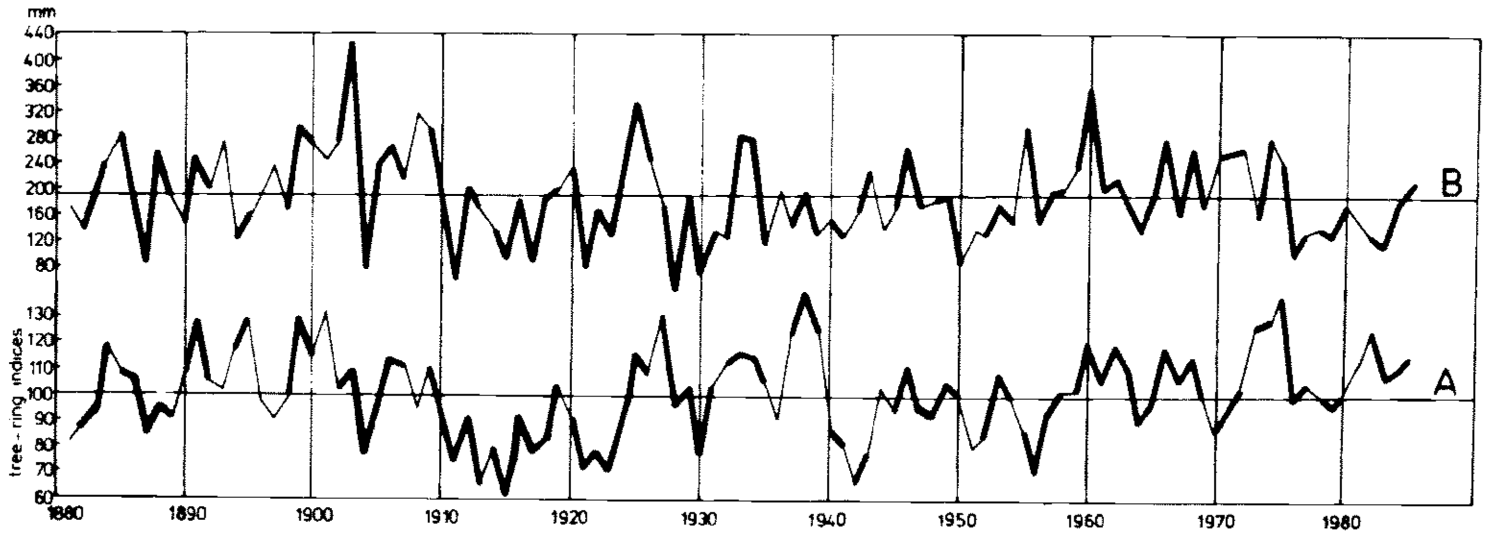

Figure 4. Comparison of the standardized tree-ring chronology of *Quercus robur* from the Gibiel reserve in the Niepołomice Forest (A) with June-July precipitation in Cracow (B).

Table 1. Coefficients of correlation and percentages of agreement for temperature (T) and precipitation (P) for *Quercus robur* from the Gibiel reserve in the Niepołomice Forest. A= 27 trees, B= 10 selected trees. The correlation periods for temperature and precipitation are 1826-1980 and 1881-1985, respectively.

			Winter D-F	Spring M-M	Summer J-A	Autumn S-N	May-July	June-July
A	Coeff. correlation	T	0.02	0.00	0.01	0.18	-0.03	-0.05
		P	0.00	0.07	0.30	-0.10	0.36	0.40
	% of agreement	T	54	45	44	50	44	34
		P	50	62	65	47	70	68
B	Coeff. corelation	P	0.04	0.18	0.41	-0.18	0.50	0.50
	% of agreement	P	47	63	62	48	73	71

3, 4). This relationship is described by the percentage of agreement at or around 70% and correlation coefficients (r_{xy}) of 0.40 (June-July), 0.36 (May-July), and 0.30 (June-August). Coefficients are even higher -- 0.50, 0.50, and 0.41, respectively (Table 1) -- for a group composed of the 10 oaks with the highest coefficients between growth and precipitation.

High total precipitation in June-July is conducive to radial growth, while low precipitation reduces it. This is evident when the standardized tree-ring chronology is compared with the precipitation curves for June-July, May-July, and June-August, especially when these are smoothed by using moving means according to equation $b = (a + 2b + c) \times 0.25$ (Figure 5).

From the relationships determined here, conclusions regarding precipitation in the past can be drawn from analyses of modern and fossil oak wood from riparian forest and oak-hornbeam habitats similar to those of the Gibiel reserve.

The influence of air temperature on oak ring widths is less significant. The highest positive correlation occurs for the preceding year in the period January-April. The correlations for the year of growth are close to zero or negative (June) except for August. The inverse relationship between growth and temperature is emphasized by the percentages of agreement (Figure 3, Table 1). This relationship contrasts with that in the British Isles where high temperatures during the growing season favor oak growth (Pilcher and Gray 1982).

Ecological interpretation of the relationships found is a separate problem, as they appear to indicate the existence of a considerable water deficit in June and July. This seems somewhat

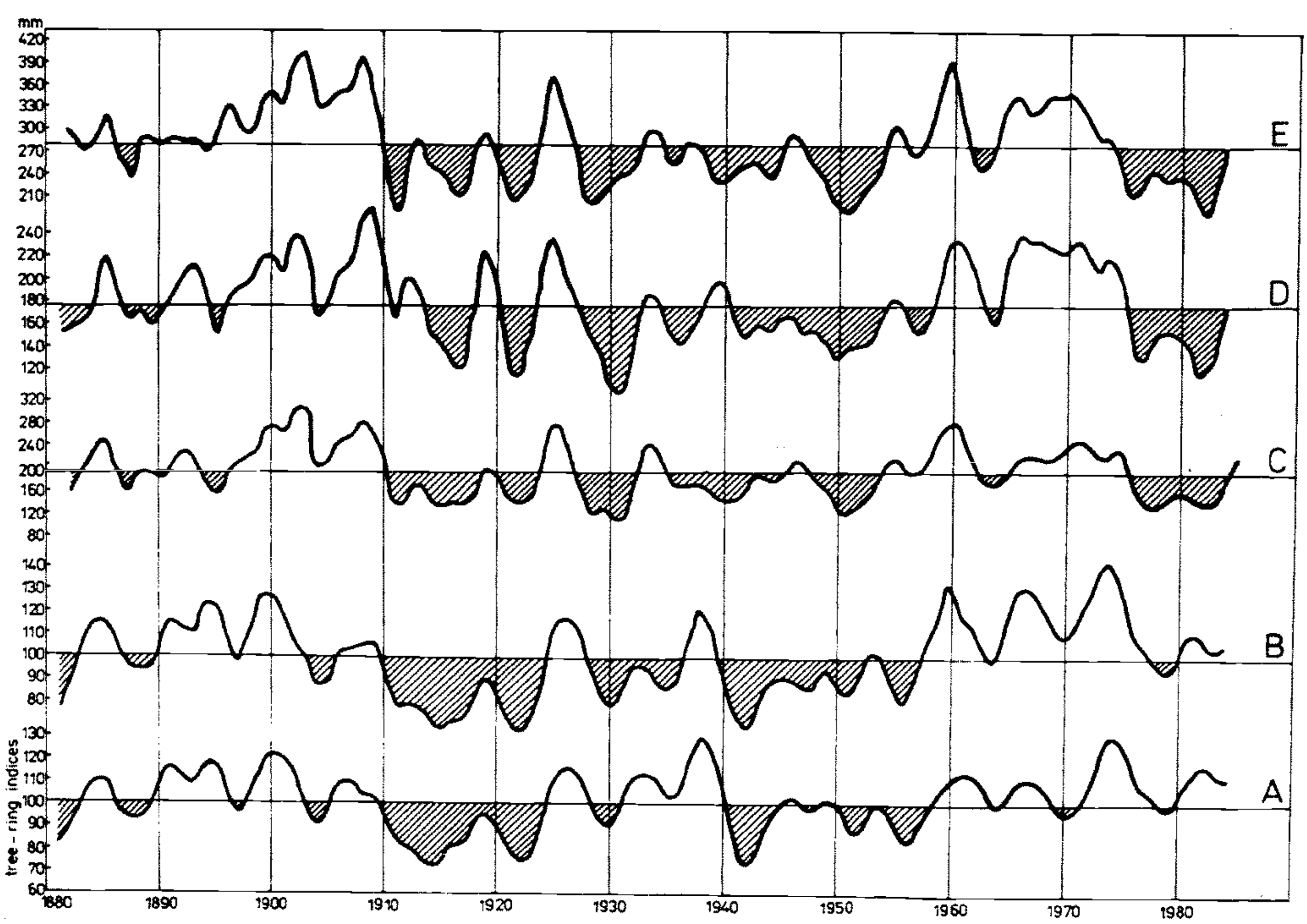

Figure 5. Comparison of standardized oak tree-ring chronology from the Gibiel reserve in the Niepołomice Forest: A= 27 trees, B= 10 selected trees, with total precipitation for June to July (C), May to July (D), and June to August (E). Curves were adjusted by mean moving method (see text).

unlikely because oaks grow in the moist oak-hornbeam and alder-elm forest habitats, in which there is plenty of water. Moreover, with high water in the Vistula, the northern margins of the reserve are sometimes inundated by the Drwinka. Though in dendroclimatological investigations of oak, some cases of equally strong correlation between radial growth and precipitation do exist, they concern markedly different site conditions only. For instance, Pilcher (1976) found a correlation of 0.47 between oaks and October-September precipitation at Rostrevor in the Mourne Mts. of Ireland. This relationship, however, held only for oaks growing on acid, stony soil, where the underlying rock was part of the igneous intrusion complex.

The positive correlation between oak growth and precipitation in the Gibiel reserve cannot be attributed to a deficit of water caused by the drainage work that was carried out in the forest in the beginning of the previous century, but mainly in the period 1904-1932. This drainage did not change the character of the observed relationship, which is similar throughout the period 1881-1985. The correlation coefficients between tree-ring width indices and June-July precipitation are 0.43 (1881-1904), 0.57 (1905-1932) and 0.23 (1933-1985). It cannot be ruled out that for the oaks in question, we are dealing with an indirect effect of precipitation on growth, through a decrease in the food supply of phyllophagous insects, especially oak leaf roller moths, *Tortrix* sp., and cockchafers, *Melolontha* sp.. Roller moth caterpillars, mainly *Tortrix viridiana*, can consume up to 40% of the total production of oak leaves (Bandoła-Ciolczyk and Witkowski 1976). Information on the limiting effect of phyllophagous insects on ring widths of the oak is provided by Wellenhofer (1948), Christensen (1987), and others. It is difficult to say exactly to what extent profuse precipitation and low air temperatures in June and July affect the development of phyllophages. Perhaps in the case of oaks from the Gibiel reserve, the positive effect of precipitation on growth results from several factors.

Full elucidation of these interesting problems requires comparative dendroclimatological investigations in other parts of the Niepołomice Forest, and detailed analysis of soils with particular attention to the water conditions.

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REFERENCES

Adamczyk, B.
1984 Soils. In *Forest Ecosystems in Industrial Regions*, edited by W. Grodziński, J. Weiner, and P. F. Maycock, pp. 11-16. Springer-Verlag, Berlin.

Bandoła-Ciolczyk, E., and Z. Witkowski
1976 Energy flow through oak leaves and caterpillars feeding on them in an oak-hornbeam ecosystem of the Niepołomice Forest *Bull Acad. Pol. Sci.* CL. II 24: 385-392.

Bednarz, Z.
1981 Relationship of tree-ring widths in the Tatra Mountains to variations in monthly temperature and precipitation. *Mitteillungen Forstlichen Bundesversuchsanstalt*, Vien, 142: 367-389.
1984 The comparison of dendroclimatological reconstructions of summer temperatures from the Alps and Tatra Mountains from 1741-1965 *Dendrochronologia* 2: 63-72.
1987 The 225-year tree-ring chronology of oak *Quercus robur* L. in the Niepołomice Forest near Kraków. *Dendrochronologia* 5: 59-68.

Christensen, K.
1987 Tree-rings and insects: The influence of cockchafers on the development of growth rings in oak trees. In *Proceedings of the International Symposium on Ecological Aspects of Tree-Ring Analysis*, edited by G. C. Jacoby and J. W. Hornbeck, pp. 142-154. United States Department of Energy.

Eckstein, D., and J. Pilcher
1982 Europe. In *Climate from Tree-Rings*, edited by M. K. Hughes, P. M. Kelly, J. R. Pilcher, and V. C. LaMarche, Jr., pp. 142-150. Cambridge University Press, Cambridge.

Eckstein, D., and B. Schmidt
1974 Dendroklimatologische Untersuchungen an Stieleichen aus dem maritimen Klimagebiet Schleswig-Holsteins. *Angewandte Botanik* 48: 371-383.

Ermich, K.
1953 Wpływ czynników klimatycznych na przyrost debu szypułkowego (*Quercus robur* L.) oraz sosny zwyczajnej (*Pinus sylvestris* L.): Próba analizy zagadnienia. (The effect of climatic factors on the increment of *Q. robur* and *P. sylvestris*: Attempted analysis of the problem.) Prace roln.-leśne. *PAU*, 68.
1959 The investigations of the seasonal course of the diameter growth of *Pinus sylvestris* L. and *Quercus robur* L. *Acta Soc. Bot. Poloniae* 28(1):15-63.

Gray, B. M., and J. R. Pilcher
1983 Testing the significance of summary response functions. *Tree-Ring Bulletin* 43: 31-38.

Grodziński, W., J. Weiner, and P. F. Maycock (Editors)
1984 *Forest Ecosystems in Industrial Regions*. Springer-Verlag, Berlin.

Hughes, M. K., P. Legged, S. J. Milsom, and F. A. Hibbert
1978 Dendrochrochronology of oak in North Wales. *Tree-Ring Bulletin* 38: 15-23.

Leuschner, H. H., A. Delorme, and H. C. Hofle
1987 Dendrochronological study of oak trunks found in bogs of northwest Germany. In *Proceedings of the International Symposium on Ecological Aspects of Tree-Ring Analysis*, edited by G. C. Jacoby and J. W. Hornbeck, pp. 298-318. United States Department of Energy.

Pilcher, J. R.
1976 A statistical oak chronology from the north of Ireland. *Tree-Ring Bulletin* 36: 21-27.

Pilcher, J. R., and M. G. L. Baillie
1980a Six modern oak chronologies from Ireland. *Tree-Ring Bulletin* 40: 23-24.
1980b Eight modern oak chronologies from England and Scotland. *Tree-Ring Bulletin* 40: 45-58.

Pilcher, J. R., M. G. L. Baillie, B. Schmidt, and B. Becker
1984 A 7272-year tree-ring chronology for western Europe. *Nature* 312: 150-152.

Pilcher, J. R., and B. Gray
1982 The relationships between oak tree growth and climate in Britain. *Journal of Ecology* 70: 297-304.

Trepińska, J.
1971 The secular course of air temperature in Cracow on the basis of the 140-year series of meteorological observations (1826-1965) made at the Astronomical Observatory of the Jagiellonian University. *Acta Geoph. Pol.* 19 (3): 277-304.

Ważny, T.
1987 Dendrochronology of oak in Poland. In *Proceedings of: Methods of Dendrochronology - I*, edited by L. Kairiukstis, Z. Bednarz, and E. Feliksik, pp. 229-237. International Institute for Applied Systems Analysis /Polisch Academy of Sciences-Systems Research Institute, Warsaw.

Wellenhofer, W.
1948 Untersuchungen über die Ursache der Eichenjahrringschwankungen und Aufstellung einer langjährigen Spessart-eichen-Jahrring-Chronologie. Inaugural-Dissertation. München.