

epilimnion in oxygen-18 during the summer months, with respect to local precipitation and groundwater inflow, is about 2‰ (Wachniew 1995). Starting from early Holocene, a gradual reduction of the isotope enrichment by about 1.5‰ due to the diminishing residence time of water in the lake would be required to explain the observed general decreasing trend of $\delta^{18}\text{O}$. Although the fluctuations of the water balance of Lake Gościąg during the Holocene cannot be reconstructed quantitatively, it is clear that they have a potential to modify substantially the average oxygen-18 content of the lake water and, consequently, the oxygen-18 content of the deposited calcite.

The $\delta^{18}\text{O}$ profile during early Holocene (ca. 11,500 to 8500 cal BP) reveals a relatively constant level, with two small maxima around 11,000 and 9000 cal BP, matching the high water-level stands of the Lake Gościąg system (Starkel et al., Chapter 8.5). As mentioned above, conditions of calcite formation during this period were very similar to those prevailing during the Younger Dryas. The beginning of relatively fast decrease of $\delta^{18}\text{O}$ (around 8500 cal BP) is marked by a dramatic reduction of Mn content in the sediments, by more than one order of magnitude (Łącka et al., Chapter 8.2). This is also the time when Ruda stream started to develop as a main drainage of the entire system of lakes, in response to a substantial increase of precipitation rate in the region (Starkel et al., Chapter 8.5.). Gradual decrease of $\delta^{18}\text{O}$ between ca. 8500 and 6300 cal BP could then be related to diminishing mean residence time of water in the lake and the resulting smaller evaporative enrichment of oxygen-18. Between ca. 6500 and 3700 cal BP the oxygen-18 trend is reversed: the $\delta^{18}\text{O}$ increases gradually by about 0.5‰. Mineralogical analyses indicate active growth of calcite crystals in the sediments deposited during this time period (Łącka et al., Chapter 8.2). Because the temperature of the re-crystallization process was at least 10°C lower than the typical temperature of calcite formation in the epilimnion, the newly formed calcite in the sediments will be substantially enriched in oxygen-18 (by about 2.5‰).

Gradually increasing content of secondary calcite in the bulk sediment might be responsible for the apparent increasing trend of $\delta^{18}\text{O}$ in the bulk carbonate. After a distinct drop around 4000 cal BP, the $\delta^{18}\text{O}$ record stabilizes again for about 2000 years, indicating a relatively stable water balance of the lake. Calcite crystals that are formed in the lake during this time period are similar in size and shape to those formed during early Holocene (Łącka et al., Chapter 8.2).

The above discussion clearly demonstrates that more detailed studies of the possible changes of water balance of Lake Gościąg during the Holocene would be required to better understand the parameters controlling $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ of authigenic carbonates deposited in the lake during this time period.

8.7. SPECTRAL ANALYSIS OF POLLEN INFLUXES FROM VARVED SEDIMENTS OF LAKE GOŚCIAŹ, POLAND

*Raymond Young, Adam Walanus, Rob Lingeman, Eva T. H. Ran, Bas van Geel, Tomasz Goslar & Magdalena Ralska-Jasiewiczowa**

The sediments from Lake Gościąg are suitable for time series analysis, as they consist of annual laminae (Goslar, Chapter 6). The laminations provide almost absolute certainty about the duration of events registered in the cores. Lamination in the upper ca. 8 m of the cores is less clear than farther down, which makes the chronology a floating one. However, counting of laminae and radiocarbon datings show that the top contains ca. 3200 laminae, and that the total of ca. 12,800 annual laminae in the cores G1/87 and G2/87 were formed from late Allerød up to the present (Goslar, Chapters 7.2 and 8.1).

Autocorrelation analysis reveals a significant correlation of the winter-layer thickness to that of the year before, probably caused by the winter-material being so fine-grained and light that it takes up to a year to deposit. However, it provides no indications for periodic patterns, as the partial autocorrelation coefficients at lags 2 through 25 are not significant.

In the present study we have carried out a spectral analysis on pollen influxes in the Lake Gościąg sediment (data published earlier as percentages by Ralska-Jasiewiczowa & van Geel 1992). The samples had been taken at intervals regularly spaced in time, according to the annual lamination, which made these data more suitable for time-series analysis than palynological data usually are. Following the line of reasoning by Young (1997) we used global significance assessment procedures, for the analysis involved the calculation and testing of many power spectra including many powers themselves. We interpret the results in terms of cycles in climate or human influence.

Data

The time series analysed consist of pollen influxes for 19 selected taxa recovered in the G1/87 core. We selected the most abundant pollen taxa representing elements of the regional vegetation, and we excluded from the analysis the taxa most indicative for human influence. Observations in the time series represent the number of pol-

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len grains deposited per square cm per year. We use influxes instead of percentages of the pollen sum, because in this way the analysed series are more independent from each other.

We constructed as compound variables the sums of influxes from a number of pollen taxa. Total influx is the sum of influxes of all pollen-sum taxa as shown in the diagram of Ralska-Jasiewiczowa & van Geel (1992). Arboreal influx is from all trees and taxa in the tree layer as shown in the same diagram. Non-arboreal influx is from all other pollen-sum taxa. Early-flowering wind-pollinated forest trees include *Pinus*, *Quercus*, *Betula*, and *Corylus*. Insect-pollinated taxa are *Acer*, *Calluna*, *Frangula*, *Fraxinus*, *Hedera*, *Rhamnus*, *Tilia*, *Taxus*, *Ulmus*, *Viburnum*, and *Viscum* (although *Calluna* and *Tilia* may almost behave like anemophilous taxa; Faegri & Iversen 1950). Taxa indicative for wet conditions are *Alnus*, *Betula*, *Fraxinus*, *Populus*, and *Salix* (although *Betula* may also grow in drier conditions).

We selected the samples numbered 150 through 208 as shown in the diagram in Ralska-Jasiewiczowa & van Geel (1992), because they were sampled most regularly. Samples were 10 varves thick, in principle taken one for every 50 varves. The 64 observations cover 3200 years (from ca. 7800 to 4600 cal BP). This time span allows for the interpretation of quasi-periodicities between 800 and 100 years.

Methods

General statistics

We carried out all statistical and time-series analyses with help of the computer program Systat versions 5.1 and 5.2 for the Macintosh, unless stated otherwise.

Data processing

We used linear interpolation, taking into account the two nearest neighbours, in order to make distances between samples equal. Interpolation resulted in a minor decrease in the variance of data, a decrease assumed to have a minor effect on spectral analysis, so we did not compensate for it. After interpolating, we detrended the time series by taking the residuals of a linear regression of influx on time.

Spectral analysis

We calculated periodograms for all taxa and compound variables in Systat, which uses an ordinary Fourier transform, in which according to Chatfield (1989) the periodogram I at frequency ω , $I(\omega)$, equals:

$$I(\omega) = \frac{NR_p^2}{4\pi} \tag{1}$$

N : number of observations in the time series.
The amplitude of the p th harmonic, R_p , equals:

$$R_p = \sqrt{a_p^2 + b_p^2} \tag{2}$$

in which the Fourier series coefficients, a and b , equal:

$$a_p = \frac{2}{N} \sum x_t \cos\left(\frac{2\pi p t}{N}\right) \tag{3a}$$

$$b_p = \frac{2}{N} \sum x_t \sin\left(\frac{2\pi p t}{N}\right) \tag{3b}$$

$$a_{\frac{N}{2}} = \sum \frac{(-1)^t x_t}{N} \tag{3c}$$

for $p = 1, \dots, N/2 - 1$;
 x_t : observation at time t .

We scaled $I(\omega)$ in such a way that its mean value in a periodogram equalled s^2/π , s^2 being the sample variance in the time series.

We obtained stable power spectra by smoothing the periodograms using a window with weights 0.5, 1, and 0.5. This is close to Chatfield's (1989) rule of thumb to smooth using a window of $N/40$ values long. Such a smooth window resulted in stable behaviour in time and in power spectra, showing all the major and consistent peaks appearing in the raw periodograms.

Periods of peaks in the power spectra are indicated plus or minus the bandwidth conform Jenkins (1961). In our case of smoothed spectra, the bandwidth is three-quarters of the frequency increment between subsequent periodogram ordinates. As period is inversely related with frequency, the bandwidth expressed in years is different for each spectral estimate and skewed around the central period.

For reasons given in the next paragraph the power spectra show the log-transformed power.

Significance of the power

We based significance assessment of the power on the assumptions of Chatfield (1989). As for most taxa (all except *Taxus* and *Corylus*), first-order autocorrelation coefficients of influx values are not significant, so it is reasonable to expect a spectrum with constant power of σ^2/π (σ^2 being the parametric variance in the time series).

Confidence limits around the expectation can be constructed from the following relationship:

$$\frac{v \cdot \hat{f}(\omega)}{f(\omega)} = \chi^2(v, \alpha) \tag{4}$$

v : degrees of freedom, which equals $2m$, m = the number of values in the smooth-window (in our case, $m = 2$)

$\hat{f}(\omega)$: observed power;

$f(\omega)$: expected power;

$\chi^2(v, \alpha)$: chi-square with v degrees of freedom and probability α .

Under the null hypothesis the expected power would equal σ^2/π , so we substituted the latter for $f(\omega)$ in equation (4). Subsequent substitution of S^2 , the sample vari-

ance, for σ^2 and rearrangement of terms leads to the confidence interval for the expectation, S^2/π equal to

$$\left[\frac{\chi^2(v, 1 - \alpha/2) \cdot S^2}{v \cdot \pi}, \frac{\chi^2(v, \alpha/2) \cdot S^2}{v \cdot \pi} \right]$$

We made this confidence interval independent of spectrum level and frequency by log-transforming the power. Jenkins (1961), Jenkins & Watts (1968) and Chatfield (1989) state that the variance of the observed power around the expected value depends on the level of the power itself: in fact the variance is proportional to the squared power (Jenkins 1961). According to all above authors log-transformation of the power has the advantage that the confidence intervals for all powers are alike, so that a spectrum with only one confidence interval gives an idea how important are the differences between individual powers.

In line with the reasoning by Young (1997), we calculated limits not only for 95% confidence intervals for individual powers but also for a spectrum as a whole and for the spectra of 19 taxa together (global significance assessment). As under the null hypothesis each power has a probability of 0.05 to exceed the traditional 95% confidence limits, testing all the powers in a spectrum may result in 5% significant powers. As their significance may be chance rather than an indication of a real pattern, we prefer to call such powers pseudosignificant. Following the terminology of Sokal & Rohlf (1981), and as elaborated in Young et al. (1997), we used an experimentwise error rate, α , of 0.05, and an adjusted significance level, p , equal to:

$$p = 1 - \sqrt[F]{1 - \alpha} \quad (5)$$

where α : level of significance when testing one or more power spectra, comparable to the experimentwise error rate for unplanned comparisons;

p : probability that power exceeds critical value, comparable to the adjusted significance level for an unplanned comparison;

F : number of frequencies at which powers are tested.

The number of tested powers in one spectrum equals 29: the three lowest frequencies are not taken into account, as their associated periods can be projected at the time series less than four times. This leads to an adjusted significance level of 0.0018 for a spectrum. As for 19 taxa 551 powers are tested, the adjusted significance level for a global test of all 19 spectra equals 0.000093.

However, the confidence limits associated with these adjusted significance levels are not exceeded in any

power spectrum, so none of the powers is more than pseudosignificant. The confidence limits shown in the power spectra are the traditional limits associated with unadjusted significance levels.

Results

Power spectra

Power spectra for pollen influxes are given in Fig. 8.36. No power in any spectrum in Fig. 8.36 is globally significant. However, the figure shows that peaks at some periods are pseudosignificant, and that at some periods several taxa show a peak.

Table 8.7 shows that at periods of 400, 128, 267 and 200 years most often peaks are found. However, considering pseudosignificance, periods of 800 and 533 years are the most important ones. Remarkably, at the period of 128 years the power is never pseudosignificant. At periods at which for some taxa pseudosignificant powers occur, no pseudosignificantly absent powers are found for other taxa (Tab. 8.8), and vice versa.

Discussion

As no powers exceed the global confidence limits, we consider the few powers exceeding the traditional confidence limits only pseudosignificant. Despite this limited significance of individual powers, the results as a whole suggest the existence of quasi-periodicities of 800, 533, 400, 128, 267, and 200 years, since at these periods remarkably many of the power spectra show a peak (Tab. 8.7). However, because of their limited significance caution should be exercised in statements on the existence of any of these cyclicities in pollen influxes.

This tentative recognition of quasi-periodicities in a number of power spectra is in line with Jenkins (1961). He states that confidence intervals for single spectra are not very important nor useful, since they depend heavily on assumptions of normality and stationarity of the time series and on assumptions for the spectral window. In his opinion it is far more important to see that when the experiment is repeated, a spectrum is obtained with a reasonable resemblance to the first. We would not discard the importance of confidence intervals in the evaluation of results, but we agree with the importance of repeatability.

Interpretation of any quasi-periodicity found must be of qualitative and speculative nature for two reasons. In the first place, ecological requirements of plant species

Fig. 8.36. Power spectra for pollen influxes or compound variables of pollen influxes from pollen-sum taxa in annually laminated sediments of Lake Gościąg, for the time span from ca. 7800 to 4600 cal BP. Period of peaks is indicated plus or minus bandwidth (see Methods section). Interrupted lines in spectra mark 95% confidence intervals around the expected power (see Methods section). Power spectra for *Corylus* and *Taxus* are not included, since they contain no peaks.

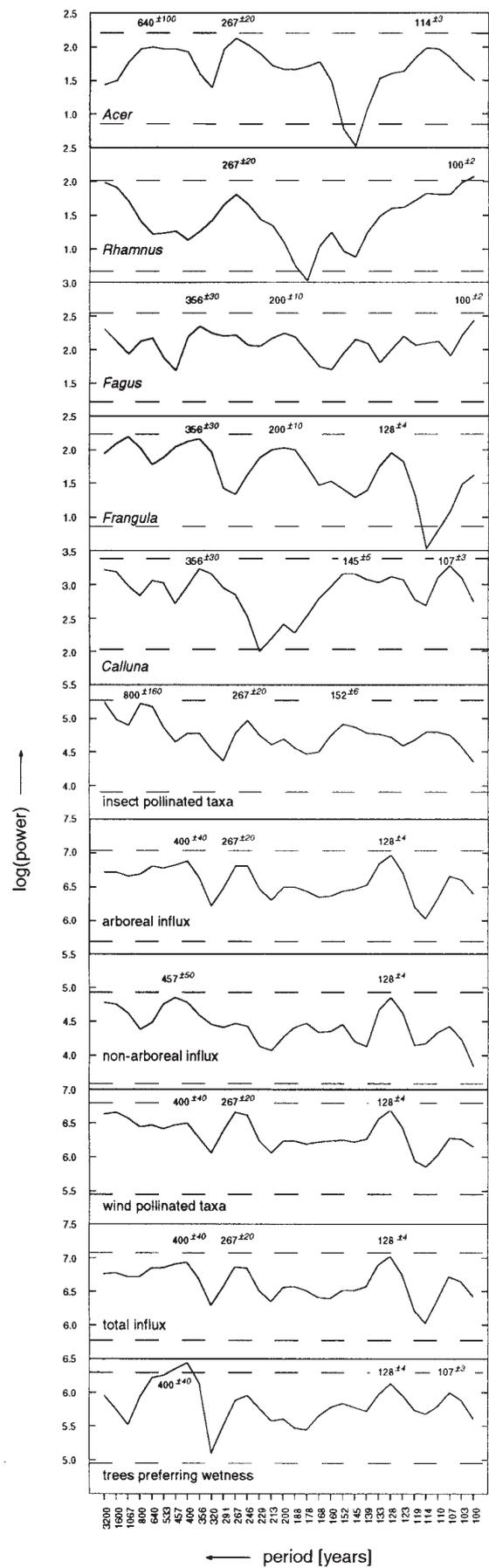
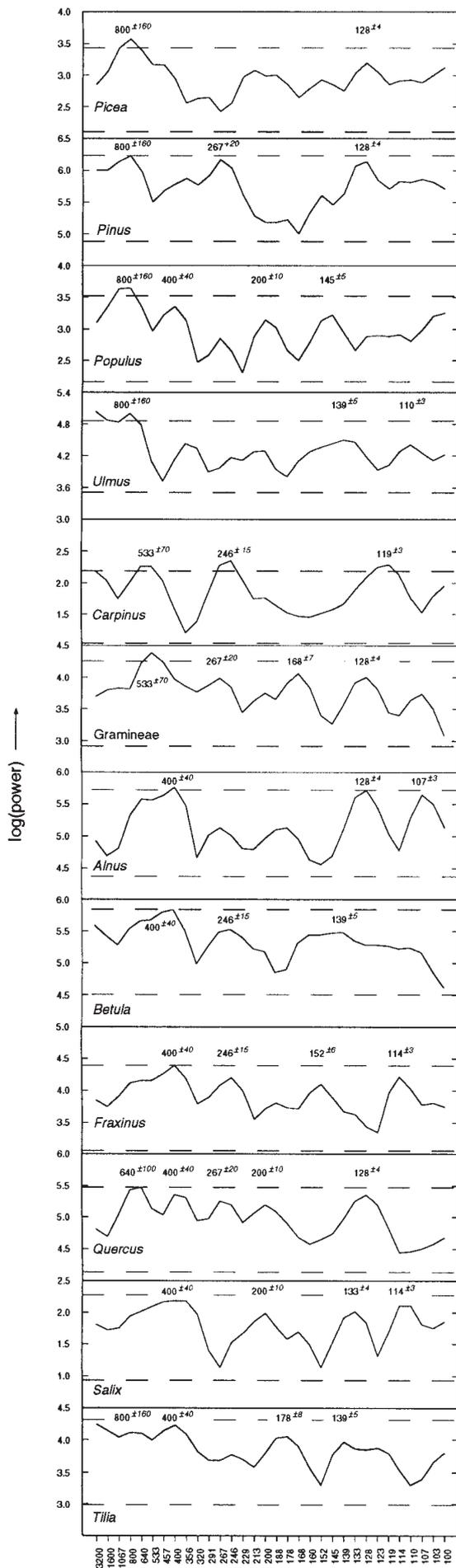


Table 8.7. Peaks in the power spectra for 19 pollen taxa and 6 compound pollen variables in annually laminated sediments of Lake Gościąg, for the time span from ca. 7800 to 4600 cal BP. As compound variables represent the sums of influxes of taxa, they are not independent from the taxon variables, and peaks in their power spectra are not counted as an occurrence. At periods with an asterisk (*) powers are pseudosignificant with probability 0.05.

Taxon/var.	Period										
<i>Picea</i>	800*										128
<i>Pinus</i>	800			267							128
<i>Populus</i>	800*	400			200						
<i>Ulmus</i>	800*										
<i>Carpinus</i>	533*		246*								119*
Gramineae	533*			267							128
<i>Alnus</i>		400*									128
<i>Betula</i>		400	246								
<i>Fraxinus</i>		400	246								
<i>Quercus</i>		400		267	200	128					
<i>Salix</i>		400			200						
<i>Tilia</i>		400									
<i>Acer</i>				267							
<i>Rhamnus</i>				267							100*
<i>Fagus</i>					200						100
<i>Frangula</i>					200	128					
<i>Calluna</i>						128					
Occurrences*	4(3)	2(2)	7(1)	3(1)	5	5	7	1(1)	2(1)		
insect pollin.	800			246							
arboreal			400		267						128
non-arbor.			400								128
wind pollin.			400		267						128
total influx			400		267						128
wet prefer.			400*								128

* – pseudosignificant powers and the most important other peaks in power spectra

cannot be used for quantitative interpretation, as pollen is often identified only to the generic or family level. Furthermore, different mechanisms concerning pollen production, transport, and pollination make the relationship between the taxon's contribution to the vegetation and to the pollen spectrum a non-linear one. In the second place, we have no data on climate sampled with the same resolution. Consequently it is not possible to relate pollen influx to climate quantitatively, and even less possible to assess the significance of such a relationship.

Some of the above quasi-periodicities appear in climate-related literature, and in the following paragraphs we will speculate on their relationship with quasi-periodicities in the pollen influx of the plants involved. Hereby we assume that long-term fluctuations in pollen influxes are mainly determined by abundance of plant taxa. However, these fluctuations may be partly determined by changes in pollen production or transport, both of which are linked to climate. It is difficult to separate the roles of

Table 8.8. Pseudosignificantly absent powers in the spectra for 19 pollen taxa and 6 compound pollen variables in annually laminated sediments of Lake Gościąg, for the time span from ca. 7800 to 4600 cal BP. Powers are pseudosignificantly absent with probability 0.05.

Taxon/var.	Period			
<i>Calluna</i>	229			
<i>Corylus</i>	229			
<i>Rhamnus</i>		178		
<i>Acer</i>			145	
<i>Taxus</i>			145	
<i>Frangula</i>				110
Occurrences	2	1	2	1

abundance, pollen production, and transport in a pollen signal. Fortunately, especially on the longer time-scales, it is reasonable to expect strong links among these three factors.

The sun-weather debate

Some quasi-periodicities that appear to occur in pollen influxes are also claimed to occur in solar output and in climate (see beneath), suggesting that the sun's behaviour may influence pollen influxes via climate. However, there is no consensus about the relationship between the sun and climate or weather. On the one hand, Lamb (1977) refers to many authors who propose a solar origin of climatic fluctuations. Such fluctuations occur for instance in the expansion and contraction of the circumpolar vortex (Willett 1949a, 1949b, 1964), precipitation patterns (Krivski 1953, Yamamoto 1967), sea levels vs. amounts of ice (Rubashev 1964), difference between summer and winter conditions (Brier 1953, Suess 1968), temperature (Tettrode 1952, Suess 1968), pressure patterns (Arai 1958, Mironovitch 1960), wind (Lamb 1967, 1977), and advance and retreat of glaciers (Wigley & Kelly 1990). Other authors he mentions find fluctuations in tree growth, which they attribute to solar activity (Outi 1961, 1962, Bray 1965, 1968).

On the other hand, a number of authors claim that the fluctuations in solar luminosity (which are related to sunspots according to Schatten 1988, Wilson & Hudson 1988, Foukal 1990, Roxburgh 1990, Stuiver et al. 1991, and Stuiver & Braziunas 1993) are not sufficient to explain the observed and reconstructed temperature fluctuations, particularly during Maunder type minima (Pitcock 1978, 1980, Wigley & Kelly 1990, Stuiver et al. 1991, Stuiver & Braziunas 1993). Stuiver & Braziunas (1993) state that, if a relationship between $\delta^{14}\text{C}$ (as a proxy for solar activity) and climate should exist, an amplification of a weak solar signal is needed. They explore such mechanisms involving UV and North Atlantic thermohaline circulation change. Besides, Stuiver et al. (1991),

in reaction to Wigley & Kelly (1990), have recalculated the correlation between (bidecadal) ^{14}C -fluctuations and Röthlisberger's (1986) glacial advance and retreat patterns, and they are not impressed by their own correlation coefficients. They calculate this correlation in way other than that of Wigley & Kelly (1990), who find the number of simultaneous ^{14}C -maxima and glacial advances significant, allowing for some uncertainty in timing and for lagging. In short, Pittock (1978) states that different studies investigating a sun-weather relationship often give contradictory results, that in many of the papers advocating this relationship any significance is the result of inappropriate statistics or of the a posteriori selection of the most favourable data, and that often the original hypotheses are elaborated to fit the data without testing this hypothesis on other data. Pittock (1980) suggests that protagonists of the sun-weather relationship reverse traditional scientific reasoning by using this relationship as the null hypothesis, and claiming that the relationship is not disproven by their results.

We do not agree with Pittock that most authors in the sun-weather debate reverse scientific reasoning. However, we agree with him that most of the correlation coefficients between solar activity and aspects of climate (for instance the ones mentioned by Lamb 1977) are too low to be more than pseudosignificant. On the other hand, Lamb (1977) mentions a considerable number of these pseudosignificant correlations between the sun and climate. Besides there is a rather great number of results from time-series analyses, suggesting quasi-periodicities in climate at the same periods as for solar activity.

400-year quasi-periodicity

Lamb (1977) refers to Suess (1965), who recognises a ca. 400-year quasi-periodicity between 5000 and 300 BC in atmospheric ^{14}C . Sonett & Finney (1990) find a significant quasi-periodicity of 413 years in the ^{14}C -concentrations in the La Jolla and Belfast tree-ring series. However, the latter authors do not consider this a primary quasi-periodicity, but a linear combination of the 2300-year and the 965-year primary quasi-periodicities. Lamb (1977) also refers to analysis of Chinese astronomical discoveries over more than 4000 years by Link (1958, 1964) and Link & Linkova (1959), who find an approximately 400-year quasi-periodicity in average length and activity of the '11-year' solar cycles and in cloudiness of Chinese nights. More recently, Xu (1990) finds a quasi-periodicity of 417 years in ca. 2000 years of sunspot observations by Chinese and other astronomers.

The taxa for which our power spectra suggest a 400-year quasi-periodicity are *Populus*, *Alnus** (* indicates that this quasi-periodicity is pseudosignificant), *Betula*, *Fraxinus*, and *Salix* (trees of mostly wet circumstances), as well as *Quercus* and *Tilia* (trees of drier conditions). Al-

though almost all compound variables in Tab. 8.7 appear to have a quasi-periodicity of 400 years, only for the sum of pollen from trees preferring wet conditions this quasi-periodicity is pseudosignificant. These results might suggest that fluctuations in pollen influx for these taxa are partly caused by fluctuations in water level or water table. In order to test this hypothesis, it would be interesting to check this quasi-periodicity's phase for these taxa relative to each other, by means of cross-spectra, cross-correlation, or correlation of filtered data. We do not know whether any such fluctuations if they exist would be related to sunspot cycles or any other of the above quasi-periodicities of 400 years.

128-year quasi-periodicity

We found no indication in the literature of any climate-related quasi-periodicity of 128 years, as appears to occur in our power spectra for *Picea*, *Pinus*, *Alnus*, *Quercus*, and *Frangula*, Gramineae, and *Calluna*. However, human activities like cutting of trees and subsequent cultivation of crops may also influence vegetation. The period of 128 years is rather close to the period mentioned by Iversen (1949) as the 'landnam' period of ca. 100 years, although Iversen (1956) also mentions that it may be as short as 50 years. With the 'landnam' period he means the period in which a Neolithic population arrives at a spot, cuts and burns the forest, uses the land until the regenerated forest has again become so dense that a new forest clearance would be necessary, and then leaves, after which the vegetation is left to recover in part. However, it is not to be expected that different groups of people in an area are all in the same phase of this 'landnam' cycle, so we do not think it is a very likely explanation for the 128-year quasi-periodicity.

200-year quasi-periodicity

Of the quasi-periodicities probably present in our pollen-influx time series, the 200-year quasi-periodicity is most often found in climatic records. For instance, Lamb (1967, 1977) recognises a ca. 200-year quasi-periodicity in the frequency of southwesterly surface winds in England. Lamb (1965, 1977) also recognises quasi-periodicities of 170–200 years in 1000-year-long records of temperature and, significantly, of rainfall in England. Sonett & Finney (1990), unlike Thomson (1990), find a significant 200-year quasi-periodicity in the tree-ring thickness of Mount Campito bristlecone pinewood, and then suggest, in line with La Marche (1973), that this quasi-periodicity is caused by solar-modulated temperature fluctuations. The century-scale fluctuations in ^{14}C in tree-rings are attributed to a ca. 200-year quasi-periodicity by Suess (1973, 1974), Suess & Linick (1990), Thomson (1990), and others. However, Sonett & Finney (1990)

consider this quasi-periodicity a linear combination of other quasi-periodicities. All these authors as well as Stuiver et al. (1991) and Stuiver & Braziunas (1993) propose a solar origin for these ^{14}C -fluctuations, also supported by a 202-year quasi-periodicity in the ^{10}Be -record in Antarctic ice cores (Raisbeck et al. 1990). Xu (1990) finds in a 2000-year long sunspot record compiled from observations in both Asian and western sources that the 213-year quasi-periodicity is the most significant one.

The taxa for which our power spectra suggest a 200-year quasi-periodicity are *Populus*, *Quercus*, *Salix*, *Fagus*, and *Frangula*. This combination of taxa does not clearly suggest a cause for this quasi-periodicity.

267-year quasi-periodicity

Xu (1990) finds a quasi-periodicity of 263 years in the already mentioned sunspot record. Aaby (1976) finds a significant quasi-periodic variation with a period of 260 years in peat decomposition in a Danish raised bog, indicating fluctuations in moisture conditions, probably related to changes in precipitation or temperature.

Taxa for which our power spectra indicate a quasi-periodicity of 267 years are *Pinus*, Gramineae, *Quercus*, *Acer*, and *Rhamnus*. This combination of taxa does not clearly suggest a cause for this quasi-periodicity.

800-year quasi-periodicity

Lamb (1965, 1977) proposes a quasi-periodicity of ca. 800 years after visual inspection of a 1000-year record of both temperature and rainfall in England. However, these time series are too short to allow any statistical evaluation of this observation. Lamb (1977) also supposes that conjunctions and alignments of the inner or greater planets with respect to the sun (for instance the opposition occurring every 840 years) might influence the amount of sunspot, by the varying tidal pull exerted by the planets on the solar envelope. However, all authors addressing the matter at a discussion on climate and variability of the sun (Pecker & Runcorn 1990) propose a solar internal magnetic mechanism to explain fluctuations in the solar activity (Foukal 1990, Gough 1990, Ribes 1990, Roxburgh 1990). Also Xu (1990) does not refer to an 800-year quasi-periodicity in the historical sunspot record. Sonett & Finney (1990) find a quasi-periodicity of 753 year in ^{14}C -fluctuations in tree-rings, but they consider it a harmonic of the 2311-year modulation that they also find.

In our study trees indicating a quasi-periodicity of 800 years are *Picea**, *Pinus*, *Populus**, and *Ulmus**. Besides *Ulmus* also the other insect-pollinated taxa together show signs of an 800-year quasi-periodicity. Hence this quasi-periodicity may be related to temperatures in summer, high temperatures favouring insect numbers and pollina-

tion, and also to wind intensities during the warmer part of the year. High windiness on the one hand may have a positive influence on pollen transport of wind-pollinated taxa such as *Picea*, *Pinus*, and *Populus* but may on the other hand have a negative influence on pollen transport of insect-pollinated taxa, for instance *Ulmus*. In order to test this hypothesis, it would be interesting to check this quasi-periodicity's phase for these taxa relative to each other. We do not know whether such fluctuations if they exist would be related to sunspot cycles or any other of the above quasi-periodicities of 800 years.

533-year quasi-periodicity

Stuiver & Braziunas (1993) mention a quasi-periodicity of 512 years in the ^{14}C -record in tree-rings between 12,000 and 8000 cal BP, with an occasional reactivation near 5000 and 3000 cal BP. They suggest North Atlantic deep-water flux oscillations to explain these ^{14}C -fluctuations, probably linked with the ca. 600-year quasi-periodicity in sea-surface temperature fluctuations found by Eglinton et al. (1992).

We find a suggestion of a quasi-periodicity of 533 years in pollen influxes of *Carpinus** and Gramineae*, quite close to the one of 512 years. It is possible that fluctuations in deep-water fluxes have an influence on atmospheric circulation and prevailing winds. If *Carpinus* and Gramineae were particularly distributed with respect to Lake Gościąg, such fluctuations in prevailing winds might cause changes in pollen influx from these taxa. However, our pollen influxes are from a part of the Holocene in which this 512-year oscillation appears to have been rather inactive. Another explanation for the 533-year quasi-periodicity may be that *Carpinus* and Gramineae fluctuations are anthropogenic. As *Carpinus* grows on fertile soil, it is possible that human settlers especially cut forests of *Carpinus*, after which Gramineae are cultivated and/or invade the area. In periods of diminishing human influence *Carpinus* might recover and Gramineae decline. In order to test this hypothesis, this quasi-periodicity's phase should be checked for these taxa relative to each other.

Possible dependence of influxes

We chose to analyse pollen influxes instead of percentages of a pollen sum, because of the obvious interdependence of percentages per taxon, an inter-dependence that hampers the assessment of global significance. However, pollen influxes may also depend upon each other. If *Lycopodium*, the marker added to reconstruct the volume related to the pollen counted, is over-represented in comparison with the number of pollen grains, the influxes of all taxa are underestimated by the same factor. Such over-representation or under-representation may be

result of poor mixing or the Poisson or binomial error in counting, an error getting higher with increasing total influx. It is not to be expected, however, that there is a quasi-periodic pattern in these errors in *Lycopodium* counts. Summarising, there is probably dependence of pollen influxes, but most probably no dependence of the power spectra for influxes of different taxa.

Unfortunately it is not possible to test the influence of over-representation or under-representation of *Lycopodium* on dependence of different taxa in the frequency domain, since it is impossible to separate the role of sample volume and representation in fluctuations of *Lycopodium* counts.

Lack of significance

We would like to make some remarks on the fact that we did not find any globally significant quasi-periodicity in pollen-influx data from the Gościąż sediments. It has to be stressed that both the very long varve chronology and the pollen content of the sediment have been studied and determined very carefully and in great detail. This combination of factors makes the palynology of the varve-dated Gościąż sediments one of the most interesting and reliable palynological data-sets available, particularly for time-series analysis purposes. Before this study several authors have attempted to find patterns in time series of different aspects of the Gościąż sediments (Walanus 1989a, 1989b, Young 1997). Although at selected parts of the varve time-series indications of quasi-periodicities or other patterns exist, in none of the articles the authors would claim to have found significant patterns in the time-series. Also the results of the present study on pollen influxes contain indications for quasi-periodicities, but none of these quasi-periodicities is (globally) significant.

The fact that careful analysis of such precise and reliable data does not result in significant patterns indicates that researchers working with palynological or other soil-related data that have a less precisely known time basis should not expect too significant quasi-periodicities and also should be very careful in interpreting the outcome of any time-series analysis. For even if the results contain seemingly (globally) significant quasi-periodicities, these might be caused by quasi-periodic patterns in the sedimentation rate instead of in pollen, vegetation, or climate, or they might be artifacts of the reconstructed time basis.

Conclusions

In power spectra for pollen influxes in sediment cores of Lake Gościąż, representing the period of ca. 7800–4600 cal BP, only few powers are pseudosignificant, and none is globally significant, taking into account the num-

ber of spectra and powers calculated. However, at some periods remarkably many power spectra show a peak. This suggests that there may be quasi-periodic patterns in behaviour of many taxa, for which a common cause may exist. A quasi-periodicity of 400 years appears to occur, which may be explained by fluctuations in water level or water table, probably caused by fluctuations of precipitation or temperature. Also a quasi-periodicity of 800 years appears to be present, for which we suggest fluctuations in summer temperatures or windiness as possible explanations. Indicated quasi-periodicities of 128 and 533 years might be explained by forest clearance and subsequent extensions of grass or heath. Another explanation for the 533-year quasi-periodicity might be a relation with North Atlantic deep-water flux oscillations. We could not relate indicated quasi-periodicities of 200 and 267 years to any anthropogenic or climatic mechanism, whether linked to solar activity or not. Our results indicate that researchers working with palynological or other soil-related data that have a less precisely known time basis than the Gościąż data should not expect too significant quasi-periodicities and also should be very careful in interpreting the outcome of any time-series analysis.

8.8. DISCUSSION OF THE HOLOCENE EVENTS RECORDED IN THE LAKE GOŚCIAŻ SEDIMENTS

Leszek Starkel, Tomasz Goslar, Magdalena Ralska-Jasiewiczowa, Dieter Demske, Kazimierz Różański, Bożena Łacka, Andrzej Pelisiak, Krystyna Szeroczyńska, Bogumił Wicik & Kazimierz Więckowski

Just as for the Late-Glacial period (Chapter 7), this chapter summarizes the Lake Gościąż data presented in Chapters 8.1 through 8.7, combined in the form of a table (Tab. 8.9). It illustrates the most distinct events and processes documented by data of different types on the common time scale. The construction of the table is the same as for that shown in Chapter 7.8.

The discussion below is a natural continuation of the Late-Glacial synthesis (Chapter 7.8), which ended at the Younger Dryas/Holocene transition. To cover the whole Holocene, we decided to repeat here the description of that transition, though in somewhat more condensed form.

In this table, however, some included data come from the Demske's Ph. D. thesis (1995) which will be published in the second part of Lake Gościąż Monograph. We decided to do so, because these data seemed to be essential for understanding the complete basic image of environmental changes.

Younger Dryas/Holocene transition (11,510 cal BP)

The Younger Dryas/Holocene transition was marked by the rapid rise of the $\delta^{18}\text{O}$ curve and blooms of *Te-*