

CHAPTER 8

INTERPRETATION OF VEGETATION CHANGE FROM POLLEN
ANALYTICAL DATA

The interpretation of vegetation change from palynological evidence involves:

- (i) the recognition of sequential trends in the plant microfossil record not explicable by random or non-biological factors,
- (ii) the equation of such pollen assemblages with existing or hypothetical vegetation communities to reveal the nature of the ecological change involved and
- (iii) the identification of causal mechanisms for any vegetation changes found.

This chapter attempts to recognise and explain the nature of changes in the palynological record of the two Markham Valley lake sites. In so doing possible causes are necessarily invoked. However, these are discussed in a broader context in the succeeding chapter.

THE NATURE OF THE DATA

The form of the palynological data dictates their potential usefulness and manner of interpretation. In comparison with most temperate regions, pollen assemblages from the lowland tropics are comprised characteristically of few relatively abundant taxa and a large number of much less frequently encountered types. Unless very many grains are counted, statistical confidence limits on the occurrence of most taxa are very wide. Thus, referring to the formula for the estimation of pollen concentration (Chapter 6), it can be seen that where four or less grains of a taxon are encountered in a sample the 95% confidence limit is equal to, or greater than, the actual count. Confidence limits can be reduced

only by counting a larger proportion of the sample, or by amalgamation of the counts for co-varying taxa. Confidence limits should also be applied to relative pollen frequency data (Mosimann, 1965, Maher, 1972).

The coexistence of pollen concentration estimates and a sound chronology allows calculation of estimates for annual pollen and spore deposition rates (PDR) for a sedimentary sequence. Liberating pollen data from the constraints of relative frequency calculation, PDR figures provide a greater potential for the interpretation of the spectral results. Truly quantitative changes in pollen deposition are open for study, and fluctuations in the frequency of selected taxa may be investigated independently of changes in the rest of the assemblage. This is especially useful when the knowledge of ecological status, and even the identification of many pollen taxa, is incomplete or obscure.

Despite the availability of PDR estimates, it is recognised that the palynological data in this study require cautious interpretation. Sufficiently narrow confidence limits can be assigned to only the most commonly occurring taxa, or groups of taxa. A large number of pollen or spore types are represented in a sample by one or two grains only. In view of the large confidence interval associated with such occurrences it make little difference to the interpretation whether these minor taxa are expressed as PDR values or as relative frequencies.

METHODS OF INTERPRETATION

The most convincing method of recognising vegetational analogues of sub-fossil pollen spectra is through the medium of contemporary pollen assemblages. Subjective comparisons may

suggest similarities between modern and ancient pollen assemblages and thus infer some similarity between vegetation types. Conversely, lack of correlation may eliminate a certain vegetation type from consideration as a modern analogue of past communities. The most accurate results are to be expected where a large number of widespread contemporary assemblages are available for comparison. In such cases statistical techniques may be used to equate sub-fossil spectra with extant vegetation communities (e.g. Kershaw, 1973b).

Once periods of similarity are identified, the pollen sequence may be divided into temporal 'pollen assemblage zones' thought to reflect a vegetation unit of either local or regional importance (West, 1970). Alternatively a zone may be defined as a period of consistent directional change in the sequence. Samples showing relative homogeneity can be united to form pollen assemblage zones either subjectively, or by means of probability statistics such as chi-square values (Kershaw, 1970). Use of more complex multivariate techniques has also been explored (e.g. Dale and Walker, 1970, Gordon and Birks, 1972). However, as Walker (1971) reminds us, statistical comparison between the pollen assemblages of neighbouring samples is legitimate only if the variation within each sample is first taken into account. This is rarely undertaken, since it involves counting numbers of replicate subsamples from each horizon.

Whilst pollen assemblage zones have a demonstrated utility in delimiting periods dominated by few abundant pollen taxa, their efficacy may be questioned where most samples are comprised of a large number of infrequently found taxa. Neither is there any theoretical reason to presume synchronous change in

different vegetation associations contributing to the pollen assemblage, unless perhaps as a result of overwhelming regional environmental change. In relative frequency pollen diagrams the fluctuations of one interdependent taxon lead to corresponding changes in other taxa thus reinforcing the impression of synchronous events. Such statistical artefacts are taken into account during subjective interpretation, but become more difficult to assess as the number of taxa involved increases. One major advantage of the PDR diagram in this respect is in allowing for the examination of individual taxa or groups of taxa independently of others. Separate zonations can be applied with greater confidence to groups of ecologically similar taxa. In addition, the temporal representation of single taxa can be described, or analysed statistically (Walker and Wilson, 1978).

INTERPRETATION OF POLLEN SEQUENCES FROM THE MARKHAM VALLEY

A variety of approaches was taken in the description and interpretation of the sub-fossil pollen records from the two Markham Valley lake sites. A solid radiocarbon chronology for Lake Wanum allows the estimation of PDR figures. At Yanamugi the tentative chronology based on radiocarbon, stratigraphic and palaeomagnetic evidence is too unsound for systematic calculation of such rates. However, comparable figures are derived for some of the more reliably dated sections of the core. Confidence intervals are shown only on summary PDR diagrams where a number of taxa are grouped together. Corresponding confidence limits for individual taxa are proportionally greater. The 95% confidence interval for *counting error* on other PDR and pollen concentration figures may be calculated using the data in Appendix III.

In describing the pollen sequences, the representation of the more important taxa is first considered in relation to their supposed vegetational source. The array of taxa, or selected components thereof, is then divided into pollen assemblage zones. These zones are defined as periods of similarity or consistent trends in the PDR or relative abundance of taxa. The ecological implication of trends shown by individual taxa and groups of taxa is sought, as far as possible, by reference to contemporary pollen assemblages. The pollen data are not considered sufficiently robust to allow comprehensive use of statistical techniques either for erection of assemblage zones or comparison with contemporary spectra.

THE POLLEN RECORD FROM LAKE WANUM

Twenty-eight samples were analysed from the 13.81 m long core LW II, the most ancient sediments retrieved during 1974. The sampling interval varied between 13 cm and 119 cm, being closest in the more slowly sedimented sections of the core. The approximate age difference between neighbouring samples is typically 350 years. A suite of radiocarbon dates (Chapter 3) provides an excellent chronology for the core. Sediment accumulation rate 'C' (Fig. 3.11c) derived from these determinations enables calculation of PDR estimates for the whole sequence. The total PDR, and sub-totals for herbaceous swamp taxa and dry land taxa are plotted against the inferred radiocarbon age in Fig. 8.1. Also shown are the sediment accumulation rates for 'organic' and 'inorganic' fractions (from Fig. 3.13) and the incidence of carbonised particles in each of three size classes.

Considerable variation in total PDR exists between samples. Values estimated range from less than 1 000 grains $\text{cm}^{-2} \text{yr}^{-1}$ to a maximum of over 40 000 grains $\text{cm}^{-2} \text{yr}^{-1}$. Before accepting these figures as representative of the true PDR, possible causes of error are briefly considered.

The 95% confidence interval for counting error shown on these curves may represent an underestimate of this error in some circumstances.

The radiocarbon-based sedimentation rate employed obviously influences the PDR results. Sediment accumulation rate 'C' is chosen as the most acceptable for the core as a whole. However, this takes no account of known secular variations in atmospheric radiocarbon as does rate 'B' (see Chapter 3). Use of the latter curve as the basis for PDR calculations would lead to a slight reduction in total PDR estimates between the radiocarbon ages of 2000 BP and 4300 BP. Even after such adjustment, these PDR values would remain amongst the highest encountered in the sequence.

The accumulation rate used for calculation of PDR assumes a constant sedimentation rate between radiocarbon samples. No account is thus taken of fluctuations of shorter periodicity. As such variations in sedimentation are more effectively averaged during periods of slow accumulation they may become significant when the accumulation rate is high, e.g. between 3400 BP and 4300 BP. Large fluctuations in PDR are indeed found during this period and this factor may remain the largest unaccountable source of error affecting the PDR estimates.

FIGURE 8.1. Lake Wanum core LW II: Pollen deposition rates (PDR) for major groups (+ 95% confidence limits), carbonised particle and sediment accumulation rates

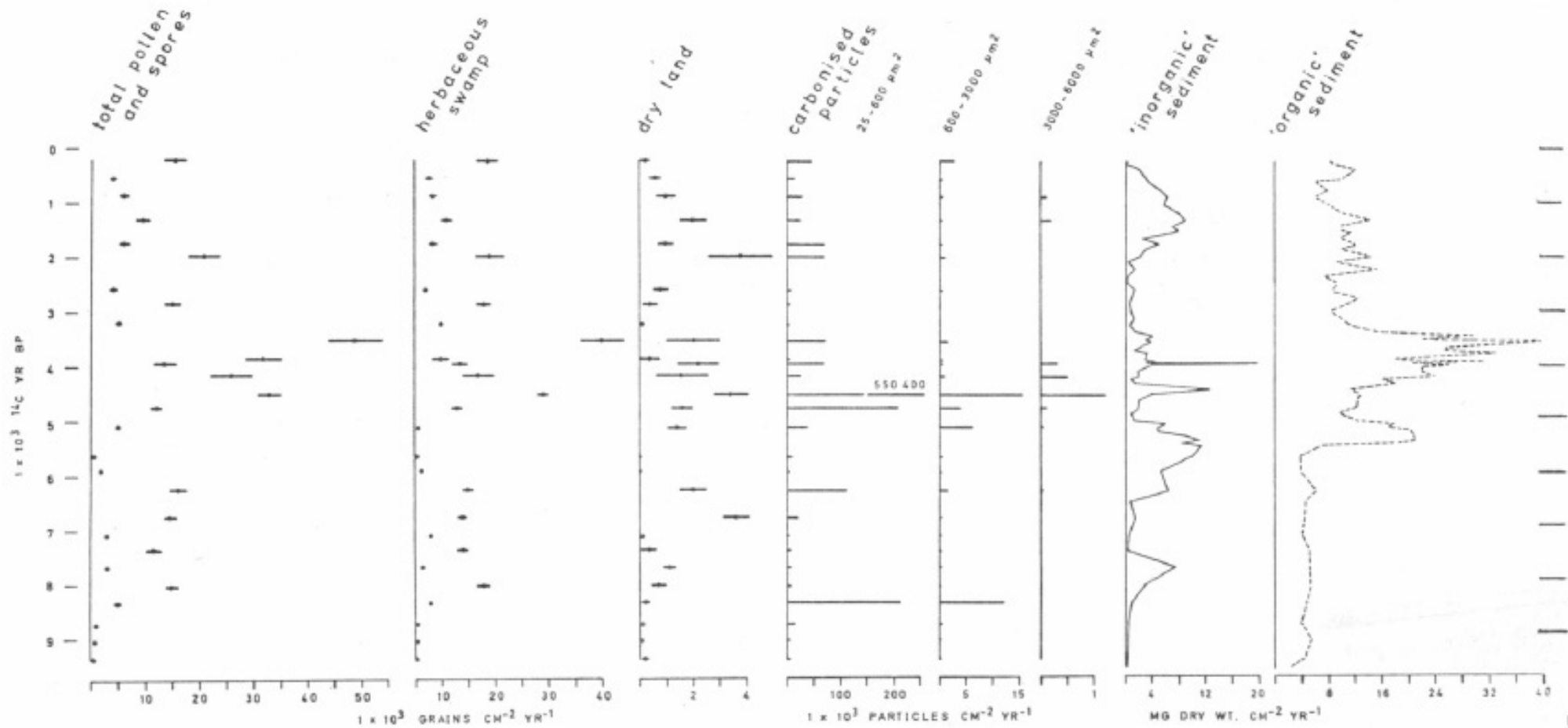
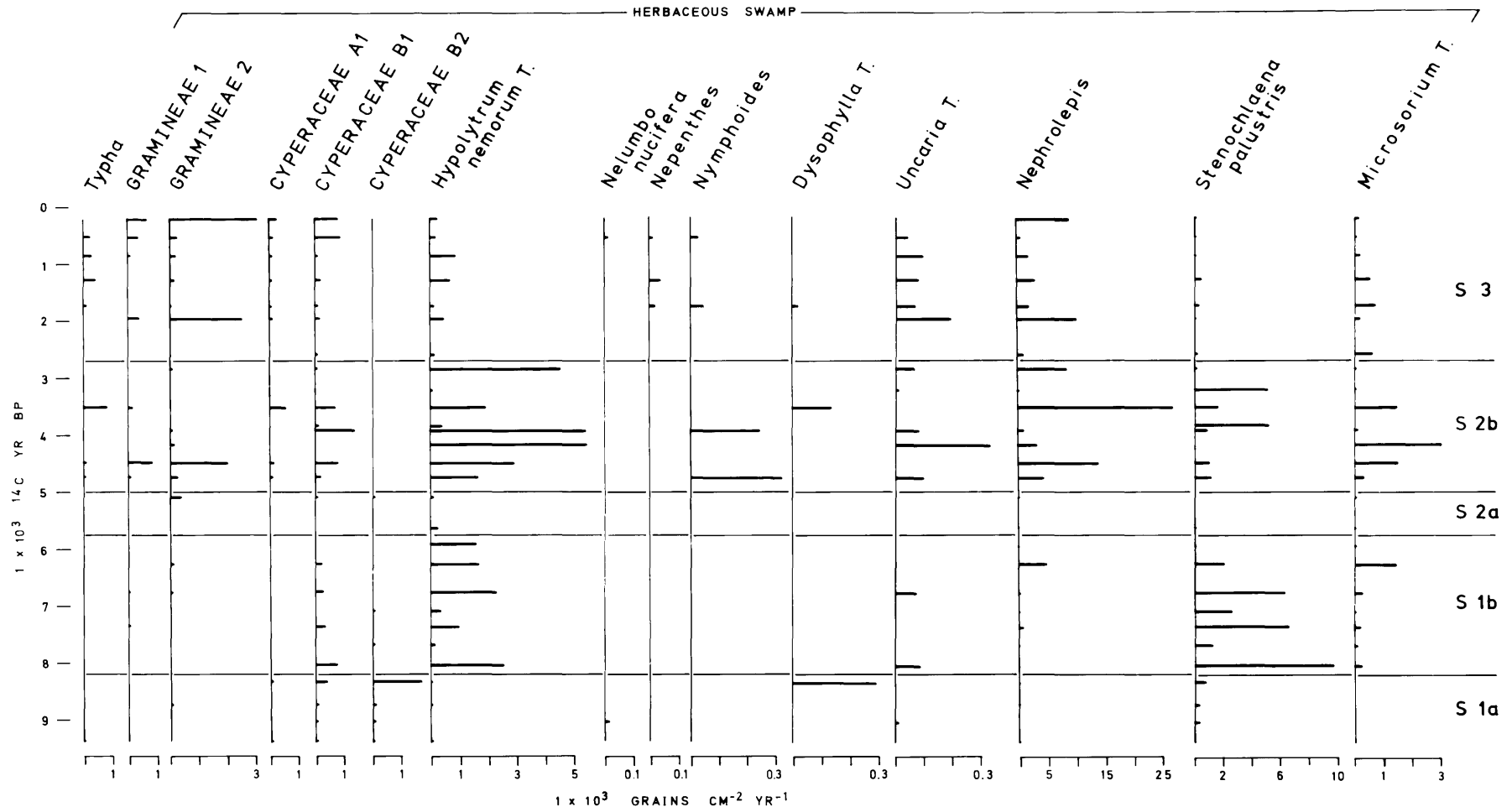


FIGURE 8.2. Lake Wanum core LW II: PDR for herbaceous swamp pollen and spore taxa



Post-depositional destruction of pollen or spores, either selectively or *in toto* is a problem in some depositional environments. This possibility should be considered where stratigraphic evidence reveals oxidising conditions or where the PDR appears abnormally low.

EVIDENCE FOR CHANGES IN HERBACEOUS SWAMP VEGETATION AT LAKE WANUM

As shown in Fig. 8.1 the herbaceous swamp pollen and spore taxa dominate the majority of pollen assemblages from core LW II. The relatively few structural and floristic dominants of the swamp vegetation are well represented in the sub-fossil record. Of equal importance, the main features of the ecology and, to a lesser extent, the contemporary pollen deposition are known. The palynological evidence for vegetation change within the swamp environment is therefore considered first, separately from the pollen record of the less well represented dry-land vegetation.

The estimated PDR of individual herbaceous swamp taxa are shown on an age axis in Fig. 8.2. Relative frequencies of the same taxa are plotted in Fig. 8.3 against stratigraphic depth. The latter diagram allows comparison with the contemporary pollen assemblages, also calculated on a relative frequency basis.

The palynological record of herbaceous swamp taxa

Hypolytrum nemorum T. pollen is recorded from all but one (1950 cm) of the core samples. Although poorly represented in sediments older than 8200 BP it becomes abundant between 8200 BP and 5800 BP and reaches its highest PDR from 5000 BP to 2700 BP. The taxon is an important component of the pollen assemblage from 2700 BP to the top of the core, although the PDR are lower than during the previous 2000 years. The species appears an obligate

hydrophyte, although it is occasionally found in only periodically inundated swamp localities. Although contemporary observations show *H. nemorum* to be an erratic pollen producer, the record suggests that the large sedge has been a significant component of the vegetation of the north-east bay since at least 8200 BP.

Stenochlaena palustris spores are also well represented throughout the sequence, comprising a very high proportion of the total swamp taxa prior to 7200 BP (Fig. 8.3). However, this abundance may be largely an artefact of low total PDR as the PDR of the spore increases to its highest values around 8200 BP, and continues at a generally high level until approximately 3000 BP. At this time the representation of *S. palustris* decreases to fairly constant, though lower, PDR values.

Nephrolepis hirsutula is probably the species represented by the great majority of *Nephrolepis* spores, although *N. biserrata* may contribute to the spore taxon in non-swamp locations. Whilst *Nephrolepis* spores are present throughout the core, their representation increases considerably subsequent to 5000 BP.

Occurrence of grass pollen smaller than 20 μm (Gramineae 1) associated with a larger proportion of Gramineae 2 (max. dimension 20-25 μm) may indicate presence of the swamp grass *Leersia hexandra*. Substantial PDR figures for both size classes are found between 5000 and 4000 BP and from about 2000 BP to the present.

Pollen of Cyperaceae other than *Hypolytrum nemorum* occurs throughout the deposit. Differences in the representation of the several pollen morphological classes must be interpreted with caution. The morphology of only the more common species has been studied, and many fall into more than one category. A wider range

of cyperaceous pollen classes may be seen in the sediments prior to 8200 BP. Categories B1 and B2 are the most common, A1 and A2 being present in some samples. Since 8200 BP the grains most frequently found belong to the smaller size classes, in particular B1, although Cyperaceae A1 become more common subsequent to 5000 BP. *Cyperus platystylis* and *C. polystachos* are the only common species contributing to class A1, and their pollen forms a large proportion of class B1 also.

Microsorium T. spores first appear in the sequence around 8200 BP but show their greatest abundance since 5000 BP. Although a species of *Microsorium* is a component of floating root-mat vegetation at the present time, it is unlikely that the spore taxon is unique to this species.

Nepenthes pollen is confined to the most recent 2000 years of the sequence and is thought to represent *N. mirabilis*. This species is found in well developed floating root-mat vegetation although it also occurs in periodically inundated or otherwise damp grassland localities. *Uncaria gambir* is also a component of floating root-mat vegetation and contributes a proportion of *Uncaria* T. pollen. This taxon occurs throughout the core, but becomes more abundant subsequent to 5000 BP.

Neither *Nelumbo nucifera* pollen, nor *Nymphoides* pollen (almost certainly from *N. indica*) are common in the deposits. However both are obligate aquatics and useful indicators of water depth. Two *N. nucifera* grains are recorded from the sample at 1950 cm showing the species' presence by at least 9100 BP. In contrast, *Nymphoides* pollen is not found until about 4800 BP.

Typha pollen occurs in small quantities in a number of samples, and reaches a fairly high PDR within the last 2000 years, although it is absent from the most recent sample. Neither

Typha, nor *Sparganium antipodum* T., represented by a single pollen grain, appears to grow in the vicinity of Lake Wanum today.

Herbaceous swamp pollen assemblage zones

Zone Sla: 9500-8200 BP (1970-1900 cm)

During the period of 1300 years represented by the four oldest pollen analysed samples, sediment accumulation rates are very slow. Estimated PDR figures, both for swamp and non-swamp taxa, are low although they show a general increase towards the top of the zone.

The most abundant taxa encountered are *Stenochlaena palustris* spores, and Cyperaceae pollen of morphological classes A1, B1 and B2. Minor quantities of other herbaceous swamp taxa, *Typha*, *Sparganium antipodum* T., cf. *Colocasia*, *Nelumbo nucifera* and *Nephrolepis* are also represented. A peak of *Dysophylla* T. pollen occurs at the top of the zone in conjunction with an increase in Cyperaceae class B2 pollen and a general rise in PDR. Grass pollen is present throughout the zone, although none falls into the smallest size class (Gramineae 1) suggesting that *Leersia hexandra* may have been absent from the site.

Comparison of relative frequency pollen assemblages from this zone with contemporary spectra reveals no direct parallel. Sample SS 23 from the swamp marginal vegetation at Redhill shows the closest similarity, containing high proportions of Cyperaceae and larger grass pollen classes, *Hypolytrum nemorum* T., and spores of *Nephrolepis*. Most significant is the large representation of *Dysophylla* T. pollen matching that found at the top of zone Sla.

The proportion of *Stenochlaena palustris* spores, however, is considerably lower in the contemporary assemblage than in the core. Although not particularly common in the swamp marginal vegetation at Redhill, *S. palustris* can be found in such habitats and is reported to be exceedingly common in open swamp forest throughout the Malayan peninsula (Holttum, 1932).

Zone Slb: 8200-5750 BP (1900-1740 cm)

Organic sediment accumulation rates in this zone remain similar to those of the preceding period, although inorganic accumulation shows a slight peak at about 7700 BP. In contrast, estimates both of total PDR and herbaceous swamp PDR, although fluctuating, show large increases over rates for the previous zone, Sla.

The highest sustained PDR figures for *Stenochlaena palustris* spores, up to $9\ 500\ \text{cm}^{-2}\ \text{yr}^{-1}$, are found in this zone, and the species comprises 70% to 90% of the herbaceous swamp pollen and spore sum. *Hypolytrum nemorum* T. pollen is well represented with higher PDR figures becoming more common in the upper part of the zone. Spores of *Nephrolepis* are recorded from all samples. Cyperaceae pollen of class B1 occurs throughout although PDR values show a decline towards the end of the zone.

Zone Slb sees the first occurrence, albeit in small quantities, of other herbaceous swamp taxa. *Microsorium* T. spores are present in all samples and grass pollen of the smallest size category (Gramineae 1) may indicate the presence of *Leersia hexandra*.

Again, no direct parallel exists between the pollen spectra of this zone and any modern assemblage. No contemporary sample adequately reflects the predominance of *Stenochlaena palustris* in association with substantial frequencies of *Hypolytrum nemorum* T. and a low proportion of *Nephrolepis* and *Microsorium* T. spores. Although samples SQ 51 (*Leersia hexandra* root-mat vegetation) and SQ 50 (open water *Nelumbo nucifera* association) show similarly high values for *S. palustris*, they contain few or no *Nephrolepis* spores and none of *Microsorium* T. Towards the top of zone Slb the proportion of *S. palustris* declines and that of *Nephrolepis* increases. These spectra more closely resemble the contemporary sample SQ 40, taken from the rooted *Hypolytrum nemorum* vegetation association.

Lack of a direct modern analogue for the pollen assemblages of this zone makes characterisation of the probable swamp vegetation difficult. The relative dominance of *Stenochlaena palustris* spores appears, by analogy with contemporary spectra, to be associated with sparse vegetation cover or open water conditions. Alternatively, it may reflect the proximity of open swamp forest or swamp marginal vegetation rich in *S. palustris*, as proposed for zone Sla. In either case the herbaceous swamp vegetation of zone Slb could resemble the present day rooted *Hypolytrum nemorum* association of shallow water. This association also contains *S. palustris* but little or no *Nephrolepis hirsutula*. The increased incidence of *Nephrolepis* spores during the latter part of zone may reflect the proximity of floating root-mat vegetation as appears the case in contemporary samples.

Zone S2a: 5750–5000 BP (1740–1570 cm)

A greater than five-fold increase in the rate of organic sedimentation occurring at about 5500 BP is maintained until c. 5000 BP. Inorganic influx also increases substantially, reaching the highest sustained rates in the core between about 5700–5200 BP. The two pollen analysed samples from the zone are characterised by very low PDR values both for herbaceous swamp and dry-land taxa.

Hypolytrum nemorum T. pollen and *Nephrolepis* spores are recorded from both samples, whilst *Stenochlaena palustris* is present only in the lower. The upper sample of the zone shows various other cyperaceous pollen and a substantial proportion of Gramineae 2. However, no grass pollen of the smallest size class indicative of *Leersia hexandra* was found.

The taxonomic composition of zone S2a appears similar to that of the previous zone, but with an increase in the proportion of Cyperaceae B1 and B2, and a substantial decrease in that of *S. palustris*. The cause of the dramatic decline in PDR to figures similar to those of zone S1a remains enigmatic. Revertance to the marginal swamp conditions of the earlier zone appears unlikely in view of the continued presence of *H. nemorum* T., and lack of pollen indicative of marginal conditions. Reduced pollen deposition could result from a decrease in the cover of swamp vegetation, possibly caused by a rise in water level. A rapid influx of inorganic sediment such as occurs at this time may have had an effect on the vegetation. However, a hypothesis of reduced swamp vegetation is hard to reconcile with the increase in the organic sediment accumulation rate during the later part of the zone.

Zone S2b: 5000-2700 BP (1570-1030 cm)

Organic sedimentation rates and the PDR of herbaceous swamp taxa reach their highest values during the earlier part of zone S2b. Although *Nephrolepis*, *Stenochlaena palustris* and *Hypolytrum nemorum* T. are the most abundant, the zone shows the greatest diversity of herbaceous swamp taxa encountered in the whole sequence. Pollen of various Cyperaceae, Gramineae 1 and 2, *Uncaria* T., *Typha* and even *Dysophylla* T. are present, as are *Microsorium* T. spores. *Nymphoides* pollen first occurs at the base of the zone.

Comparison of the pollen spectra of zone S2b with contemporary assemblages suggests similarities with a range of herbaceous swamp vegetation types. The high proportion of *Hypolytrum nemorum* T. pollen in the earlier part of the zone parallels that of sample SQ 40 from the rooted *H. nemorum* vegetation association. The considerable proportion of *Nephrolepis* spores recorded in the sub-fossil assemblages suggest the presence of floating root-mat vegetation such as that represented by the contemporary sample SQ 35. The wide range of pollen taxa recorded may reflect a variety of vegetation associations contributing to the palynological record of the zone. It is quite possible that herbaceous swamp vegetation during zone S2b consisted of a mosaic of associations with floristic composition essentially similar to those occupying the south swamp area of Lake Wanum at the present day.

Zone S3: 2700 BP to present (1030-640 cm)

In this most recent pollen assemblage zone the organic sedimentation rate, although fluctuating, declines to values intermediate between those of zone S2b and of the lower zones. Herbaceous swamp PDR also shows a decline to values between 5 000 and 20 000 grains $\text{cm}^{-2} \text{yr}^{-1}$.

By far the most abundant taxon throughout the zone is *Nephrolepis*. A considerable decline in the PDR of *Hypolytrum nemorum* T. is seen, but the sedge remains consistently represented. *Stenochlaena palustris* spores also occur in all samples although less abundantly than in zone S2b. *Microsorium* T. is represented throughout and shows a relative increase in abundance over the previous zone. Pollen of *Nepenthes* and *Uncaria* T. is found in a number of samples. Cyperaceae pollen of classes A1 and B1 become more frequent towards the top of the zone, as does that of *Typha* and of the two smallest size classes of Gramineae. Isolated grains of *Nymphoides*, *Nelumbo nucifera* and *Dysophylla* T. also occur.

There is close correlation between the proportions of major taxa represented in zone S3 and two contemporary assemblages associated with floating root-mat vegetation. Sample SQ 35 exhibits a very high proportion of *Nephrolepis* spores and a substantial number of *Microsorium* T. Sub-fossil spectra with a higher ratio of *Hypolytrum nemorum* T. to *Nephrolepis* resemble more closely the surficial sample from short core LWMC 3. This assemblage also contains a variety of other sedge and smaller grass pollen classes as do the later samples of zone S3.

It is therefore suggested that the dominant vegetation type throughout zone S3 has been a well developed floating root-mat vegetation of floristic composition similar to that of the

'Group A' association (Chapter 5). Pollen indicative of *Leersia hexandra* mat, various sedges and *Nymphoides indica* completes the parallel between the pollen spectra of this zone and those from the mosaic of largely floating vegetation seen in the north-east bay of Lake Wanum at the present day.

Constraints on the use of contemporary assemblages

Comparison of contemporary herbaceous swamp pollen spectra with sub-fossil assemblages is shown to be an effective means for reconstruction of past vegetation associations. In cases where the zonal pollen assemblages do not resemble closely any modern pollen spectrum (zones Sla, Slb) it is possible that they represent vegetation associations not extant today.

Most sub-fossil assemblages do however resemble one or more contemporary spectra to some extent, and the lack of exact correlation is probably due to other factors. Most core samples integrate several years' pollen deposition. In the more slowly accumulating sediments they may represent 15 years or more, during which time the local vegetation may have changed.

Comparisons between assemblages from different areas may be misleading. The south swamp of Lake Wanum is a large area of fairly uniform water depth whereas at the margin of the north-east bay water depth increases sharply offshore. In the latter situation one might expect a closer juxtaposition of vegetation associations characteristic of different water depths. Thus assemblages might incorporate pollen and spores from a wider selection of taxa.

THE DEVELOPMENT OF SWAMP VEGETATION IN THE NORTH-EAST BAY OF
LAKE WANUM

The pollen record of the last 9500 years can be interpreted largely by analogy with the present herbaceous swamp associations of the Lake Wanum area.

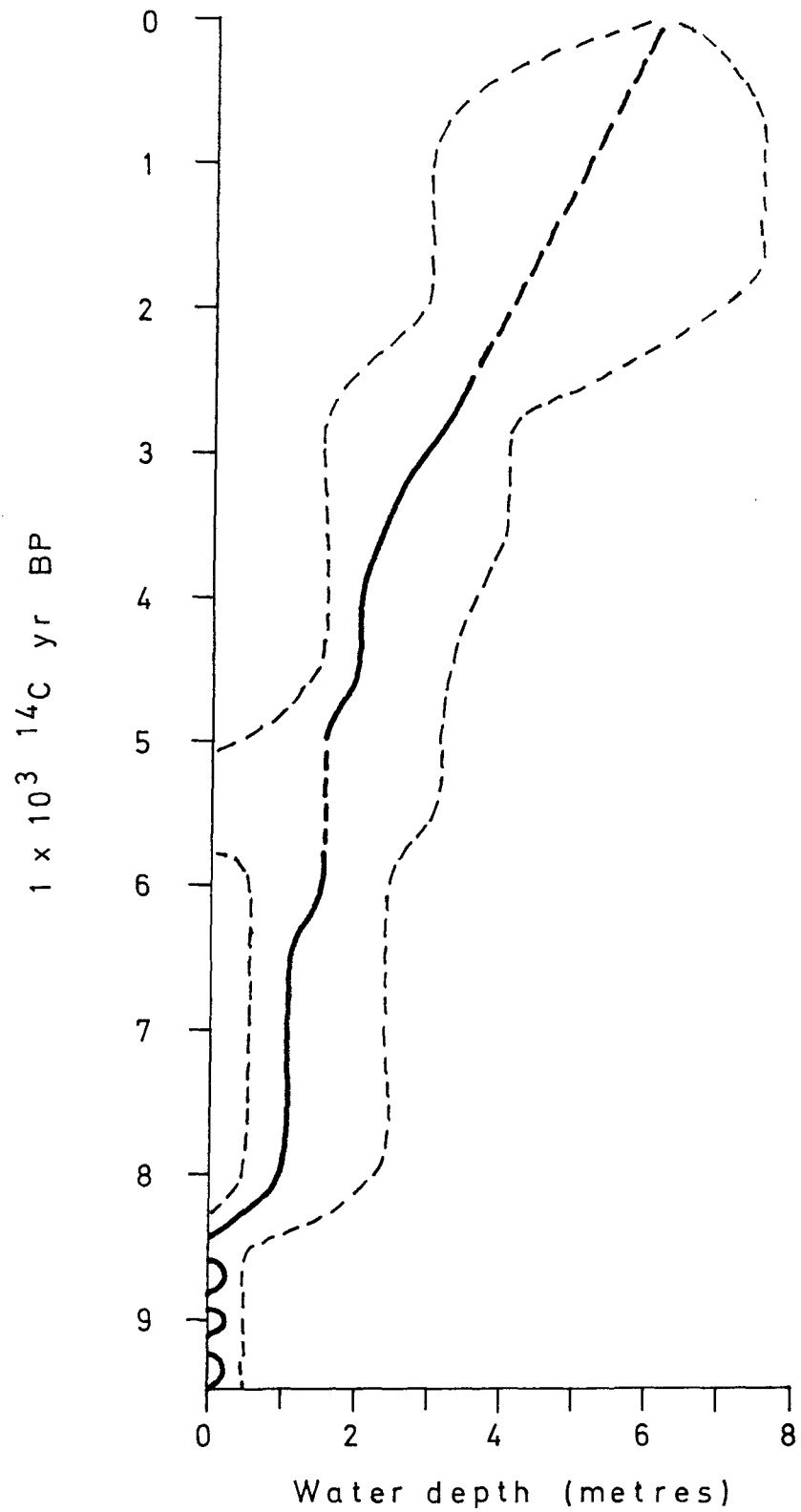
The oldest period of 1300 years (zone S1a) is thought to represent periodically inundated or marginal swamp conditions. A change to a permanent, though shallow water, swamp environment takes place at around 8200 BP at the onset of zone S1b. This vegetation, probably dominated by rooted *Hypolytrum nemorum* association persisted for approximately 2500 years. A subsequent period of up to 750 years (zone S2a) records very low PDR figures coincident with high influx rates of inorganic sediment.

From 5000 BP, the beginning of zone S2b, the herbaceous swamp flora appears to diversify. There is suggestion of both rooted and open water vegetation associations. With the increase in the PDR of *Nephrolepis* spores, free-floating root-mat vegetation appears important for the first time. Conditions during this zone may resemble the swamp vegetation mosaic of the Lake Wanum south swamp today.

At some time between 3000 and 2000 BP the vegetation becomes dominated by the floating root-mat vegetation characteristic of the latter part of zone S3, an association essentially similar with that found at the coring site today. *Leersia hexandra* root-mat may have become somewhat more abundant in the most recent millennium.

The preceding synopsis suggests an increase in the absolute water level and a general trend to increased effective water depth at the core site during the past 9500 years. This

FIGURE 8.4. Schematic Holocene water depth record for the site of core LW II



conclusion is in agreement with the stratigraphic record of relatively shallow water swamp deposits rather than deeper water limnic sediments.

A WATER LEVEL RECORD FOR LAKE WANUM

Knowledge of the ecology of the contemporary herbaceous swamp vegetation allows tentative reconstruction of a more detailed water depth record. This interpretation relies both on the records of individual taxa possessing known water depth tolerances, and on analogy between the habitat of modern vegetation associations and those reconstructed from the palynological record. Several important assumptions are thus implicit:

- (i) that water depth tolerances for both individual taxa and vegetation associations have remained constant throughout the Holocene,
- (ii) that all ancient swamp vegetation associations are broadly analogous with the extant associations surveyed and
- (iii) that the area of vegetation reflected in each sediment pollen assemblage is largely known.

The water depth ranges for species and associations have probably remained constant. Although the vegetation of zones Sla and Slb cannot be equated directly with any contemporary association, it is considered broadly similar to an existing herbaceous swamp association. The area contributing to sub-fossil pollen assemblages is almost certainly influenced by inconstant factors such as local bathymetry and vegetation structure.

A schematic construction of trends in the effective water depth at the site of core LW II is shown in Fig. 8.4. The central curve represents the proposed path of general water depth during the

Holocene. The broader limits indicate the maximum and minimum water depths considered probable, assuming most sub-fossil assemblages to reflect the vegetation in the close vicinity (perhaps less than 10 m) of the coring site.

From 9500 to 8500 BP a fluctuating water level with a maximum depth of 20 cm to 30 cm is suggested. Standing water is indicated by *Nelumbo nucifera* pollen but may have been intermittent, becoming permanent only after 8500 BP when pollen of the aquatic herb *Dysophylla verticillata* is abundant. From 8200 BP to about 5750 BP (zone S1b) the swamp vegetation is thought to consist at least in part of a rooted *Hypolytrum nemorum* association. By inference, the water depth remained fairly constant at 1.0 m to 1.5 m during this period. The decline in the PDR of *Stenochlaena palustris* spores could be interpreted as a retreat of the swamp margin perhaps due to increasing water depth.

Any changes in water depth during the 750 years of zone S2a remain enigmatic. By the start of zone S2b (5000 BP) the water was probably 1.5 m to 2.0 m deep, although the suggested coexistence of rooted and floating vegetation communities makes accurate assessment difficult. A further increase to a depth of 3.0 m to 3.5 m by 2700 BP is indicated by the predominance of floating root-mat vegetation. This rise may have started at around 4000 BP, or may have taken place more rapidly at a later date. With the onset, in zone S3, of floating vegetation insensitive to rising water level the assessment of effective depth becomes impossible. It is virtually certain that the water depth has not fallen below 3.5 m to 4.0 m during the last 2500 years. A steady rise to the present depth of 6.25 m is assumed for this period. However the current water depth may have been achieved or even exceeded earlier in zone S3.

The trend of water level at the site of core LW II over the Holocene shows a general rise in excess of that accountable solely due to infilling of the lake basin. The greater part of the increase in water level and effective water depth has taken place during the past 5000 years. No prolonged decline in water level is apparently recorded although minor fluctuations of short periodicity, such as shown by the present lake level, may also have occurred in the past.

Absolute rise in lake level

Whilst the effective water depth curve (Fig. 8.4) appears valid for the western margin of the north-east bay, trends may have differed in other areas of lake.

The absolute lake surface level relative to the 1974 datum may be calculated for any date by subtracting the estimated effective water depth at site LW II (Fig. 8.4) from the radiocarbon age/depth curve of Fig. 3.10a. This procedure takes no account of any post-deposition compaction of the sediments. Using the absolute lake surface level calculated in this way, some estimates of effective water depth at the site of core LW I can be derived. At 2070 BP the lake level lay perhaps 5 m below the 1974 datum, when the sediment/water interface was 9.3 m below datum at LW II, and 12.3 m at LW I. The effective water depth at LW I was thus at least 3 m, and probably closer to 8 m. The present effective depth at LW I is 2 m, and at LW II 6.25 m. There thus appears to have been a decrease in water depth at the site of LW I over the past 2000 years in contrast to the trend seen at LW II. However, lack of a comprehensive series of radiocarbon dates from core LW I precludes the construction of a comparable effective water depth curve.

HERBACEOUS SWAMP VEGETATION AND ORGANIC ACCUMULATION

The greater proportion of the organic sediment in marginal areas appears to be detritus derived from aquatic macrophytes. Water depth is shown to be the major control on the distribution of this herbaceous swamp vegetation. It may be hypothesised that water depth, through its effect on vegetation, influences organic deposition. Comparison of the effective water depth curve (Fig. 8.4) with the organic sediment accumulation rate (Fig. 8.1) may therefore be instructive.

In a periodically inundated or static shallow water swamp environment (zones S1a and S1b) little organic detritus accumulates. When a rise in water level occurs only those rooted associations that can accommodate the increased water depth by virtue of fast detrital sediment accumulation can persist. This could be the case for the *Hypolytrum nemorum* association in zones S2a and S2b. If the water level increases dramatically, rooted vegetation is excluded, and only free floating root-mat associations can continue to occupy the area. This process may have taken place within zone S3. Floating root-mat vegetation, due to its relative stability and insular distribution, possibly contributes less organic detritus to the sediment surface.

EVIDENCE FOR CHANGES IN DRY-LAND VEGETATION AT LAKE WANUM

The pollen analytical record of dry-land vegetation is much more fragmentary than that available for the herbaceous swamp. In most samples from core LW II, dry-land taxa constitute only a small proportion of the total pollen and spore count. Even so, the number of different dry-land taxa encountered frequently exceeds that of swamp taxa. With many taxa poorly represented, it becomes

difficult to recognise statistically significant variations in pollen frequencies. In addition, the identity of many dry-land pollen and spore types is uncertain, and data on their ecological status limited (see Table II.1).

Due to this paucity of data the pollen record of dry-land vegetation requires circumspect interpretation. Comparison of sub-fossil assemblages with contemporary spectra is found to be of limited interpretative use. Nevertheless changes are recognised in the pollen records of a number of taxa that appear to possess ecological significance. Estimated PDR for selected taxa from various ecologically defined groups are plotted against age in Fig. 8.5.

The palynological record of dry-land taxa

Non-forest pollen: Although grasses are represented throughout the sequence, few Gramineae grains attributable to dry-land species are present prior to 6300 BP, and do not become abundant until 5100 BP. Patterned grass grains larger than 30 μm (Gramineae 5), perhaps deriving from *Themeda australis*, first occur at about 6800 BP, and are consistently represented only in the sediments of the last 3000 years.

Few other dry-land taxa show continuous representation throughout the sequence. *Trema* pollen is first recorded at about 8050 BP but is best represented subsequent to 5350 BP. The highest PDR values (up to 350 grains $\text{cm}^{-2} \text{yr}^{-1}$) are achieved between 5100 BP and 4500 BP, and from 2000 BP to the present.

Similar trends are apparent for *Macaranga* pollen. Although present from almost the base of the core, the PDR increases sharply between 6700 BP and 6200 BP and after 5350 BP. Maximum PDR estimates for *Macaranga* reach 750 grains $\text{cm}^{-2} \text{yr}^{-1}$.

FIGURE 8.5. Lake Wanum core LW II: PDR of selected dry land pollen and spore taxa

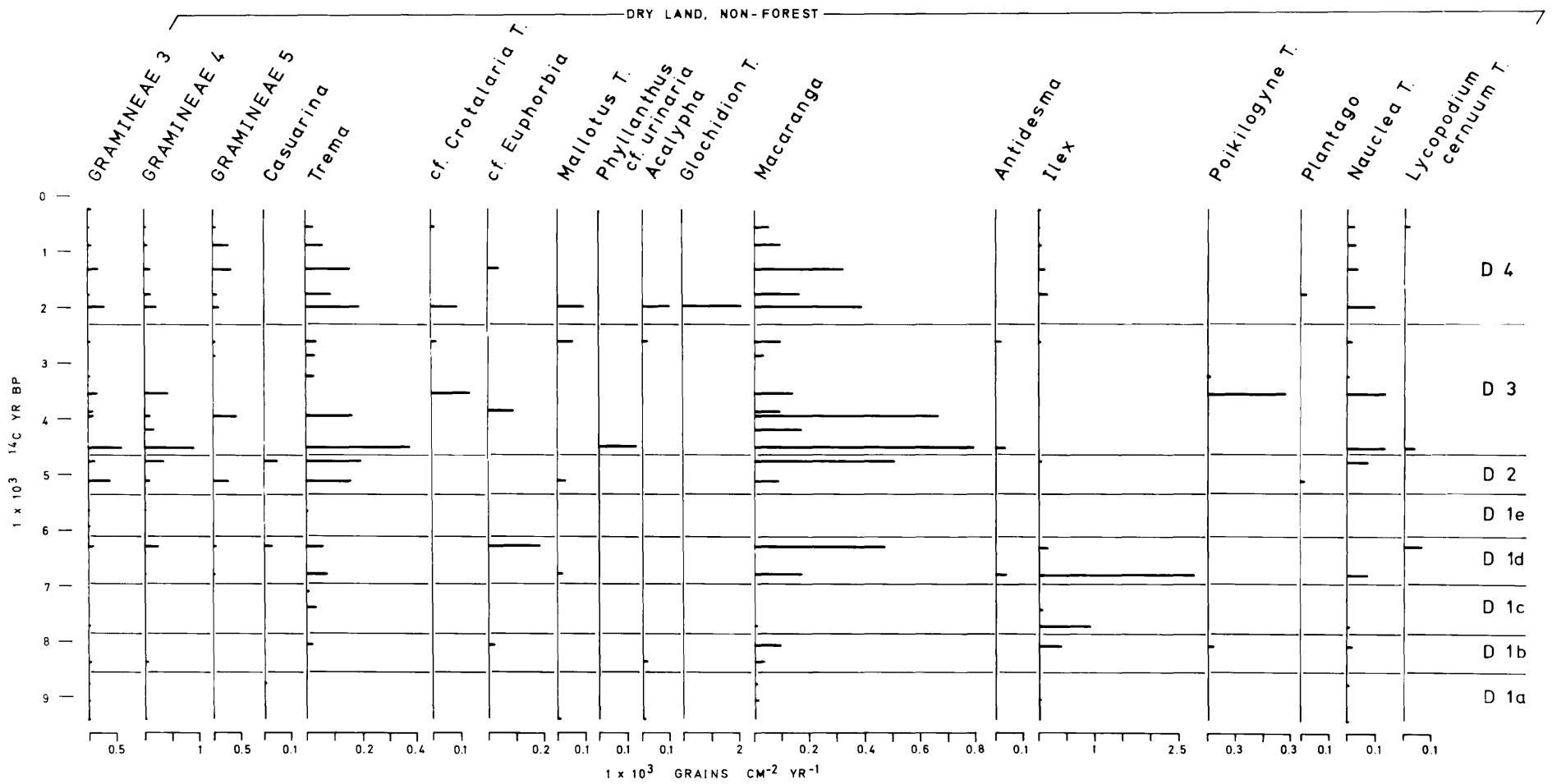


FIGURE 8.5 (Cont.). Lake Wanum core LW II: PDR of selected dry land pollen and spore taxa

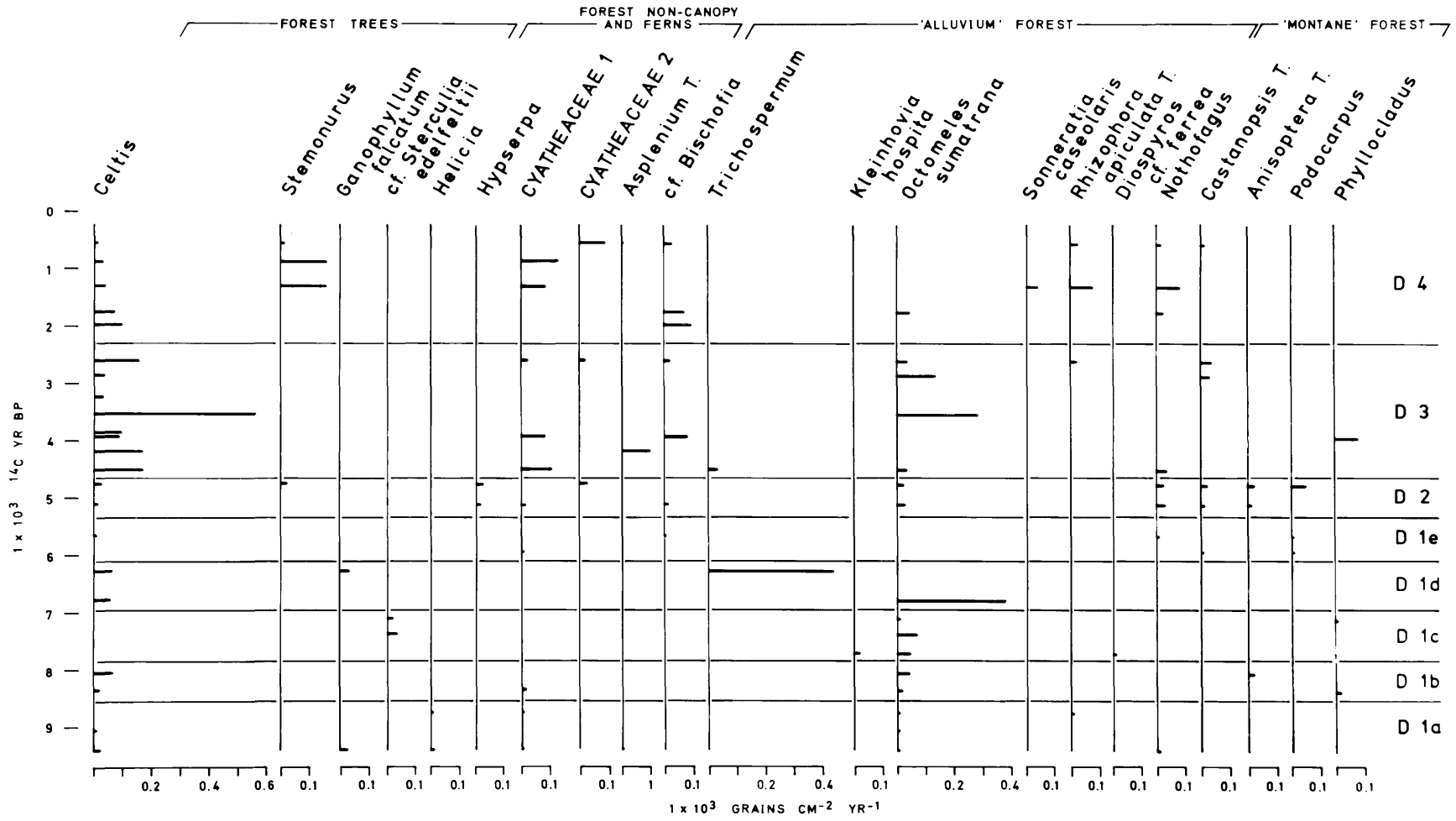
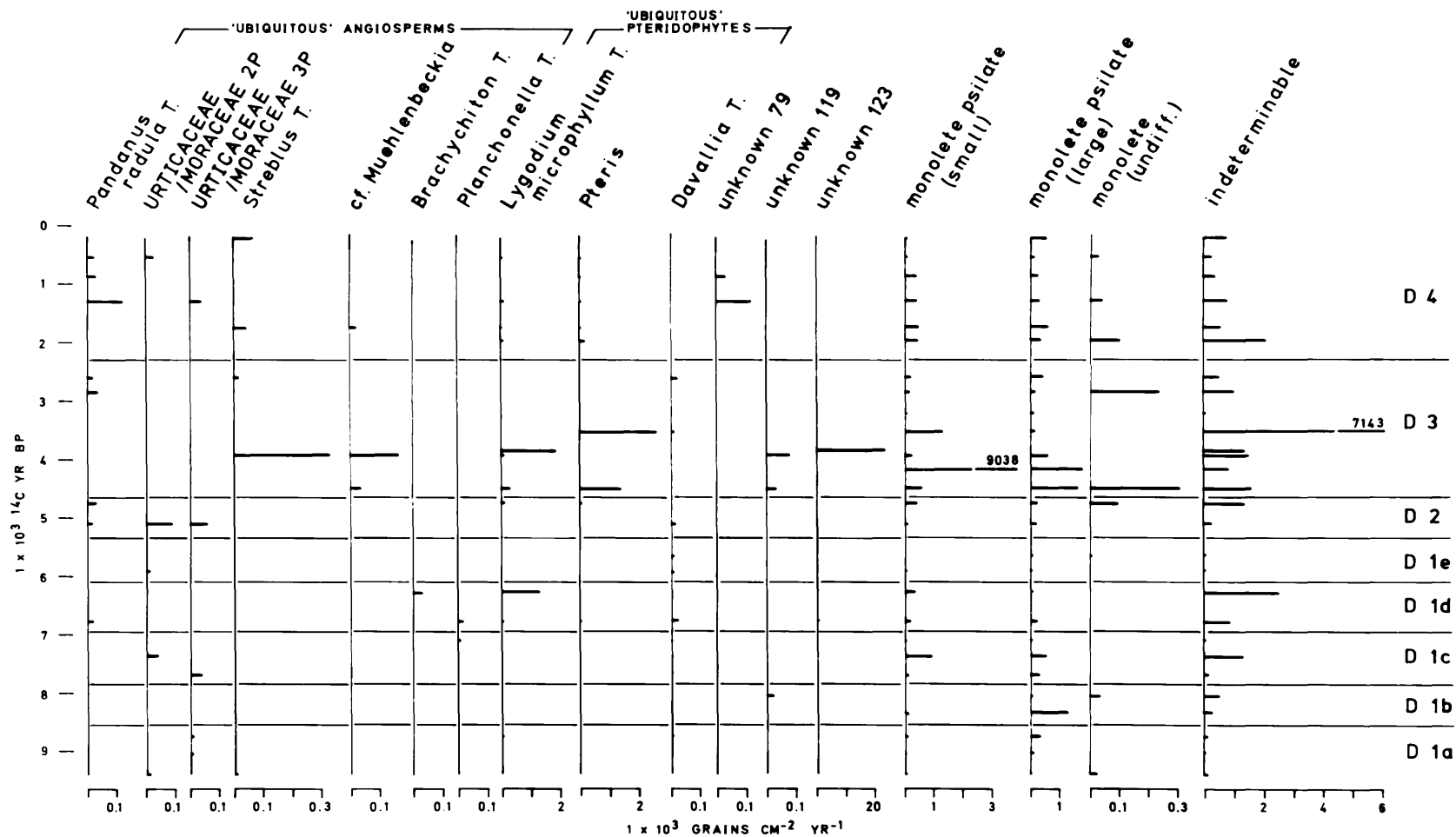


FIGURE 8.5 (Cont.). Lake Wanum core LW II: PDR of selected dry land pollen and spore taxa



Nauclea T. pollen is intermittently represented throughout the core, with highest PDR values being found between 5350 BP and 1800 BP.

Many dry-land forest taxa occur in the pollen record only occasionally, and in small quantity. Although *Mallotus* T. and *Acalypha* are present throughout the core they show an increased PDR around 3000 BP to 2000 BP. Pollen of cf. *Crotalaria* T. occurs first at about 3600 BP. Several representatives of woody shrub or herb taxa, *Phyllanthus* cf. *urinaria*, *Glochidion* T. and *Poikilogyne* T., show isolated but high peaks in PDR since 4700 BP.

The pollen record of *Ilex* contrasts with the trend shown by most non-forest taxa. This taxon reaches very large PDR values, up to 2 700 grains $\text{cm}^{-2} \text{yr}^{-1}$, between 8050 and 6250 BP. It is almost unrepresented from this date until 2600 BP when it reappears, although with much lesser abundance.

Forest trees: *Celtis* is the only commonly occurring pollen taxon in the category and is present throughout most of the core. Small peaks in abundance are seen around 8500 BP to 8100 BP and 6800 BP to 6250 BP, whilst a major increase in PDR occurs between 4600 BP and 3500 BP. From about 2700 BP the PDR of *Celtis* declines constantly.

Only minor occurrences of other tree taxa in this category are found. *Ganophyllum falcatum*, cf. *Sterculia edelfeltii* and *Olea* pollen occur in the lower sections of the core whilst *Spiraeopsis* T. and *Stemonurus* are found in the sediments of the last 1500 years.

Non-canopy forest pollen, and forest ferns: Both categories are poorly represented in the pollen record from core LW II. *Helicia* occurs sparsely prior to 8750 BP. Myrtaceae pollen is found intermittently throughout the sequence with a slight increase in PDR around 4600 BP to 4000 BP. Other taxa, *Hypserpa*, Cyatheaceae and *Asplenium* T. appear more common since 5350 BP.

'Alluvium' forest: *Octomeles sumatrana* is the most abundant taxon in this ecological category, and occurs throughout the core. The tree is consistently represented during the oldest 3000 years of the sequence, its PDR increasing to a peak of nearly 4 000 grains $\text{cm}^{-2} \text{yr}^{-1}$ around 6800 BP. *Kleinhovia hospita* and *Diospyros* cf. *ferrea* occur at about 7800 BP, and a large peak in the PDR of *Trichospermum* is seen at 6300 BP. Pollen of cf. *Bischofia* is more abundant between 5700 BP and 1500 BP, whilst most occurrences of *Rhizophora apiculata* T. pollen are recorded in the last 3000 years of the core.

'Montane' forest: *Nothofagus* and *Castanopsis* T. show the greatest occurrence, other taxa, *Podocarpus*, *Phyllocladus*, *Elaeocarpus* T., *Anisoptera* T. and cf. *Engelhardia* being found only very infrequently. Although the ecological category appears better represented subsequent to 5100 BP, this may be an artefact of the faster deposition rate as no more than two grains of a single taxon are found in any sample.

Ubiquitous pollen and spores: A few taxa whose ecological status is unclear show consistent trends of possible significance. *Pandanus radula* T. pollen occurs sparsely since 7000 BP and appears

more common in the last 1300 years. Undifferentiated Urticaceae/Moraceae pollen are more abundant prior to 5000 BP, whereas *Streblus* T. largely occurs subsequent to 4600 BP as does cf. *Muehlenbeckia*. Sparse representation of *Brachychiton* T. and *Planchonella* T., possibly from 'alluvium' forest trees, occurs around 7000 BP.

Spores of *Lygodium microphyllum* T. are found throughout the sequence with very high PDR values in samples around 6300 BP and 3900 BP. *Pteris* spores also show very high PDR from 4600 BP until 3500 BP and are also frequent in the sediments of the last 2000 years.

The majority of monolete psilate spores undoubtedly derive from ferns of the herbaceous swamp vegetation, in particular from *Nephrolepis hirsutula* and *Microsorium*. Their PDR closely reflects that of the swamp ferns.

Dry-land pollen assemblage zones

The pollen record of dry-land taxa is divided into assemblage zones largely on the basis of changes in the most abundant ecological category, that of non-forest pollen. The representation of other ecologically defined groups is too low to allow separate zonation.

Zone D1: 9500-5350 BP (1970-1670 cm)

Pollen representative of 'alluvium' forest is present from the base of the core until about 6100 BP. *Octomeles sumatrana* predominates, although *Kleinhovia hospita* and *Diospyros* cf. *ferrea* are also recorded. The presence of *Brachychiton* T. and *Planchonella* T. grains around 7000 BP to 6100 BP could also be

associated with 'alluvium' or riparian forest, as might *Antidesma*. The PDR of *O. sumatrana* increases to a peak at 6800 BP but the taxon is absent from the remainder of the zone. A subsequent peak in *Trichospermum* pollen is seen but 'alluvium' forest taxa are generally unrepresented between 6100 and 5350 BP.

Zone D1 may be subdivided on the basis of the representation of various non-forest taxa. Two phases of increased PDR for this ecological category are recorded. The first, zone D1b, occurs between 8550 and 7850 BP (1920 cm to 1880 cm). During this episode, PDR values for *Macaranga* increase substantially and *Trema* pollen first appears in the sequence. There is also a slight increase in the representation of grass pollen, although not in the Gramineae 5 class. Several possible pollen indicators of herbs and shrubs are recorded, including cf. *Euphorbia*, *Acalypha* and *Poikilogyne* T.

The second episode, zone D1d (6940 to 6100 BP, 1820 cm to 1760 cm), is similar in character. Increases in the PDR of the non-forest taxa are even more marked. *Trema* and, in particular, *Macaranga* pollen show dramatic increase, and Gramineae class 5 pollen occurs for the first time. An increase in the PDR of other dry-land grass pollen classes is seen. *Casuarina*, cf. *Euphorbia*, *Mallotus* T. and *Lygodium microphyllum* T., possibly a component of the dry-land non-forest vegetation, are also encountered.

The pollen records of two well represented non-forest trees, *Nauclea* T. and *Ilex* do not follow this pattern of episodic increase. The very high PDR of *Ilex* between 8050 BP and 6250 BP is likely to be derived locally, possibly from *Ilex arnhemensis*.

This shrubby tree occurs today in grassland bordering Redhill swamp and its pollen is abundant in contemporary assemblage SS 23 from the site. *Nauclea* T. is present from the base of the sequence until about 6700 BP. A larger number of ecologically diverse genera of the sub-family Naucleae contribute to the *Nauclea* T. pollen taxon (Table II.1). *Nauclea orientalis* is commonly found in riparian or lake marginal situations in the Lake Wanum vicinity.

With the exception of the mentioned 'alluvium' forest taxa the PDR of forest pollen is very low during zone D1. *Celtis* is the most abundant taxon represented throughout the period. During both zones D1b and D1d the representation of *Celtis* pollen increases synchronously with the non-forest pollen taxa.

The three zones not dominated by pollen of non-forest taxa, although difficult to characterise by their pollen assemblages, include a number of forest taxa. In zone D1a (9500 BP to 8550 BP, 1970 cm to 1920 cm) the forest tree taxa *Ganophyllum falcatum* and *Olea* occur, with various vines and understorey taxa; *Calamus*, *Helicia*, Cyatheaceae and *Asplenium* T. A proportion of the undifferentiated Urticaceae/Moraceae pollen may also derive from forest species. Zone D1c (7850 BP to 6950 BP, 1880 cm to 1820 cm) records pollen of cf. *Sterculia edelfeltii*, Myrtaceae and Urticaceae/Moraceae.

Very low PDR estimates are shown for zone D1e (6100 BP to 5350 BP, 1760 cm to 1670 cm). An assemblage of non-forest and forest taxa is seen, including Gramineae, *Trema*, *Antidesma*, *Celtis*, Cyatheaceae, cf. *Bischofia* and Urticaceae/Moraceae.

Zone D2: 5350-4650 BP (1670-1510 cm)

During this period the pollen assemblage is dominated by a few non-forest taxa. Substantial increases are seen in the PDR of the grasses, *Trema*, and *Macaranga*. *Casuarina*, *Mallotus* T., *Plantago* and *Nauclea* T. are also present. The PDR of forest pollen is low, although *Celtis* is found. 'Alluvium' forest is represented by pollen of *Octomeles sumatrana* and cf. *Bischofia*.

Zone D3: 4650-2300 BP (1510-960 cm)

Although PDR values for the major non-forest taxa remain as high or higher than for zone D2 during the first 1000 years of zone D3, a declining trend is evident. Notable is the representation of some forest taxa. The PDR of *Celtis* increases to the highest figures seen in the core (nearly 600 grains $\text{cm}^{-2} \text{yr}^{-1}$). Myrtaceae pollen, possibly from subcanopy trees, increases in representation as do the forest ferns Cyatheaceae and *Asplenium* T. Of the ecologically 'ubiquitous' taxa *Streblus* T., cf. *Muehlenbeckia*, *Lygodium microphyllum* T. and *Pteris* also show peaks in occurrence during this period.

From about 3600 BP, the PDR of most taxa decline, although that of *Celtis* less so than the non-forest representatives. In contrast, *Octomeles sumatrana*, present throughout the zone, records a large increase in PDR.

Zone D4: 2300 BP to Present (960-640 cm)

A renewed increase in the PDR of many non-forest taxa begins by 2000 BP. Although rates for individual pollen types are generally slightly less than for zone D2 and the lower part of zone D3, a larger number of taxa show increased representation. Grass pollen, especially Gramineae 5, *Trema* and *Macaranga* record the

greatest increase in PDR. Pollen characteristic of herbs and shrubs, cf. *Crotalaria* T., cf. *Euphorbia*, *Euphorbia hirta* T., *Plantago* and *Acalypha*, is well represented in the zone. A large peak of *Glochidion* T. pollen occurs in the initial sample of the zone at about 2000 BP. *Nauclea* T. shows a fairly constant PDR throughout the period.

Of the forest pollen taxa, *Celtis* is present at the base of the zone, but its PDR subsequently declines sharply.

Stemonurus is abundant between 1500 BP and 600 BP and Myrtaceae pollen and spores of Cyatheaceae also occur in the zone.

Octomeles sumatrana is not well represented after 1750 BP although there are isolated occurrences of the predominantly mangrove taxa, *Sonneratia caseolaris* and *Rhizophora apiculata* T.

Ecologically 'ubiquitous' taxa represented include *Pandanus radula* T., *Streblus* T., and spores of *Pteris* and *Lygodium microphyllum* T.

The inferred age of the uppermost sample analysed from core LW II is 225 BP. However there appears to be little significant difference between this pollen assemblage, and one from the surficial sediments of the nearby short-core, LWMC 3. Comparison of relative pollen frequencies for both samples shows a slight increase in Gramineae and *Macaranga* pollen in the more recent sediment. The proportions of *Trema* and *Celtis* are similar in both samples although those of *Octomeles sumatrana* and Urticaceae/Moraceae are greater in the contemporary assemblage. However no major changes are reflected in the pollen record of the last 250 years.

DRY-LAND VEGETATION CHANGE IN THE LAKE WANUM VICINITY

The pollen evidence comprises the combined records of individual taxa that are frequently ambiguous or obscure. Despite these limitations, clear trends are shown in the dry-land taxa pollen diagrams. These trends may be tentatively interpolated to produce a fragmentary picture of changes in the ecology of nearby dry-land vegetation.

Most of the pollen and spore taxa recorded from the core can be found in contemporary assemblages from the near vicinity of the lake. Conversely, none of the modern assemblages from higher altitudes (180 m to 1 000 m) show any close counterpart in the sub-fossil record. Small quantities of 'montane' forest tree pollen, in particular *Nothofagus*, *Phyllocladus* and *Podocarpus*, are recorded throughout the core. However, pollen of these taxa is seen to be efficiently transported into contemporary low altitude spectra, and there is no suggestion that these genera were formerly more abundant in the vicinity than today.

'Alluvium' or riparian forest, characterised chiefly by *Octomeles sumatrana* pollen appears better represented in the early Holocene, prior to about 6500 BP. The high PDR values for *Ilex* between 8050 BP and 6250 BP are interpreted as possibly indicative of woody swamp-marginal vegetation. Subsequently, the pollen representation of both taxa declines considerably although *O. sumatrana* reappears after 5350 BP and again achieves a high PDR between 3700 BP and 2700 BP. It is interesting to compare the representation of these two taxa with the reconstructed swamp vegetation communities and the water depth curve for the LW II site (Fig. 8.4). Although both taxa occur during the initial 1300 years of the sequence (swamp zone Sla), an increase in relative frequency and PDR is seen between 8200 BP and 6250 BP, in the initial

phase of zone Slb. The rise in water level postulated for about 8200 BP may have led to the increased importance of 'alluvium' forest and *Ilex* within the vicinity. As suggested previously, high PDR values for *Stenochlaena palustris* spores at this time could possibly have been associated with 'alluvium' or riparian forest rather than with herbaceous swamp vegetation. Further rise in water level, such as may have occurred at about 6500 BP, could explain the apparent recession of 'alluvium' forest and swamp marginal vegetation from the immediate vicinity of the coring site.

Whilst this hypothesis may explain the sequence of development during the first 3000 years of the swamp's history, it does not adequately account for increased representation of *Octomeles sumatrana* later in the core, at a time of postulated deeper water conditions.

The most evident trend in the dry-land pollen sequence is the increasing representation in the later Holocene of certain non-forest taxa. The most abundant of these are the grasses, and the tree genera *Trema* and *Macaranga*. Also showing the same pattern are other woody and herbaceous taxa, including various Euphorbiaceae, cf. *Crotalaria* T. and *Poikilogyne* T. Many of these pollen taxa can be identified with light-demanding species of forest regeneration or grassland communities. In Papua New Guinea highland pollen records *Trema* and *Macaranga* in particular often appear to be associated with human induced forest disturbance or clearance (Powell *et al.*, 1975, Walker and Flenley, in press) and Morley (1976) postulates a similar association for lowland sites in Malesia. Although circumstantial, several lines of evidence suggest human disturbance to be the primary cause of the expansion of non-forest vegetation in the Lake Wanum area also.

The relationship between pollen of the forest tree genus *Celtis* and that of the non-forest taxa is of especial interest. During zone D1b, increase in the PDR of the non-forest taxa is matched by similar increase in the PDR of *Celtis*. In zone D1d *Celtis* pollen shows an increased PDR, but it is much less than the increase in the selected 'disturbance' taxa, particularly *Macaranga*.

The onset of zone D2 at 5350 BP sees a large increase in the PDR of non-forest pollen. During this period *Celtis* registers only a very slight increase in PDR. Much higher values for *Celtis* pollen are seen in the initial part of the succeeding zone (D3) in association with similarly high PDR of Gramineae, *Macaranga*, and to a lesser extent *Trema*. Although the PDR of most taxa decline in the latter part of the zone, the decrease in *Celtis* is less marked. The tree pollen thus becomes proportionally more abundant during this time, accounting for up to 15% of the dry-land pollen sum.

The most recent 2300 years (zone D4) sees a renewed increase in the PDR of grasses, *Trema*, *Macaranga*, and a number of other non-forest pollen taxa. The PDR values for *Celtis*, however, decline during this zone. The taxon represents only 1.5% of the dry-land pollen seen in the surficial sediment from core LWMC 3. *Celtis* pollen is absent from PT 5, the closest trap to the coring site, even though it dominates the count from PT 4, in forest to the east of Lake Wanum.

The pollen record thus appears to suggest that *Celtis* is promoted during the initial two 'disturbance' phases, prior to 5350 BP. After this date, however, the *Celtis* PDR is inversely correlated with that of the major non-forest taxa. It is possible

that the apparent synchronicity in the lower sediments is due only to the averaging effect of the slower sedimentation rate.

The second major change seen in succeeding 'disturbance' zones is in the representation of pollen thought to derive from dry-land grass species. The PDR values for such grass pollen are very low in zone D1b, and only slightly higher in zone D1d. The latter zone sees the first occurrence of Gramineae class 5 grains, some of which may be associated with the main grassland species today, *Themeda australis*. The grass PDR tends to increase synchronously with other dry-land taxa, but Gramineae pollen becomes proportionally more important in the later zones. The representation of Gramineae 5 is significantly higher in zone D4.

Of especial interest is the close correlation between the PDR of the 'disturbance' taxa, and the estimated influx of carbonised plant fragments (Fig. 8.1). These charcoal particles are presumably produced as the result of fire in the dry-land vegetation. The first large peak in carbonised particles occurs in the lower sample of zone D1b, and increased influx is also seen during the second 'disturbance' episode, zone D1d. The major peak in carbonised particle influx is recorded in zone D2, and the early part of zone D3, where PDR values for 'disturbance' taxa, especially *Macaranga*, are also very high. The incidence of carbonised particles is low for the latter part of zone D3, but increases, although still at a fairly low level, at the start of zone D4. The charcoal particles are assigned to three size classes, each showing a generally similar pattern of representation. The largest fragments are, however, almost absent from the earliest zones, and become most abundant in the initial part of zone D3. Many of these large particles can be identified as fragments of monocotyledonous cuticle, possibly from grasses.

Thus it seems likely that the increased representation of non-forest pollen in the sequence at least partially reflects anthropogenic impact on the vegetation. The early 'disturbance' zones, prior to 5350 BP appear to favour increased representation of secondary forest trees, such as *Celtis*, and other woody taxa. It is possible that the preponderance of *Celtis* in the forest to east of Lake Wanum today reflects a history of human impact. As vegetation disturbance becomes perhaps more frequent, or intense, woody taxa such as *Trema* and *Macaranga* are favoured. This appears the case during zone D2, and the earlier part of zone D3. In zone D3, and especially from the start of zone D4 (2300 BP), a greater proportion of the pollen of dry-land grasses and of grassland herbs is found.

The extent of grassland and non-forest vegetation

Some estimate of the areal extent of the vegetation contributing to the pollen assemblages is crucial in the reconstruction of past communities. This is especially true when attempting to assess the extent, and thus any extension, of the non-forest and grassland vegetation previously recognised in the pollen record.

Some insight can be gained from the comparison of PDR figures. The PDR estimates in the LW II core for total dry-land pollen and spores (including 'ubiquitous' angiosperm taxa, but not 'ubiquitous' spores as many are produced by herbaceous swamp ferns) range from 30 grains $\text{cm}^{-2} \text{yr}^{-1}$ to 3 800 grains $\text{cm}^{-2} \text{yr}^{-1}$. In contrast, estimated annual aerial influx rates to the three pollen traps in the Lake Wanum area for this group of taxa were 377 800 grains cm^{-2} for PT 4 in disturbed forest, 98 000 grains cm^{-2} for PT 4 in *Celtis* dominated forest and 240 grains cm^{-2} for

the floating trap, PT 6. As can be seen, PDR estimates from the sediments fall into the lower end of this range. A few values are even lower than those shown in the isolated floating trap, but in no sample do the PDR estimates for dry-land taxa approach those recorded by the two traps located within forest.

Assuming that PDR estimates from sediments may be compared with the solely aerial pollen influx of the traps, several conclusions are suggested. At no time was dry-land vegetation growing on the site of core LW II as sediment PDR values do not approach the high influx rates found in the pollen traps. However, dry-land vegetation may have been closer to the site in the past than its distance (*c.* 50 m) today. In zone D1d, D2 and the early part of zone D3, PDR values for non-forest 'disturbance' taxa are considerably higher than those for the most recent period. Pollen assemblages of these earlier zones may thus record events that are either different in character, more extensive, or closer to the coring site, than those seen in the younger sediments. None of these possibilities can be certainly excluded. Qualitative differences between succeeding zones have been shown, and the lower water level especially prior to about 3500 BP could have allowed dry-land vegetation closer to the site. It is thus not admissible to equate the increased PDR values for 'disturbance' taxa with a general extension of non-forest or grassland vegetation.

Dry-land PDR estimates in the core are, for the most part, greater than those from the centre of the north-east bay today (PT 6). The pollen assemblages of the core may therefore reflect, to some extent, more localised events. Very low PDR values for *Celtis*, a taxon with abundant sources within the lake's

catchment, occur in the upper samples of the core and in all contemporary spectra but PT 4. This also suggests that the majority of the dry-land pollen contributing to the core assemblages originates in the fairly local area, certainly within several hundred metres, and possibly much less. Conversely, a small 'regional' or long-distance component, is reflected in the occurrence of pollen of taxa restricted to higher altitudes.

Further circumstantial evidence as to the extent of the 'disturbance' events may be suggested by the carbonised particle data (Fig. 8.1). It is probable that only a small proportion of the charcoal produced by a fire is aurally dispersed (Corlett, unpubl.) and that most enters the lake via slopewash (Swain, 1973). Assuming, perhaps unrealistically, that charcoal is not carried far once in the lake, the proportion of carbonised particles to pollen of 'disturbance' taxa may indicate the proximity of the fires. Thus zone D1b shows a high proportion of carbonised particles to pollen, perhaps reflecting a local event. The proportion of charcoal is lower during the later zones, especially in zone D4, perhaps indicating that the 'disturbance' events occurred further away from the coring site.

VEGETATION DISTURBANCE AND INORGANIC SEDIMENTATION

The sedimentary record (Figs. 8.1 and 3.6) shows discrete phases of inorganic influx that appear restricted to the western margin of the north-east bay of Lake Wanum. As the vegetation 'disturbance' also appears predominantly local, comparison with these allochthonous horizons may be profitable.

The first inorganic deposition peak in the LW II core occurs at about 7700 BP in zone D1c, although a slight rise in deposition rate is seen towards the end of the previous 'disturbance' zone D1b. The longest sustained phase of inorganic sediment deposition is found from about 6300 BP to 5250 BP. This horizon, although apparently initiated during zone D1d, reaches its greatest influx in zone D1e, a section of the core with very low PDR values for both swamp and dry-land taxa.

The inorganic sediments of these early zones are composed of orange- or grey-brown gritty sand (*Grana arenosa*) with lesser proportion of grey clay (*Argilla steatodes*). However, the composition of the influx phases subsequent to 5000 BP is qualitatively different. Grey clay (*As*) predominates, whilst *Grana arenosa* is absent. Narrow clay bands occur within zone D3 at about 4400 BP and 3900 BP. Both are synchronous with increases in the PDR of 'disturbance' taxa. The most recent phase of sustained inorganic sediment influx occurs during zone D4. Here too the peak in clay deposition is approximately contemporaneous with increased PDR values for 'disturbance' taxa.

There is thus some circumstantial evidence to link increased pollen representation of disturbed vegetation and grassland with deposition of grey clay during the last 5000 years. Prior to this, the peaks in inorganic influx are different in nature and do not appear to be correlated with pollen or charcoal evidence for vegetation disturbance. Even in the upper part of the sequence there is no simple correlation between phases of disturbance and grey clay deposition. Zone D2 shows the highest PDR values for

many 'disturbance' taxa and a large number of carbonised particles, yet lacks any influx of grey clay, although a narrow peak is shown shortly after, in zone D3.

Inorganic sedimentation is influenced to a large extent by the depositional environment of the site. Increases in water depth and in distance from shore that have taken place particularly since 5000 BP may be the prime cause of the change in the inorganic sediments subsequent to this date.

THE POLLEN RECORD FROM YANAMUGI

The 10.38 m long core YAN 2, collected from the margin of the sago swamp at Yanamugi, was selected for pollen analysis. Twenty-three samples were taken, most at intervals of 40 cm, although in some upper sections of the core the interval was increased to 80 cm.

The basal age of core YAN 2 probably lies between 1000 BP and 2000 BP. The core thus possesses a much shorter pollen record than that available from Lake Wanum. The temporal interval between samples is in the order of decades, rather than hundreds of years. The sequence therefore may thus be useful for the finer resolution of short term vegetational events.

The chronology of the sediments is not firmly established. A correlation between the relative chronologies of cores YAN 2 and YAN 1 has been suggested (Fig. 4.9b, Table 4.4) but this is not sufficiently reliable to allow general calculation of annual pollen deposition rates. The pollen data for Yanamugi core YAN 2 are therefore presented as pollen concentrations for the major ecological groups (Fig. 8.6), whilst selected individual taxa are shown in Fig. 8.7 as percentages of the total pollen sum. The

total pollen and spore concentration is seen to fluctuate considerably. Some of the lowest values occur between 450 cm and 600 cm, partially coinciding with the section of suggested rapid clay influx between 450 cm and 800 cm. Pollen concentrations in samples between 600 cm and 800 cm are generally higher, although some lesser values are recorded. An increase in pollen concentration is seen in the uppermost sediments, between 240 cm and 120 cm. In the lower part of the core, below 1035 cm, the inferred sedimentation rate drops substantially. This decline is not reflected by consistently higher pollen concentrations, however.

Adjustment of the pollen concentration values for the inferred sedimentation rate (Table 4.4) produces a wide range of PDR estimates. The least, 420 grains $\text{cm}^{-2} \text{yr}^{-1}$ occurs in the basal sample of the core, whilst the greatest, over 44 000 grains $\text{cm}^{-2} \text{yr}^{-1}$, is from the sample at 670 cm, due to the assumption of an extremely rapid sediment accumulation at this time. Many PDR values, including those from the better dated top metre of the core, occur within the range of 2 500 to 7 000 grains $\text{cm}^{-2} \text{yr}^{-1}$. These values are similar to those found for the non-swamp component of many spectra in the Lake Wanum core LW II.

The pollen record of individual taxa

Herbaceous swamp taxa: The most common taxa represented are the various grass pollen classes. Few Gramineae 1, possibly indicative of *Leesia hexandra*, occur. The main swamp grass at Yanamugi today is *Phragmites karka*. Most pollen from this species falls into classes 3 and 4 (not included in the herbaceous swamp category) and into Gramineae 2. These three categories of grass pollen show an increase above about 400 cm, although all are present throughout the core.

FIGURE 8.6. Yanamugi core YAN 2: Pollen concentration of major ecological groups, and frequency of carbonised particles

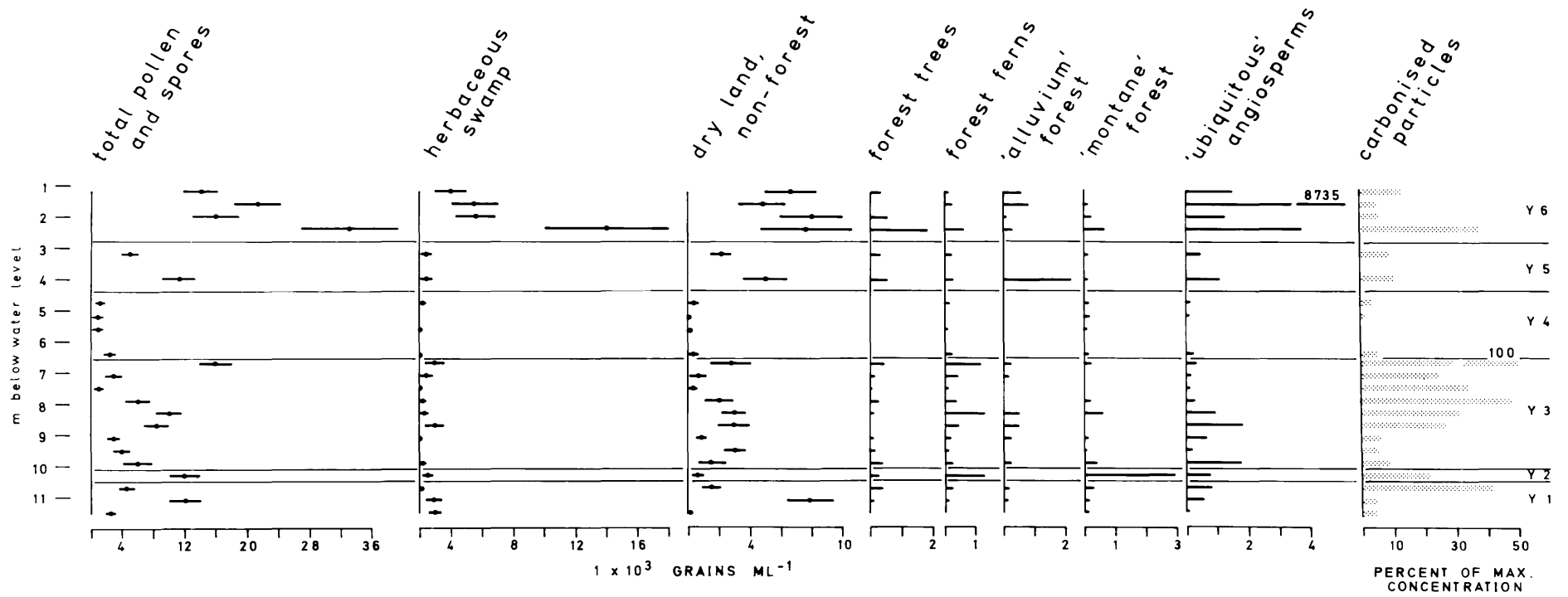


FIGURE 8.7. Yanamugi core YAN 2: Relative frequency diagram for selected pollen and spore taxa

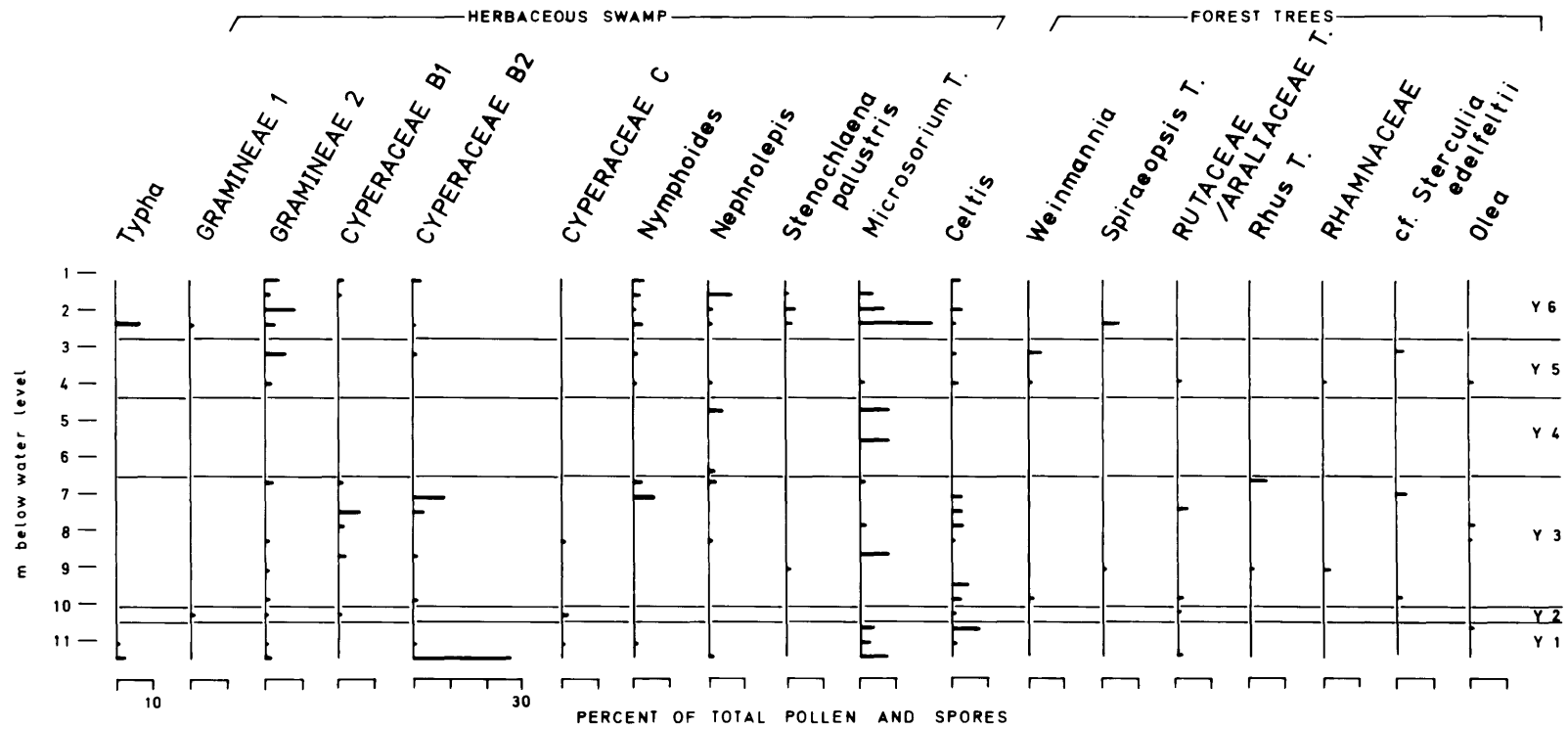


FIGURE 8.7 (Cont.). Yanamugi core YAN 2: Relative frequency diagram for selected pollen and spore taxa

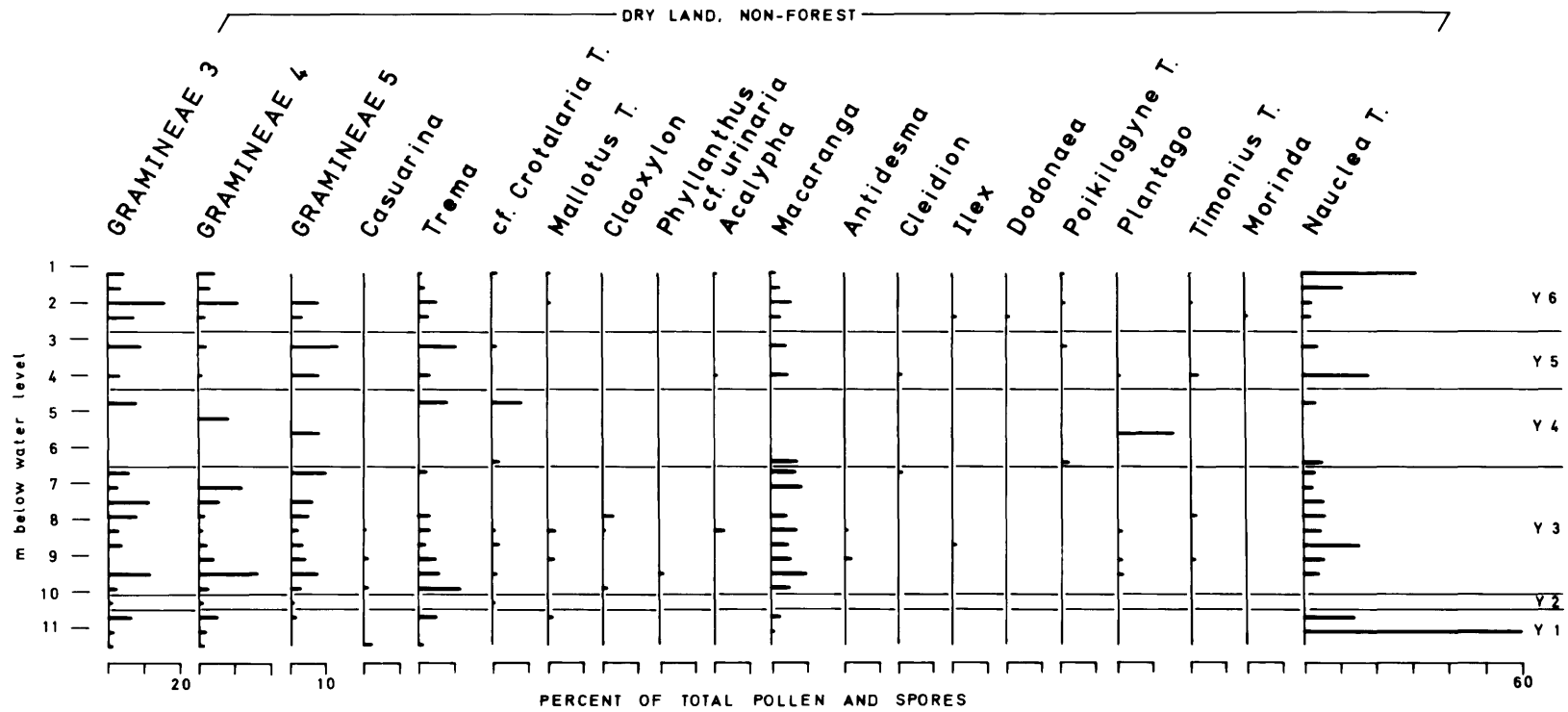


FIGURE 8.7 (Cont.). Yanamugi core YAN 2: Relative frequency diagram for selected pollen and spore taxa

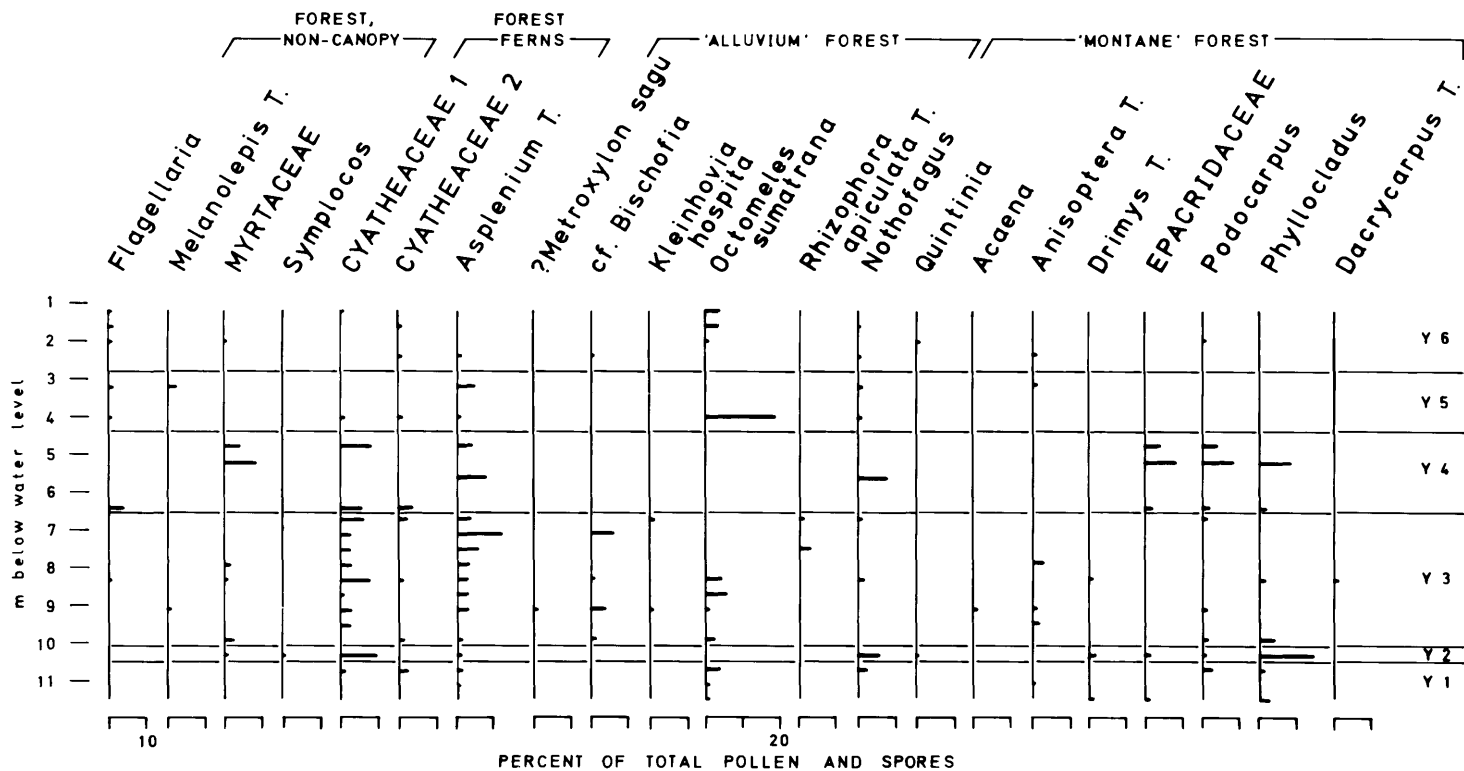
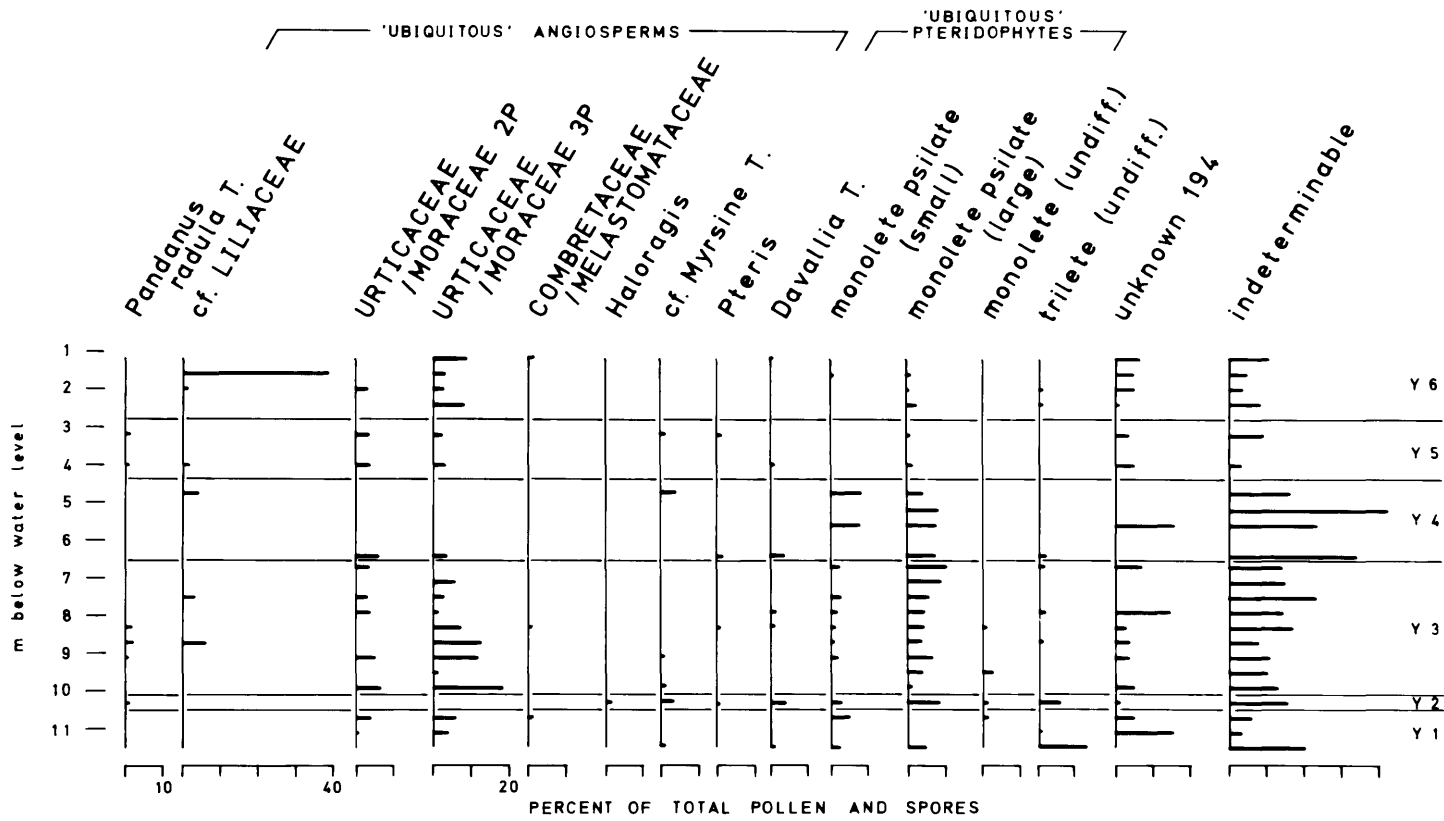


FIGURE 8.7 (Cont.). Yanamugi core YAN 2: Relative frequency diagram for selected pollen and spore taxa



Sedge pollen also occurs throughout the sequence. Cyperaceae B2 comprises a large proportion of the basal sample assemblage. It is present in lesser quantity between 700 cm to 775 cm, and above 320 cm. Pollen of Cyperaceae class B1 shows a similar distribution apart from its absence from the basal sample. Some grains attributed to Cyperaceae class C are found in the lower sediments.

Nymphoides pollen is the only indicator of floating leaved aquatic vegetation. Scattered occurrences are found throughout the core, but the taxon is consistently represented only in samples from 400 cm and above.

Lake marginal plants, or shallow water floating vegetation, are probably represented by the taxa *Uncaria* T., *Nephrolepis*, *Stenochlaena palustris*, and *Microsorium* T. All show increased abundance above 300 cm in the core although *Microsorium* T., *Uncaria* T., and to a lesser extent *Nephrolepis* are found throughout the sequence.

Metroxylon sagu is a major component of the contemporary lake marginal and swamp vegetation at Yanamugi. Only one grain tentatively attributed to the palm was found (at 910 cm).

Dry-land, non-forest taxa: Grass pollen is the most abundant component of this ecological category also, although as suggested above a proportion may derive from swamp species. Gramineae class 5 is less abundant below 990 cm, and is absent from the two most recent samples.

Macaranga and *Trema* are well represented throughout the sequence. Their occurrence follows a pattern similar to that shown by the dry-land grasses, both being less abundant below 990 cm.

Various taxa possibly representative of non-forest shrub and herb species are found although none is common. Those most frequently encountered are cf. *Crotalaria* T., *Mallotus* T., *Claoxylon*, *Acalypha*, *Poikilogyne* T. and *Timonius* T. *Casuarina* pollen occurs only below 800 cm and *Plantago* also appears more frequent in the lower part of the core.

Pollen of *Nauclea* T. is present in abundance throughout much of the core. The taxon shows greater fluctuation in representation than do the grasses, *Trema* or *Macaranga*. It forms a large proportion of the pollen sum in samples from 1160 cm, 160 cm and 120 cm. The most likely source of this pollen may be the riparian forest associated with Sina Creek, although there are many trees of *Nauclea* species, e.g. *Nauclea orientalis*, in the grasslands of the Markham Valley floor.

Forest tree taxa: *Celtis* pollen shows a pattern of representation similar to that of *Trema* and *Macaranga*, although it is proportionally slightly more abundant in the lower sediments. A number of other forest tree taxa are infrequently found. Of these, *Weinmannia* T., Rutaceae/Araliaceae, cf. *Sterculia edelfeltii* and *Olea* are the most common. The unidentified pollen taxon UK 194, present throughout the core, may also derive from a forest tree species as it dominates the contemporary pollen assemblage of the local forest.

Non-canopy forest taxa: Pollen of the vine *Flagellaria* is distinctly more frequent in the samples from 400 cm and above. Myrtaceae pollen occurs in small quantities throughout the sequence.

The spores of forest ferns, predominantly Cyatheaceae and *Asplenium* T. are much more abundant in the sediments below 440 cm. Both show much reduced percentages in the more recent samples and contemporary assemblages.

'Alluvium' forest taxa: *Octomeles sumatrana* is the most abundant taxon in this category, occurring consistently below 800 cm but also substantially represented in the sample at 400 cm. A slight increase in abundance is also seen in the most recent three samples. Pollen of cf. *Bischofia* shows a similar distribution and *Kleinhovia hospita* occurs infrequently in the lower part of the core. The presence of two grains of *Rhizophora apiculata* T. may be attributed to long-distance transport from the lower Markham Valley.

'Montane' forest taxa: A much larger number of 'montane' taxa are recorded in the Yanamugi sediments than at Lake Wanum. The most abundant are *Nothofagus* and *Anisoptera* T., found throughout the core, and Epacridaceae, *Phyllocladus* and *Podocarpus*, restricted, or almost so, to the sediments below 440 cm. The pollen concentration figures for the total of this ecological category remain fairly constant, with the exception of a large peak in the sample from 1030 cm.

'Ubiquitous' angiosperm taxa: Undifferentiated pollen of Urticaceae/Moraceae is the most abundant taxon in this category. Diporate and triporate grains of the taxon occur throughout the core and constitute nearly 20% of the contemporary assemblage from core YANMC 1. Forest trees, such as *Pipturus*, probably contribute to the taxon, but the majority of the pollen may derive from non-forest urticaceous genera. Pollen of cf. Liliaceae is first represented at 870 cm. The taxon generally occurs in small

proportions, but accounts for nearly 45% of the pollen sum in the sample at 160 cm. It is possible that the source is a lake marginal or swamp taxon. *Pandanus radula* T. pollen is sparsely represented throughout the sequence. That of cf. *Myrsine* T. is more abundant in the lower core, especially in the sample from 1030 cm, and may be associated with the 'montane' group of taxa.

'Ubiquitous' pteridophyte taxa: Almost all 'ubiquitous' spore taxa are absent, or less abundant above 440 cm. The pattern of representation is thus similar to that of the forest ferns, and 'montane' forest categories. Most abundant above 440 cm are the large monolete psilate spores, possibly deriving from *Microsorium* or *Asplenium* species.

Pollen assemblage zones

Zone Y1: 1150-1050 cm

In the deepest sample from core YAN 2, the pollen concentration is low, and the assemblage is dominated by herbaceous swamp taxa. Pollen of Cyperaceae class B2 possibly reflects the presence of *Eleocharis dulcis*. *Typha* pollen occurs and Gramineae 2 pollen and *Microsorium* T. spores may derive from herbaceous swamp vegetation. The high proportion of swamp pollen taxa in this sample may be associated with the band of compact organic detritus from 1152-1153 cm at the base of the core. This horizon is thought to represent redeposited detritus, possibly from lake marginal vegetation.

Swamp taxa are little represented in the two succeeding samples, the predominant pollen taxon being *Nauclea* T. Proportions of other dry-land non-forest taxa are low, although *Trema*, *Macaranga*, and various Gramineae occur. Forest trees are

represented by pollen of *Celtis*, Rutaceae/Araliaceae, *Olea*, and possibly by the unidentified pollen taxon UK 194. *Octomeles sumatrana* occurs in the zone, and undifferentiated Urticaceae/Moraceae grains are also present.

Zone Y2: 1050-1010 cm

This zone consists of a single sample (1030 cm to 1031 cm) from the proximity of the dark gritty horizon at 1032 cm to 1037 cm. The sample is uniquely characterised by the high proportion and pollen concentration of taxa assigned to the 'montane' forest category. *Phyllocladus* pollen is best represented, but pollen of *Nothofagus*, *Quintinia*, *Drimys* T., Epacridaceae and *Podocarpus* also occur. The 'ubiquitous' pollen taxa cf. *Mysine* T. and *Haloragis* present in the sample may also derive from 'montane' vegetation. Many spore taxa are also better represented in this zone. A rise in the proportion of the forest fern Cyatheaceae occurs, although not in the values for *Asplenium* T. Increases are seen in the concentrations of 'ubiquitous' pteridophytes, especially of monolete psilate spores, and various unidentified spore taxa.

Zone Y3: 1010-655 cm

The pollen concentration of the sediments of this zone fluctuates, but does not generally reach values as high as in some samples of the preceding zones.

Swamp vegetation is only sparsely represented. There is increasing occurrence of Cyperaceae pollen towards the top of the zone, and *Nymphoides* and ?*Metroxylon sagu* are also found.

A large number of dry-land pollen taxa contribute to the pollen spectra of the zone, non-forest taxa being particularly abundant. An increase in the occurrence of the larger grass pollen grains, especially of the Gramineae 5 class, is seen. *Macaranga* and *Nauclea* T. are well represented by fairly constant percentages throughout the zone. *Trema* is also abundant, although a slight decline occurs towards the top of the zone. Amongst other non-forest taxa represented are *Casuarina*, cf. *Crotalaria* T., *Mallotus* T., *Antidesma*, and *Plantago*.

Celtis is the best represented of the forest trees, occurring in most samples. Rutaceae/Araliaceae, *Rhus* T., cf. *Sterculia edelfeltii* and *Olea* are also recorded. Myrtaceae pollen, possibly from understorey trees, is found in several samples.

The forest ferns, Cyatheaceae and *Asplenium* T. show their greatest abundance in zone Y3. The frequency of Cyatheaceae spores (mainly Cyatheaceae 1, those without a perisporium) is fairly constant. Percentages of *Asplenium* T. increase towards the top of the zone. The 'ubiquitous' monolete psilate fern spores are also abundant throughout.

'Alluvium' forest is represented in the earlier part of the zone by *Octomeles sumatrana* pollen. *Kleinhovia hospita* and cf. *Bischofia* also occur, and *Rhizophora apiculata* T. pollen is found in the upper section of the zone.

Most of the 'montane' taxa present in zone Y2 continue to occur, although at lower frequencies, in zone Y3. In addition, isolated grains of cf. *Engelhardtia*, *Acaena*, *Anisoptera* T., *Rapanaea* cf. *achradaefolia* T. and *Dacrycarpus* T. are found.

Undifferentiated pollen of Urticaceae/Moraceae is fairly abundant and the unidentified pollen type UK 194 is also present.

Zone Y4: 655-440 cm

This zone coincides with stratigraphic evidence for very rapid sediment deposition. Plant detritus accumulation occurs between 640 cm and 540 cm and a rapid influx of clay from 540 cm to 420 cm is suggested by the inferred chronology. As a consequence, very low pollen concentrations are recorded in the four samples of zone Y4. The total pollen sum is also small, ranging from 12 to 53 grains. Dry-land non-forest pollen is present, but a larger proportion of the count comprises 'montane' forest taxa and 'ubiquitous' fern spores.

Zone Y5: 440-280 cm

Zone Y5 sees a return to a more moderate sedimentation rate, and increased pollen concentrations. In many respects the pollen spectra of this zone and zone Y3 are very similar.

Nymphoides is present in the upper part of Y3, and throughout Y5, although there is a drop in the proportion of Cyperaceae pollen.

The pollen concentration of dry-land taxa shows an increase over zone Y3, and the category comprises nearly 50% of the pollen sum. Grass pollen representation also rises, especially in the Gramineae 2 and Gramineae 5 classes. *Trema*, *Macaranga* and *Nauclea* T. are the most abundant taxa.

Forest trees are represented by essentially the same taxa as in zone Y3, *Celtis* and *Weinmannia* T. being the most common. Pollen of the vine *Flagellaria* occurs in both samples from the

zone. A large peak of *Octomeles sumatrana* pollen is seen at 400 cm, but other 'alluvium' forest taxa are absent.

Of the 'ubiquitous' pollen taxa, Urticaceae/Moraceae remain represented, and *Pandanus radula* T. is also present. The unidentified taxon UK 194 comprises about 5% of the pollen sum during the zone.

The major difference between the pollen assemblages of zone Y5 and the previous zones lies in the markedly decreased representation of 'montane' forest and various pteridophyte taxa. A few grains of *Nothofagus* and *Anisoptera* T. occur but spores of Cyatheaceae and the small monolete psilate class are almost absent.

Zone Y6: 280-120 cm

The most recent pollen assemblage zone of the YAN 2 core sees a general increase in pollen concentration. Herbaceous swamp taxa show proportionally the largest increases. The representation of *Nymphoides* pollen increases to about 2% of the sum throughout the zone, and *Typha* and Cyperaceae B1 and B2 pollen also occur. Increases in Gramineae classes 3 and 4, and to a lesser extent class 2, may suggest the presence of *Phragmites karka* near the site. Most other taxa included in the herbaceous swamp category probably represent lake marginal vegetation. *Uncaria* T., *Nephrolepis*, *Stenochlaena palustris* and *Microsorium* T. fall into this category, as may cf. Liliaceae pollen. All these taxa show increased representation in zone Y6. There is little open swamp today at Yanamugi, although some floating root-mat associations exist close to shore. It is suggested that the swamp and aquatic vegetation of this period probably resembles that observable at the present time both in floristic structure and general distribution.

The dry-land pollen assemblages remain similar to those of the previous zone with grasses, *Trema* and *Macaranga* well represented. *Nauclea* T. also occurs, showing a large increase in frequency in the two uppermost samples of the zone. Forest trees continue to be represented by *Celtis* pollen, and *Flagellaria* occurs consistently. The proportion of *Octomeles sumatrana* increases towards the top of the zone. Very few pollen taxa of 'montane' forest are represented, and values for forest fern and other pteridophyte spores are also low. Urticaceae/Moraceae pollen show a slight increase in representation over zone Y5, and the unidentified UK 194 pollen taxon remains present.

The pollen spectra from zone Y6 are thus very similar to the contemporary pollen assemblages from Yanamugi. Particularly close correlation is found with the surficial sediment assemblage from core YANMC 1. Less similarity exists with the moss polster, SS 27-28, from within the neighbouring forest, as this sample is dominated (80%) by the unidentified pollen taxon UK 194. The proportion of herbaceous swamp taxa is generally lower in the surficial sediment, presumably due to the greater distance from the lake margin. Cyperaceae, Gramineae 4 and 5, *Nymphoides* and *Microsorium* T. all record lower frequencies, whilst *Nephrolepis* and *Stenochlaena palustris* are absent from the modern assemblage.

The percentages of dry-land taxa in zone Y6 and the contemporary assemblage are fairly similar. Urticaceae/Moraceae pollen, especially diporate grains, are more abundant in the surficial sample. Less well represented than at the top of core YAN 2 are *Octomeles sumatrana* and *Nauclea* T. pollen. The pollen taxon

UK 194, presumably originating in the local forest, accounts for 20% of the pollen sum in the surficial sediment sample.

A number of taxa not found in the sub-fossil assemblages occur in the contemporary spectra. Notable are *Calamus*, *Streblus* T., *Tinospora*, *Macaranga ovatifolia* T., cf. *Sterculia* and cf. *Palaquium*. Most significant, however, is pollen of Compositae (Tubuliflorae). This taxon comprises 9% of the pollen sum in the YANMC 1 surface sample and is also found in the forest moss polster SS 27-28. Compositae pollen also occurs in the contemporary sample SS 18 from roadside 'alluvium' forest in the lower Markham Valley, but has not been identified from any sub-fossil assemblage. Herbaceous composite species are widespread post-cultivation or vegetation disturbance ruderals in the area today, but it appears that they have achieved this status only recently.

VEGETATION CHANGE IN THE VICINITY OF YANAMUGI

Swamp vegetation is represented in the pollen record of Yanamugi by fewer, generally less abundant, taxa than at Lake Wanum. Two important species are either almost absent (*Metroxylon sagu*) or impossible to distinguish (*Phragmites karka*). Despite these limitations, certain trends can be discerned in the swamp pollen record.

There is no evidence of substantial floristic change in the swamp community. Most taxa are represented to some extent throughout the sequence. The only possible exceptions are Cyperaceae class C, that occur only in the lower core, and *Stenochlaena palustris*, only sparsely represented in the sediments below 240 cm. Except for the basal sample of the core, where a high percentage of Cyperaceae B2 occurs, the proportion of

herbaceous swamp taxa is low until the onset of the most recent zone, Y6. At this time both the pollen concentration and proportion of herbaceous swamp taxa increase, comprising 40% of the pollen sum. Within this zone, spores of *Nephrolepis*, *Microsorium* T. and *Stenochlaena palustris* become more abundant. *Nymphoides* and Cyperaceae pollen show an increase over the previous zone, and pollen of Gramineae 2, 3 and 4 become more common.

The sequence is interpreted as reflecting the migration to the coring site of emergent aquatic vegetation (*Nymphoides indica*) probably by the beginning of zone Y5. Subsequently, in zone 6, herbaceous swamp vegetation comprising various ferns, Cyperaceae and perhaps *Phragmites karka* occupies the site. Floristically similar vegetation is found at the lake today. The cause of encroachment by swamp vegetation probably lies in a decrease in the effective water depth along the northern margin of the lake, presumably resulting from the accelerated clay deposition recorded in core YAN 2 between 640 cm and 420 cm.

Few consistent trends exist in the dry-land pollen record of core YAN 2 that can be interpreted in terms of vegetation change. Perhaps the most striking feature of the Yanamugi pollen diagrams is the abundance, below 440 cm, of pollen and spore taxa thought to originate from higher altitude vegetation. These include not only identifiable 'montane' forest genera, but also a wide variety of other pollen taxa and pteridophyte spores. Above 440 cm in the core their representation decreases markedly. However, it seems unlikely that this clear change in pollen assemblage reflects a change in vegetation.

It is improbable that many of the 'montane' forest tree taxa grew in close proximity to the lake at any time in the recent past, given their current altitudinal preferences (Table II.1). Many are effective pollen distributors and would be expected to dominate the pollen spectra of the core if located at, or very near, the site. Downslope aerial dispersal of *Nothofagus*, *Phyllocladus*, and *Podocarpus* pollen has already been demonstrated for the Lake Wanum area. Yanamugi is higher in altitude than Lake Wanum and is also closer to the mountain ranges south of the valley. Increased representation of higher altitude pollen might therefore be expected. However, it seems unlikely that entomophilous taxa such as Epacridaceae, or large spores of Cyatheaceae could be aerially transported in the quantities found in the sediments of the YAN 2 core. Fluvial transport, e.g. Sina Creek, seems to be the most likely dispersal agent for these taxa. The close association of the maximum concentration of the 'montane' taxa with a distinct horizon in the core adds further circumstantial evidence for this interpretation.

The possibility of actual reduction in the area of 'montane' forest within the vicinity of Yanamugi cannot be excluded, as grassland now extends to 1 000 m altitude on some local ranges. However, the decrease in the representation of 'montane' taxa within the last two pollen assemblage zones coincides with a reduced influx of allochthonous clay, also perhaps fluvial in origin. With a considerable increase in the pollen concentration of other ecological categories, these factors alone are probably sufficient to explain the pattern of occurrence of the 'montane' taxa.

Little consistent change is revealed in the dry-land vegetation surrounding the lake. Essentially the same taxa found in contemporary assemblages occur throughout the sediments. As the composition of the local forest is largely unknown, few taxa are identifiable as originating from forest tree species. In the record of non-forest taxa there appears an inverse relationship between *Nauclea* T. and pollen of the 'disturbance' taxa: mainly Gramineae, *Trema* and *Macaranga*. Without reliable PDR estimates, however, it is difficult to say whether this trend is an artefact of the relative frequency calculation. There is some coincidence between the representation of *Nauclea* T. and *Octomeles sumatrana* pollen.

As at Lake Wanum a group of pollen taxa possibly representative of vegetation 'disturbance' may be identified. Pollen of dry-land grasses are the most abundant. *Trema*, *Macaranga* and various herb and shrub representatives, particularly genera of Euphorbiaceae, are also included. At Yanamugi also there is some correlation between the occurrence of these taxa, especially Gramineae pollen, and the incidence of carbonised particles (Fig. 8.6). Charcoal fragments are most abundant in the zone (Y3) that records the greatest variety of non-forest pollen taxa. The representation of *Celtis* follows closely that of the 'disturbance' taxa, and there is no sustained trend towards increased proportions of grassland pollen in the sequence.

In summary, apart from the localised encroachment of swamp vegetation, few indications of vegetation change are recognised in the pollen record of core YAN 2. Fluctuations in the frequency of some higher altitude taxa are considered to reflect primarily the effect of fluvial inwash into the lake, the source of

which is not identified. Only minor changes occur in the pollen record of local forest and non-forest associations, and all presently extant vegetation types appear to be represented throughout the sequence. Pollen taxa attributable to grassland and 'disturbance' vegetation occur throughout, but show no marked changes in frequency. It is suggested that little substantial alteration in the composition or distribution of the dry-land plant communities around Yanamugi has occurred within the past 1000 to 2000 years.

CONCLUSIONS

Although the palynological data present a very partial record of the vegetation, it is possible to demonstrate ecological change in certain plant communities. The most precise vegetation reconstruction comes from the herbaceous swamp associations of Lake Wanum where the contemporary ecology and pollen dispersal are best known. Changes in local hydrology during the Holocene may be surmised from the known habitat preferences of herbaceous swamp associations and individual taxa. The pollen representation of 'alluvium' forest at Lake Wanum appears to reflect, to some extent, similar environmental trends.

Except for taxa of the 'alluvium' category, there is a sparse record of forest tree pollen. This is primarily due to the lack of information on the floristic composition of the local forest at both sites. The major taxon at Lake Wanum, *Celtis*, appears to be favoured by some degree of vegetation disturbance.

No pollen indisputably from cultivated plants is found although circumstantial evidence of human impact on the vegetation is available from both Lake Wanum and Yanamugi. Increased influx of carbonised particles and non-forest pollen is first seen at 8500 BP

in Lake Wanum, and the presence of substantial non-forest and grass-land vegetation is indicated throughout the sediments of Yanamugi. At neither site is it possible to identify any sequence indicative of an individual cycle of forest clearance, cultivation, and secondary regrowth.

Estimates of annual pollen deposition rates allow a much more precise interpretation of vegetational change than do relative frequency figures. The few comparable PDR values available suggest that the influx of dry-land pollen to the marginal sediments of both lakes is fairly similar. The PDR of herbaceous swamp taxa, however, is much greater at Lake Wanum. Pollen assemblages from Yanamugi show the greater taxonomic diversity.

The vegetational interpretation of the pollen assemblages in this study relies on the relatively few taxa whose affinity and ecological preferences are better known. Increased ecological and pollen morphological data would undoubtedly allow the recognition of more subtle changes in the palynological record.