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# WEICHSELIAN LATE-GLACIAL PALAEOECOLOGY AND PALAEOENVIRONMENT AT LAGO GRANDE DI MONTICCHIO (BASILICATA, S ITALY)

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RIASSUNTO - *Paleoecologia e paleoambiente del Weichseliano tardo-glaciale nell'area del Lago Grande di Monticchio (Basilicata, Italia meridionale)* - Il Quaternario *Italian Journal of Quaternary Sciences*, 9(2), 1996, 605-616 - L'articolo presenta la stratigrafia pollinica di una serie di diagrammi ottenuti da sedimenti lacustri e torbosi tardo- e post-glaciali del Lago Grande di Monticchio, unitamernte alla loro cronologia. Vengono descritte le implicazioni paleoclimatiche desunte dai dati, in particolare il maggiore dettaglio ottenuto dal confronto fra due spettri. Le implicazioni con gli schemi di circolazione atmosferica vengono prese in considerazione e confrontate con i risultati di simulazioni paleoclimatiche descritte in letteratura. Si ipotizza che alcuni aspetti della storia paleoclimatica del Mediterraneo non siano compresi nelle simulazioni paleoclimatiche attualmente disponibili in quanto operanti ad una insufficiente risoluzione spaziale.

ABSTRACT - *Weichselian late-glacial palæoecology and palæoenvironment at Lago Grande di Monticchio (Basilicata, S Italy)* - Il Quaternario *Italian Journal of Quaternary Sciences*, 9(2), 1996, 605-616 - Late-glacial pollen diagrams from mid-lake and fen cores taken at Lago Grande di Monticchio, together with their independently-derived chronologies, are presented and their pollen stratigraphy outlined. The palaeoclimate inferences that emerge from these records, especially those additional insights gained from a comparison of the two, are described. The implications with respect to atmospheric circulation patterns are considered and compared to the results of published palaeoclimate simulations. It is concluded that some aspects of palaeoclimate history in the Mediterranean region are not captured by currently available palaeoclimate simulations because they have insufficient spatial resolution.

Keywords: Pollen, palæovegetation, palæoclimate, Italy
Parole chiave: Polline, paleovegetazione, paleoclima, Italia

## 1. INTRODUCTION

Lago Grande di Monticchio is one of two maar lakes located in the explosion crater to the west of the peak of Monte Vulture, near Melfi in the Basilicata region of southern Italy (40°56'40"N, 3°10'50"E) (Fig. 1). The longest axis of the lake is ca. 850 m and the shortest axis ca. 650 m; its surface lies at an elevation of 656 m a.s.l. The water depth reaches ca. 39 m at its deepest point, although most of the basin is relatively flat-bottomed, with water depths of <10 m. The lake is bordered to the west by an area of fen and fen woodland and the surrounding inner slopes of the crater principally are wooded, the dominant tree species being *Fagus sylvatica* (beech) and *Quercus cerris* (Turkey oak). Watts *et al.* (1996b) provide accounts of the climate at the lake and of the more general regional vegetation setting. Accounts of the bathymetry (Hansen, 1993), as well as of the lamination-based chronology (Zolitschka & Negendank, 1996), tephrochronology (Narcisi, 1996), sediment geochemistry (Robinson *et al.*, 1993; Robinson, 1994) and palaeomagnetic profiles (Creer, 1996) from the lake have been published recently. Watts *et al.* (1996a, b) have provided accounts of the pollen stratigraphy of two cores, one taken from the fen and the other from the mid-lake; a previous study of an earlier core from the fen provided a preliminary pollen diagram (Watts, 1985).

The purpose of the present paper is to examine in more detail than have these previous publications the palynological record of the Weichselian late glacial, in particular that obtained from the 51 m mid-lake core collected in 1990. This record differs in several respects from the parallel record obtained from the 1993 fen core

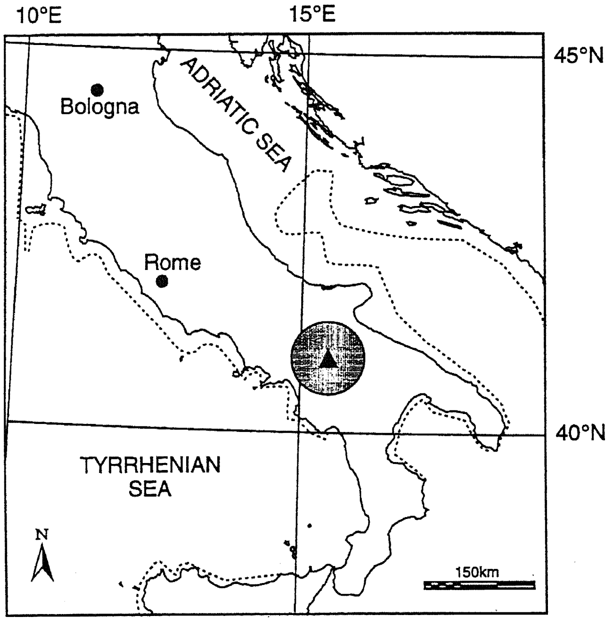

Fig. 1 - Location map. Map of the Italian peninsula showing the location of Lago Grande di Monticchio (▲). The shaded circle indicates the area within a 50 km radius of the lake that approximates to the region represented by at least the better-dispersed pollen taxa reaching the mid-lake core. The approximate position of the coastline during the last glacial maximum is shown by a dashed line.

*Localizzazione dell'area studiata. La penisola italiana con ubicazione del Lago Grande di Monticchio (▲). L'area ombreggiata rappresenta la zona entro un raggio di 50 km dal lago che si approssima alla regione rappresentata dai taxa pollinici meglio dispersi che raggiunsero la zona carotata al centro del bacino. La posizione della linea di riva durante l'ultimo massimo glaciale è indicata dalla linea tratteggiata.*

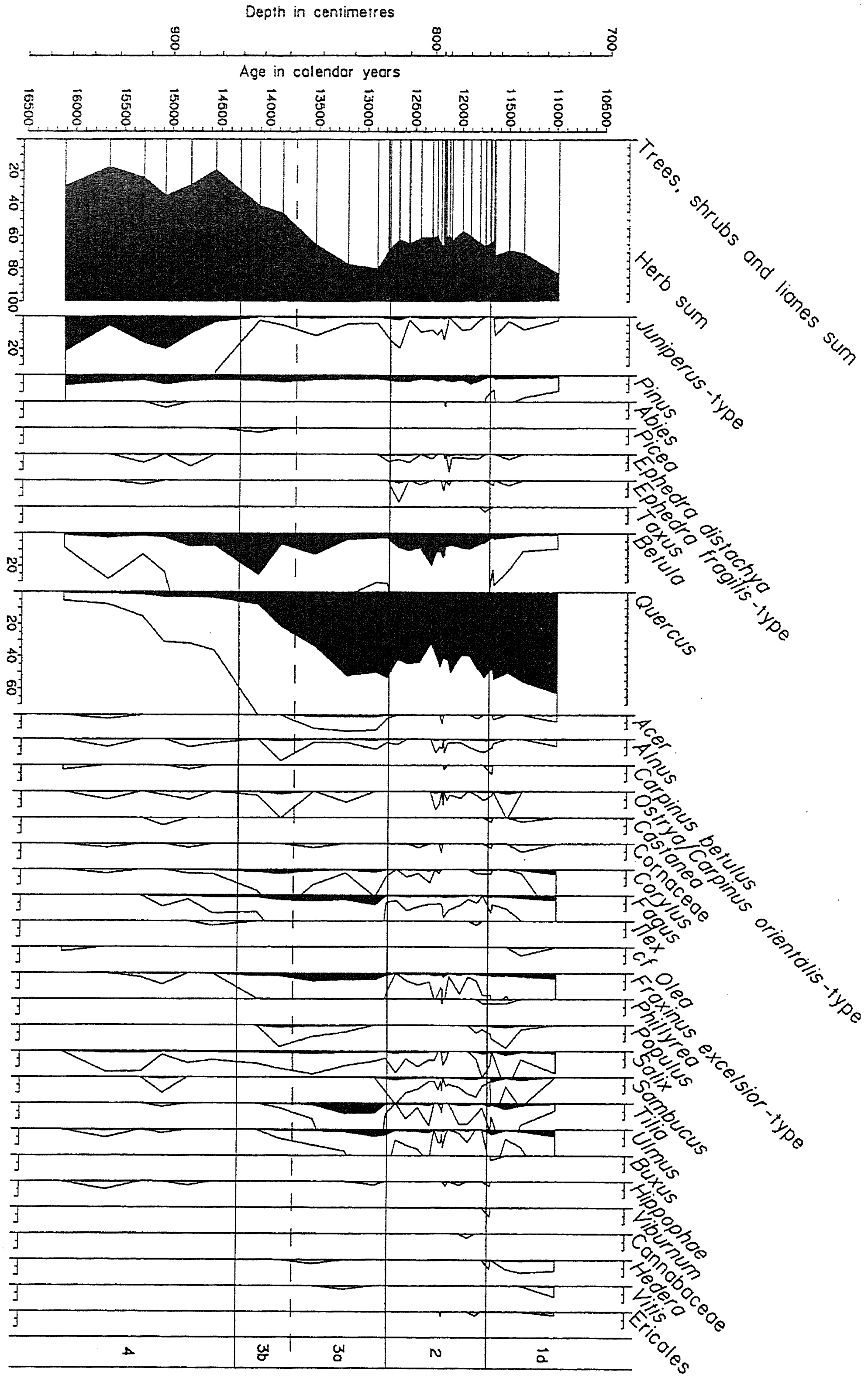

Fig. 2(a) - Lago Grande di Monticchio. Late-glacial pollen diagram from the mid-lake core. Pollen data are expressed as percentages of a sum of all terrestrial pollen taxa and are plotted against an age scale in calendar years derived from lamination counts (Zolitschka & Negendank, 1996). Summary diagram and curves for individual pollen taxa representing trees, shrubs and lianes.

*Lago Grande di Monticchio. Diagramma pollinico tardi-glaciale ottenuto dal carotaggio lacustre. I dati pollinici sono espressi in percentuale della somma di tutti i taxa pollinici terrestri e sono rappresentati lungo un'asse temporale in anni calendrici ottenuta mediante conteggio di sedimenti laminati (Zolitschka & Negendank, 1996). Diagramma riassuntivo e curve dei singoli taxa pollinici di alberi, arbusti e liane.*

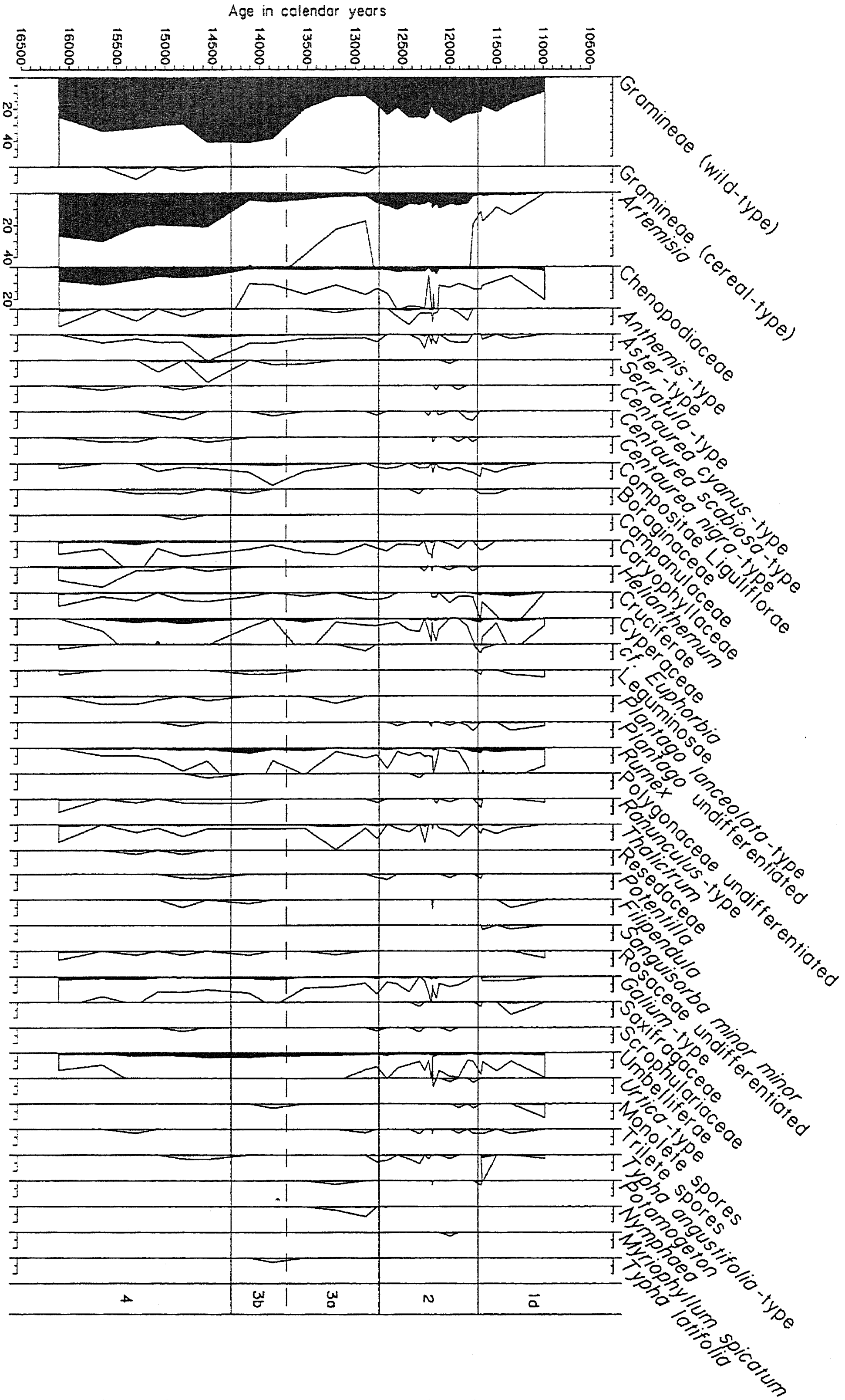

Fig. 2(b) - Lago Grande di Monticchio. Late-glacial pollen diagram from the mid-lake core. Pollen data are expressed as percentages of a sum of all terrestrial pollen taxa and are plotted against an age scale in calendar years derived from lamination counts (Zolitschka & Negendank, 1996). Curves for individual pollen and spore taxa representing herbaceous and aquatic plants.

*Lago Grande di Monticchio. Diagramma pollinico tardi-glaciale ottenuto dal carotaggio lacustre. I dati pollinici sono espressi in percentuale della somma di tutti i taxa pollinici terrestri e sono rappresentati lungo un'asse temporale in anni calendrici ottenuta mediante conteggio di sedimenti laminati (Zolitschka & Negendank, 1996). Curve di taxa pollinici e spore di piante erbacee ed acquatiche.*

Table 1 - Mid-lake core - infrequently recorded taxa
*Carotaggio lacustre.* Taxa *rari.*

| Pollen taxon | Depth (cm) | Date (Calendar yr BP) | Percentage of pollen sum |
|---|---|---|---|
| *Cirsium*-type | 802 | 12322 | 0·28 |
| | 842 | 13528 | 0·24 |
| | 893 | 14809 | 0·25 |
| *Echium*-type | 746·5 | 11499 | 0·29 |
| | 752·5 | 11653 | 0·29 |
| | 810 | 12554 | 0·24 |
| cf. *Centaurium* | 724·5 | 10983 | 0·23 |
| cf. *Hypericum* | 852 | 13862 | 0·27 |
| *Vicia*-type | 794 | 12218 | 0·26 |
| *Allium*-type | 798 | 12266 | 0·29 |
| | 818 | 12771 | 0·22 |
| Liliaceae undiffer'd | 752·5 | 11653 | 0·29 |
| | 774 | 11995 | 0·22 |
| | 852 | 13862 | 0·27 |
| *Plantago media*-type | 943 | 16107 | 0·28 |
| Primulaceae | 741 | 11346 | 0·27 |
| *Armeria maritima B* | 790 | 12190 | 0·29 |
| *Pteridium* | 746·5 | 11499 | 0·29 |
| *Equisetum* | 802 | 12322 | 0·55 |
| Alismataceae cf *Baldellia* | 790 | 12190 | 0·58 |

(Watts *et al.*, 1996b - Fig. 3). The record from the mid-lake core also provides a basis for a detailed chronology of the late-glacial events that impacted upon the vegetation of this part of southern Europe. Together the two records provide a more complete picture of the palæovegetation and palæoenvironment conditions during this period than does either alone.

## 2. WEICHSELIAN LATE-GLACIAL POLLEN STRATIGRAPHY

### 2.1 The Mid-lake Core (1990)

A pollen diagram for the interval between 16,500 and 10,500 calendar years ago in the mid-lake core is presented as Figure 2. The chronology follows Zolitschka & Negendank (1996) and is based upon lamination counts; the zone boundaries indicated follow Watts *et al.* (1996a, b). Infrequently recorded taxa not included in the diagram are listed in Table 1. Pollen assemblage zone 1d represents the early Holocene, zone 2 is correlated with the 'Younger Dryas', zone 3, which is sub-divided into two sub-zones, represents the late-glacial interstadial, and zone 4 is the full glacial. A brief account of the pollen stratigraphic characteristics of each is given below.

### 2.1.1 Pollen assemblage zone 4 - full glacial

Zone 4 ended 14,300 calendar years ago, having spanned almost 12,000 years (Watts *et al.*, 1996a). This zone is characterised by the generally high abundance of pollen of *Juniperus*-type and by abundant pollen of herbaceous taxa, especially Gramineae (wild-type), *Artemisia* and Chenopodiaceae. Tree pollen taxa are present only with low abundance; *Pinus* is relatively infrequent during the latter part of zone 4, whereas *Betula* and *Quercus* both are increasing slightly in abundance from previously extremely low values. A wide range of other tree taxa also is present but only at extremely low values. Although a wide range of herbaceous taxa is present intermittently at low values, a few are consistently present and somewhat more abundant (*e.g. Aster*-type, *Serratula*-type, Cruciferae, *Rumex, Thalictrum, Galium*-type, Umbelliferae).

Amongst those herbaceous taxa that are sparsely present, the occurrence of pollen both of Gramineae (cereal-type) and of *Centaurea cyanus*-type should be noted; other sparsely present taxa include Boraginaceae, *Helianthemum, Plantago lanceolata*-type and Resedaceae. Amongst the shrubs represented at this time are *Ephedra distachya, E. fragilis*-type and *Hippophaë.*

### 2.1.2 Pollen assemblage zone 3 - late-glacial interstadial

This zone spans the interval between 14,300 and 12,750 calendar years before present; it is subdivided into two sub-zones, the boundary occurring at 13,700 calendar years ago. Overall the zone is distinguished from zone 4 by the presence of much higher abundances of pollen of woody taxa and by both quantitative and qualitative reductions in the herbaceous pollen taxa represented.

*Pollen assemblage sub-zone 3b*

This sub-zone lasted for some 600 years; its onset is marked by a sharp increase in abundance of pollen of *Betula* and a decrease in abundance of *Artemisia* pollen. Gramineae (wild-type) pollen values are high and the diversity of herbaceous taxa is not yet markedly reduced compared to zone 4. Several herbaceous taxa maintain values comparable to those in the previous zone, notably *Rumex* and Umbelliferae. Pollen abundance values for woody taxa as a whole increase throughout the sub-zone; this is principally a reflection of increased *Quercus* pollen abundance, although with contributions from a range of other taxa including *Corylus, Fagus* and *Fraxinus excelsior*-type. After its initial peak values, *Betula* pollen decreases in abundance.

*Pollen assemblage sub-zone 3a*

The transition to this sub-zone is marked by the onset of a sharp decrease in abundance of pollen of Gramineae (wild-type) and by an increase in the diversity and abundance of pollen of woody taxa; at the same time the diversity of herbaceous pollen taxa is reduced. Perhaps the most notable feature of the sub-zone is the peak in abundance values for *Tilia* pollen; the values of > 5% reached in this sub-zone are never matched in the record of the last 76,000 years from Lago Grande di Monticchio (Watts *et al.*, 1996a). Other trees also showing increased abundance during this sub-zone include *Ulmus, Acer, Fraxinus excelsior*-type and *Fagus.* Several aquatic pollen taxa are present in this sub-zone, having previously been absent since the beginning of zone 4 (Watts *et al.*, 1996a); these include *Potamogeton* and *Nymphaea.*

### 2.1.3 Pollen assemblage zone 2 - 'Younger Dryas'

This zone extends between 12,750 and 11,700 calendar years before present, thus spanning 1,050 yr. The transition from sub-zone 3a is marked by increases in abundance of pollen of the major herbaceous pollen taxa Gramineae (wild-type) and *Artemisia,* as well as an overall increase in the diversity and pollen abundance of herbaceous taxa. Several herbaceous taxa that were present during zone 4 but absent during zone 3, or at least during sub-zone 3a, now re-appear, notably *Centaurea scabiosa*-type, *Helianthemum, Plantago* undiff., *Ranunculus* -type and *Potentilla.* Amongst the trees, pollen abundance values of *Betula* increase once again, whereas those of *Quercus* and most of the other tree taxa that increased during sub-zone 3a decrease markedly. Other woody taxa such as *Juniperus* -type, *Ephedra distachya* and *E. fragilis* -type increase in abundance or re-appear after being absent throughout zone 3.

### 2.1.4 Pollen assemblage zone 1 - Holocene

*Pollen assemblage sub-zone 1d - early Holocene*

The transition to the Holocene, dated to 11,700 calendar years ago, is marked by a sharp decrease in abundance of *Artemisia* pollen and by an increase in the diversity and abundance of pollen of woody taxa. Those taxa that increased in abundance during sub-zone 3a generally increase once again and pollen of other taxa is now present, *e.g. Olea* -type, or else forms a continuous curve for the first time since the beginning of zone 4 (Watts *et al.*, 1996a), *e.g. Hedera.* A diverse range of herbaceous taxa initially continues to be present, including many taxa that were rare or absent during the preceding zone; after about 11,000 calendar years before present, however, the variety and abundance of herbaceous pollen taxa diminishes markedly.

## 2.2 The Fen Core (1993)

Figure 3 is a detailed pollen diagram for the late-glacial section of the fen core (Watts *et al.*, 1996b); so as to facilitate comparison with the late-glacial pollen diagram from the mid-lake core (Fig. 2) the pollen data also are plotted against an age scale. Note, however, that in this case the age scale is in calibrated $^{14}$C years before present, the three relevant AMS $^{14}$C dates reported by Watts *et al.* (1996b) (CAMS 12611, 12610 and 9855 with uncalibrated $^{14}$C ages of 8,590±50, 10,460±60 and 12,540±130 yr B.P., respectively) having been calibrated using CALIB Version 3 (Stuiver & Reimer, 1993) and ages for the individual pollen samples estimated by linear interpolation/extrapolation between these three dates (9,498, 12,370 and 14,710 calibrated $^{14}$C years before present, respectively). The diagram shows the period between 11,000 and 17,000 calibrated $^{14}$C years before present. The pollen assemblage zones are those identified and described by Watts *et al.* (1996b); their numbering corresponds to the numbering of the zones described above from the mid-lake core. Although the overall period spanned by the late-glacial interstadial (zone 3) and Younger Dryas (zone 2), as well as the period spanned by each zone and sub-zone, corresponds reasonably well to the estimated duration of the same interval in the mid-lake core, there is a systematic discrepancy in the estimated ages of the zone boundaries (Table 2).

The calibrated $^{14}$C ages are between 400 and 700 yr older than those estimated using the lamination-based chronology of Zolitschka & Negendank (1996). This may indicate a systematic error in the method applied by Zolitschka & Negendank (1996) to estimate the periods spanned by sediment units that exhibit no countable laminations. Alternatively the $^{14}$C ages may be systematically too old. At Lago Grande di Monticchio the discharge of vulcanogenic $CO_2$ has already been demonstrated and shown to result in anomalously old apparent ages for contemporary aquatic plant material (Watts *et al.*, 1996a); this phenomenon also may have affected to an unknown extent the $^{14}$C age determinations upon the terrestrial macrofossils recovered from the fen core.

Watts *et al.* (1996a) also noted a discrepancy for ages estimated for events at Lago Grande di Monticchio correlated with Heinrich Events; the Lago Grande di Monticchio ages based upon the Zolitschka & Negendank (1996) chronology are systematically younger than other published age estimates for the Heinrich Events.

Table 2 - Late-glacial chronologies for the mid-lake and fen cores.

*Cronologie tardo-glaciali dei carotaggi lacustri e torbosi.*

| Pollen Assemblage Zone | Mid-lake core (1990) |  | Fen core (1993) |  |
|---|---|---|---|---|
|  | Zone boundaries | Period spanned | Zone boundaries | Period spanned |
|  | (calendar years) |  | (calibrated 14C years) |  |
| Sub-zone 1d |  |  |  |  |
|  | 11,700 |  | 12,400 |  |
| Zone 2 |  | 1,050 |  | 750 |
|  | 12,750 |  | 13,150 |  |
| Sub-zone 3a |  | 950 |  | 1,150 |
|  | 13,700 |  | 14,300 |  |
| Sub-zone 3b |  | 600 |  | 500 |
|  | 14,300 |  | 14,800 |  |
| Zone 4 |  |  |  |  |

As would be expected, the pollen stratigraphy of the fen core compares closely to that of the mid-lake core; given that thay were analysed independently, by WAW and JRMA respectively, their close similarity provides evidence of the inherent reliability of pollen-analytical data. Nonetheless, there are a few notable differences, of which the first is a tendency for the range of pollen values exhibited by any one taxon to be greater in many cases in the fen core, probably reflecting the greater influence upon this record of changes in the local vegetation within the crater. Thus, pollen of woody taxa reach greater overall abundances in the fen core, particularly during zones 1d and 2. Notwithstanding this overall trend, however, the major herbaceous taxa (Gramineae (wild-type) and

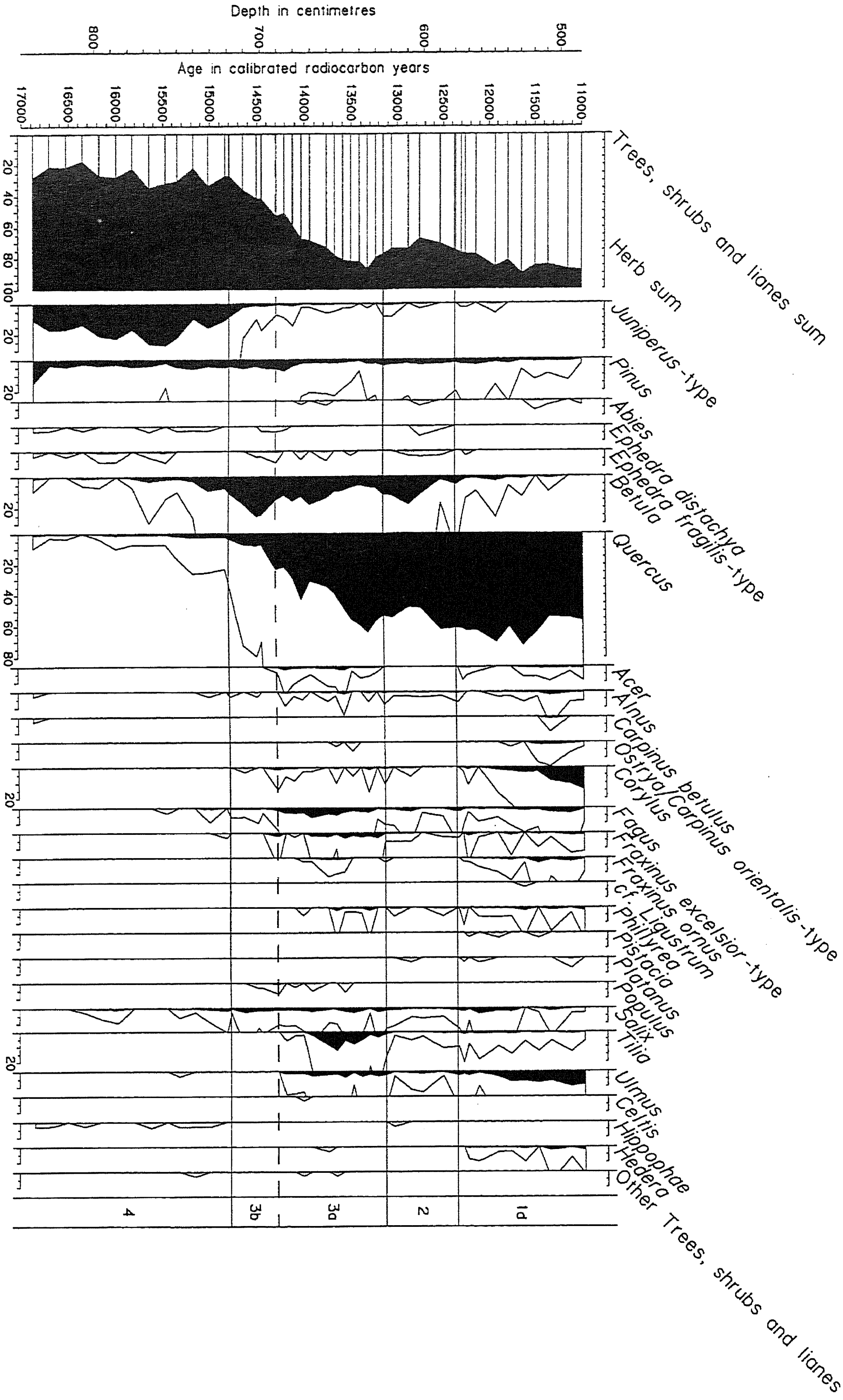

Fig. 3(a) - Lago Grande di Monticchio. Late-glacial pollen diagram from the fen core. Pollen data are expressed as percentages of a sum of all terrestrial pollen taxa and are plotted against an age scale in calibrated $^{14}C$ years linearly interpolated from the available $^{14}C$ dates. Summary diagram and curves for individual pollen taxa representing trees, shrubs and lianes.

*Lago Grande di Monticchio. Diagramma pollinico tardo-glaciale dele carotaggio della torba. I dati pollinici sono espressi in percento della somma di tutti i taxa pollinici terrestri e sono diagrammati secondo una scala cronologica in età* $^{14}C$ *calibrate interpolate linearmente utilizzando le date* $^{14}C$ *disponibili. Diagramma riassuntivo e curve individuali di taxa pollinici rappresentanti alberi, arbusti e liane.*

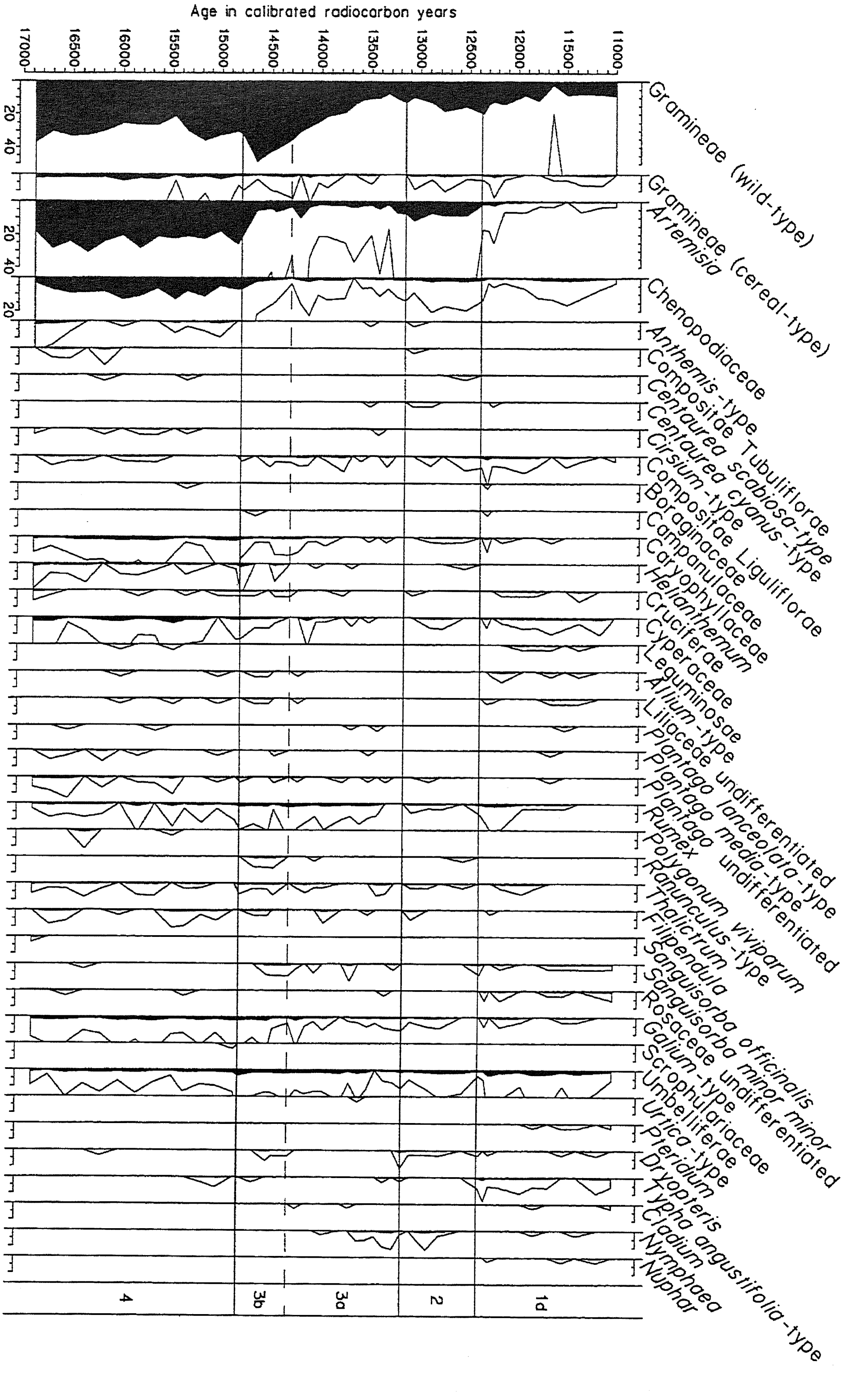

Fig. 3(b) - Lago Grande di Monticchio. Late-glacial pollen diagram from the fen core. Pollen data are expressed as percentages of a sum of all terrestrial pollen taxa and are plotted against an age scale in calibrated $^{14}C$ years linearly interpolated from the available $^{14}C$ dates. Curves for individual pollen and spore taxa representing herbaceous and aquatic plants.

*Lago Grande di Monticchio. Diagramma pollinico tardo-glaciale dele carotaggio della torba. I dati pollinici sono espressi in percento della somma di tutti i taxa pollinici terrestri e sono diagrammati secondo una scala cronologica in età $^{14}C$ calibrate interpolate linearmente utilizzando le date $^{14}C$ disponibili. Curve per i singoli taxa pollinici e spore di piante erbacee ed acquatiche.*

*Artemisia*) reach greater maximum pollen abundance values in the mid-lake core. Perhaps primarily as a result of these contrasts, the Younger Dryas fluctuation (zone 2) is somewhat more marked in the mid-lake core where pollen values for woody taxa fall more and those for Gramineae (wild-type) reach higher levels during this interval than in the record from the fen.

Another difference lies in the systematically lower values for Chenopodiaceae during zone 4 in the mid-lake core than in the fen core (mean and maximum values of 7· 6% and 11· 3% and of 9· 2% and 13· 1% for the mid-lake and fen cores respectively). This contrasts with the behaviour of Gramineae (wild-type) and *Artemisia,* both of which have very similar mean values in the fen and mid-lake cores during this zone. The remaining differences are in taxa that generally achieve only relatively low pollen abundance values during the late-glacial period. For example, *Helianthemum* persists into sub-zone 3b in the fen core, during which time it reaches its peak values in this core, in contrast to its absence in the mid-lake core during this sub-zone. Similarly, pollen of *Phillyrea* is found during sub-zone 3a only in the fen core and *Ephedra fragilis*-type pollen is found throughout zone 3 only in the fen core. Other taxa are at some times found principally in the mid-lake core, notably a number of mesic woody taxa (*Corylus, Fagus* and *Fraxinus excelsior*-type) whose pollen occurs at higher abundance levels or only in the mid-lake core during sub-zone 3b.

Differences observed in the records for aquatic taxa, notably the abundance of pollen of *Nymphaea* during zones 2 and 3a in the fen core, are to be expected given the contrasting locations of the two cores within the lake basin.

## 3. WEICHSELIAN LATE-GLACIAL PALÆOECOLOGY AND PALÆOENVIRONMENT

Interpretations of the general palæoecology and palæoenvironment of the late-glacial, as well as quantitative palæoclimate reconstructions for each of the two pollen records, have been published elsewhere (Watts *et al.,* 1996a, b). These general interpretations will not be re-iterated here; instead we focus upon the additional insight gained by comparing these two pollen records of the late glacial from Lago Grande di Monticchio; in the process we shall consider the discrepancies between the two quantitative palaeoclimate reconstructions and attempt to deduce which is likely to be closer to the actual palaeoclimate.

Given the size of the lake, the pollen catchment reflected by a mid-lake core from Lago Grande di Monticchio will extend far beyond the local vegetation within the crater. Prentice (1988) estimates what he terms the "70% radii" for various pollen taxa with respect to a lake whose surface has a radius of 300 m, close to the size of Lago Grande di Monticchio. He defines the 70% radius for a taxon as the radius of the catchment from within which 70% of the pollen of that taxon reaching the lake in question will have been derived. For a lake of 300 m radius in a homogeneous forested landscape he cites the following 70% radii: *Pinus* - 59 km, *Quercus* - 34 km, *Fagus* - 5 km and *Picea* - 2 km. These figures indicate that for *Quercus* and *Pinus* the pollen reaching the lake reflects the vegetation of the surrounding region; even for *Fagus* the pollen reaching a mid-lake core at Lago Grande di Monticchio includes a significant proportion of pollen recruited from beyond the crater rim and only pollen of taxa with limited pollen-dispersal characteristics, comparable to those of *Picea,* principally reflects plants growing within the crater.

Although the lithology of the late-glacial sediments in the fen core indicates that deposition was under water, rather than beneath a stand of fen woodland comparable to that present at the locality today, it nonetheless must have occurred close to the margin of the lake, given the topography of the lake bed and surrounding landscape. This proposition is supported by the recovery of macrofossils of a variety of terrestrial plant taxa, including trees, from the fen core but not from the mid-lake core. Such a marginal position has a pollen catchment that is defined principally by its distance from the lake shore rather than the overall lake radius. Thus the pollen catchment for the fen core will have been much more local for all taxa, and proportionately more so for less effectively dispersed pollen taxa. In general, we can infer that well-dispersed pollen taxa that are more abundant in the fen core reflect plant taxa that were growing at greater abundance in the crater than elsewhere in the landscape, and vice versa.

Thus it seems that, especially during intervals when the overall abudance of trees on the landscape increased, tree cover was relatively greater within the crater than elsewhere; in contrast, the steppic herbaceous taxa, including Gramineae (wild-type) and *Artemisia,* remained relatively more extensive in the region as a whole. This likely reflects the influence of the lake on the microclimate within the crater, an effect that is apparent today. The body of water provides both a thermal buffer, because of its heat capacity, and a source of moisture, the evaporation of which tends to maintain a higher relative humidity within the crater than in the surrounding landscape. Tree growth thus may have been favoured within the crater by a combination of more mesic conditions and less extreme summer temperatures than in the surrounding region. In such a case the palaeoclimate reconstructed from the mid-lake core pollen assemblages can be expected to estimate more accurately the regional palæoclimate, whereas the reconstruction based upon pollen assemblages from the fen core will reflect the local microclimatic conditions and potentially could be misleading with respect to macroclimatic conditions.

Anomalously, however, the palæoclimate reconstruction for zone 4 from the fen core (Watts *et al.,* 1996b) indicates much more severe soil moisture deficiency than does that for the mid-lake core (Watts *et al.,* 1996a); this apparently is in direct conflict with the expectation that the fen core pollen assemblages should reflect the more mesic microclimate within the crater. In order to address this anomaly it is necessary to examine the contemporary spatial patterns of distribution and abundance and/or the pollen-climate response surfaces of the taxa used to make the reconstructions(1). When this is done it is apparent that amongst the pollen taxa used to make the palæoclimate reconstructions, those that most strongly indicate moisture deficiency include especially *Artemisia* and Chenopodiaceae, with the latter the most diagnostic for severe aridity (Huntley, 1990; 1994). However, as noted earlier, although both Gramineae (wild-type) and *Artemisia* pollen are equally abundant in the fen and mid-lake assemblages during this zone, pollen of Chenopodiaceae is systematically more abundant in the fen core. This readily would account for the anomaly of apparently drier conditions within the crater; it also indicates that the Chenopodiaceae in question grew in greater abundance within the crater than elsewhere on the landscape.

The most probable explanation for this relates to the ecological characteristics of many members of the Chenopodiaceae that occur most frequently on saline marshes and around the margins of saline lakes; indeed they can become locally dominant in such situations. The obvious inference is that Lago Grande di Monticchio was somewhat saline during zone 4, probably exhibiting seasonal fluctuations of water level leading to the development of hypersaline conditions in the marginal zone in summer. This would have provided a local habitat for abundant Chenopodiaceae, the pollen of which in turn leads to the reconstruction of anomalously arid conditions when the fen core pollen assemblages are considered. This hypothesis can be evaluated to some extent using the other forms of palaeoenvironmental evidence available from Lago Grande di Monticchio. The limited diatom evidence available from the fen core (Watts *et al.*, 1996b) gives some support to the inference of a degree of salinity and of a zone of seasonally-exposed littoral substrate; the diatom assemblages from zone 4 are interpreted as indicating a lake of low to moderate alkalinity, the abundance of benthic diatoms being taken as indicative of the availability of significant areas of littoral substrate for diatom colonisation. Robinson *et al.* (1993) infer increased evaporative rates during zone 4 from their measurements of sediment geochemistry, especially carbonate content. Thus both the diatom assemblages and sediment geochemistry are consistent with the inference of a degree of salinity associated with seasonal fluctuations in water level resulting from intense summer evaporation.

Given the probable local source of the Chenopodiaceae pollen that leads to the reconstruction of intense aridity during zone 4 when the fen core pollen assemblages are used, it seems that this reconstruction is likely to be misleading. The less intense aridity reconstructed from the mid-lake core is likely better to reflect the regional macroclimate conditions.

The other minor differences noted above also likely reflect differences between the local vegetation within the crater and the vegetation of the wider landscape. Thus it seems that *Ephedra* spp. producing *E. fragilis*-type pollen persisted at relatively greater abundance within the crater than regionally throughout zone 3, that members of the genus *Helianthemum* persisted and even increased locally within the crater during the first part of the late-glacial interstadial and that *Phillyrea,* a characteristically Mediterranean woody taxon, was present locally during the later part of the interstadial at greater abundance than across the region as a whole. This once again may reflect the influence of the lake upon the local microclimate; *Ephedra fragilis,* the only producer of *E. fragilis*-type pollen found in Europe today, many *Helianthemum* spp. and *Phillyrea* spp. all are restricted today to southern Europe, a majority, if not all, of them by their relative intolerance of severe cold. It is plausible that under the generally warmer conditions of the late-glacial interstadial, compared to the preceding interval, the principal ecologically important influence of the lake was to moderate the severity of winter conditions, rendering the local microclimate more favourable for these taxa than was the region as a whole.

The observation that a number of mesic woody taxa were less abundant locally than regionally during the early part of the interstadial is less easy to explain, except by recourse to suggesting either that they had distant refuges and thus were delayed in their arrival locally, or that they initially were competitively excluded from the local vegetation by less cold-tolerant taxa already present. Neither of these explanations is satisfactory. The rapidity with which the mesic taxa respond to climate fluctuations during the glacial (Watts *et al.*, 1996a) only readily can be accounted for by inferring that these taxa had numerous scattered small refugial populations throughout the region (Huntley *et al.*, in press), removing any migrational lag in their response. The abundance of pollen of *Betula* is incompatible with competitive exclusion by less cold-tolerant taxa, *Betula* being both one of the more cold-tolerant woody taxa (Huntley, 1990) and of relatively low competitive ability. The most probable explanation lies in the combined influence of the lake and of the overall no-analogue combination of environmental conditions during the few centuries spanned by sub-zone 3b. The thermally stabilising influence of the lake would reduce the extent of summer warmth as well as the severity of winter cold during a time when the enhanced seasonal contrast in quantities of solar radiation led to increased seasonality of the regional macroclimate relative to the present day. Relative to the conditions prevailing regionally, the local conditions thus would favour a mixture of those taxa less tolerant of winter cold and/or less demanding of overall growing season warmth.

Whatever its cause, the lower abundance of these mesic woody taxa during sub-zone 3b in the fen core results once again in a misleading anomaly in the palaeoclimate reconstruction. A large decrease in the mean temperature of the coldest month is reconstructed that is not seen in the reconstruction from the mid-lake core (Watts *et al.*, 1996a, b). This results from the relative lack in the pollen assemblages from the fen core of taxa

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(1) *Abies, Alnus, Betula, Carpinus betulus, Castanea, Cedrus, Corylus, Ephedra, Fagus, Juniperus*-type, *Larix, Olea, Ostrya*-type, *Phillyrea, Picea, Pinus* (Diploxylon), *Pinus* (Haploxylon), *Pistacia, Quercus* (Deciduous), *Quercus* (Evergreen), *Salix, Tilia, Ulmus, Artemisia,* Chenopodiaceae, Cyperaceae, Ericales (including *Empetrum*) and Gramineae.

associated with less severe winter conditions and used to make the reconstructions. The best analogues for spectra lacking these mesic woody taxa, and with similar combinations of relative pollen abundances for *Betula* and major herbaceous taxa to those found in the fen core during sub-zone 3b, are found today in regions that experience severe winter cold. However, as argued above on the basis of evidence from minor taxa that are not used in the palæoclimate reconstructions, the winter conditions within the crater probably were less severe than in the region as a whole. Once again, therefore, the reconstruction made from the mid-lake core is likely better to reflect the prevailing macroclimate of the time.

In the palæoclimate reconstruction from the fen core the Younger Dryas is not marked by any fluctuation in mean temperature of the coldest month. This is because of the combined effects of the limited local expression of the event and the anomalously low winter temperature reconstructions from zone 3 (Watts *et al.*, 1996a, b). Regionally, however, a fluctuation in mean temperature of the coldest month is the principal climatic change associated with the Younger Dryas event. Subsequently it is the record from the mid-lake core that probably is misleading; the very wide sampling interval during the Holocene leads to the appearance of a progressive warming of winter temperatures whereas the better-resolved record from the fen core suggests that winter temperatures remained relatively low until the mid-Holocene, around 5,500 calibrated $^{14}$C years ago, after which time less cold-tolerant taxa such as *Quercus ilex*-type appeared and increased in abundance locally (Watts *et al.*, 1996b).

## 4. DISCUSSION

Much has been written in recent years extolling the advantages of 'multi-proxy' investigations when attempting to reconstruct Quaternary palæoenvironments. Although such an approach clearly has much to offer, we have shown here that in palynological studies of lacustrine environments it sometimes also may be important to examine the records from marginal as well as mid-lake cores in order to provide a more complete understanding of the palæoenvironment. In the case of Lago Grande di Monticchio we have argued that the palæoclimate reconstruction made from the mid-lake core probably is a better reflection of the regional macroclimate than is the parallel reconstruction made from the marginal core. Nonetheless, pollen data from the marginal core complement those data from the mid-lake core and have enabled a more complete picture to emerge. We summarise below our general conclusions and discuss briefly their relationship to previous work.

The latter part of the Weichselian glacial stage (zone 4) was relatively cold with seasonal aridity that led to fluctuating water levels in Lago Grande di Monticchio; lowered water levels in summer and the development of saline conditions favoured the local growth of Chenopodiaceae. This inference is consistent with results from other sites elsewhere in Italy (Alessio *et al.*, 1986; Bonatti, 1970) and elsewhere in the Mediterranean (Lamb *et al.*, 1989; Turner & Greig, 1975). It most probably reflects a combination of high summer evaporative demand, resulting at least in part from the increasing summer insolation at this time, and from precipitation being confined principally to the winter months. Regionally a herb-dominated steppe was prevalent, although mesic and southern woody taxa probably had scattered refugial populations in favourable microhabitats. The record of Gramineae (cereal-type) and of *Centaurea cyanus*-type at this time is not regarded as evidence of human agricultural activities; the natural habitat of these taxa is dry, often rocky, steppe-like areas such as appear to have predominated in this region during this period.

Subsequently, with the onset of the late-glacial interstadial, climate conditions became generally warmer, although at the same time the summer moisture supply apparently increased so that summer aridity was reduced. The interstadial as a whole spanned ca. 1600 yr. A notable feature of the first 500 to 600 yr of the interstadial is the relative increase in pollen abundance values of Gramineae (wild-type); this contrasts with sharp reductions in *Artemisia* and Chenopodiaceae, both stronger indicators of summer aridity. During this period *Betula* was the first pollen taxon reflecting woody plants to increase; subsequently it decreased as *Quercus* and other mesic trees increased in abundance. This perhaps indicates reduced aridity but only relatively slowly warming conditions so that a mosaic of grassland and *Betula* woodlands was favoured during this relatively cooler transient stage. By the latter part of the interstadial conditions were sufficiently mesic to support the regional development of diverse nemoral forests with a substantial proportion of *Tilia.* A similar inference was made by Kelly & Huntley (1991) in their work at Lago di Martignano north of Rome.

The Younger Dryas climate fluctuation is well reflected by the pollen records from Lago Grande di Monticchio. This interval of between 750 and 1050 yr was marked principally by relatively colder winter temperatures and probably by some increase in summer aridity; forests were reduced in extent and steppic communities became more extensive. However, in contrast to many pollen records from northern Europe in which the Younger Dryas pollen assemblages closely resemble those of the latest part of the Weichselian full glacial, at Lago Grande di Monticchio the Younger Dryas assemblages record a much more extensive forest cover in the region than during the latest part of the full glacial. Nonetheless, this forest was markedly different in composition from that which preceded it during the latter part of the late-glacial interstadial. Mesic trees were reduced in abundance and diversity whereas cold-tolerant taxa, especially *Betula,* were once again more frequent. The composition of the forests thus more closely resembled that of the woodlands of the early part of the late-glacial interstadial, although the latter were less extensive. The transition to the Holocene was marked by the renewed extension of forest cover, although the composition differed once again.

This palæoenvironmental record has important implications with respect to the changes in atmospheric circulation during the last deglaciation. The palæoclimate simulations of Kutzbach & Guetter (1986) and Kutzbach *et al.* (1993) show the full-glacial to have been cooler than the present by between 4 and 8°C in both January and July in the Mediterranean region with the prevalent storm track shifted southward in both seasons. It already has been shown from the record of the last full glacial (Watts *et al.*, 1996a) that southern Italy is in a sensitive position with respect to any atmospheric circulation changes associated with changes in the temperature of the North Atlantic surface during that period. It therefore is to be expected that the northward shift of the North Atlantic polar front at the onset of the late-glacial interstadial (Ruddiman & McIntyre, 1981) would trigger a substantial palæovegetation response in this region. That this response was relatively slow, with a distinct initial phase of woodland and grassland development, may be indicative of a progressive shift in ocean surface conditions rather than of any lag in the response of the vegetation, given the rapidity of vegetation responses during the earlier part of the last glacial (Watts *et al.*, 1996a). Alternatively it may indicate that glacial maximum conditions (ca. 26,100 to 14,300 calendar years ago) had been sufficiently severe that the more mesic and/or warmth-demanding woody taxa that apparently had local *refugia* within the region during oxygen isotope stage 3 (Huntley *et al.*, in press) finally had been displaced out of the region into more remote refugial areas and thus did lag in their response to the changing conditions.

Whether progressive or more rapid, the atmospheric circulation change at the onset of the interstadial was such as to bring more moisture to southern Italy during the summer months. This may, of course, simply have been as a result of a warmer North Atlantic surface and increased evaporation; the prevalent summer storm track must have continued to lie well south of its present position in order to bring this moisture into the Mediterranean region. The evidence of increasingly moist and warm conditions during the later part of the late-glacial interstadial indicates that this combination of a relatively warm North Atlantic surface, and hence enhanced evaporation, but a more southerly summer storm track, likely persisted throughout this period.

The colder North Atlantic surface during the Younger Dryas fluctuation (Ruddiman & McIntyre, 1981) may account of itself for the reduced moisture availability and cooler conditions observed in southern Italy during this interval, no shift in atmospheric circulation being necessary. As the Holocene began, however, the northward migration of the summer storm track (Kutzbach & Guetter, 1986; Kutzbach *et al.*, 1993) could account for the relatively less moist conditions, although the warmer summer temperatures also would increase evaporative demand so that the vegetation would experience reduced water availability even if precipitation was unchanged.

The present-day Mediterranean climate, with its charactersitic summer drought, did not become established in this region until later in the Holocene. Given that the early Holocene sees the greatest northward shift in the simulated position of the summer storm track, consistent with the peak summer insolation of this time (Kutzbach & Guetter, 1986; Kutzbach *et al.*, 1993), the failure of the Mediterranean climate régime to become established at this time must be explained. One explanation is that the enhanced summer insolation itself generated greater regional storm activity within the Mediterranean basin, providing a local source of moisture independent of storm systems generated in the Atlantic. This effect may have been enhanced in the region of southern Italy as a result of rising sea level once again inundating the large area of the northern Adriatic that was dry during the glacial (Fig. 1). The effect would diminish as the summer insolation was reduced; the persistently more northerly position of the summer storm track then would lead to the increasing degree of summer drought in the Mediterranean region during the later Holocene. Such an hypothesis relating to features that have an inherent scale that is less than that of the grid used in global palæoclimate simulations cannot be evaluated using these simulations. It might, however, be tested by a combination of regional-scale palæoclimate modelling for the Mediterranean basin and high-resolution studies of marine sediments from the Mediterranean to examine the evidence for changes in the sea surface temperature since the late-glacial.

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