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Timing of aquatic and marsh-plant successions in different parts of Lake Zeribar, Iran, during the Late Glacial and Holocene

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ABSTRACT. The stratigraphy of plant macrofossils in cores from different parts of Lake Zeribar, Zagros Mountains, Iran, recorded the succession of aquatic and mire plants from the decline of the pleniglacial to the youngest Holocene. Two of the cores were correlated by the stratigraphy of regional pollen types and by calibrated radiocarbon dates. Several levels in the macrofossil diagrams thus dated indicate distinctly different stages of vegetation succession in the lake centre and near the west shore until about 16 000 cal BP. Between 16 000 and 6000 cal BP similar aquatic vegetation developed in both places. Since that time different communities again spread at the shore and in the central part. These results indicate that the analysis of a single core may provide information about changes of the past vegetation in the whole lake in certain time intervals, whereas for the other locations it may not be representative. The accuracy with which plant palaeosuccession in Lake Zeribar can be dated using the ^{14}C method does not exceed 300–500 calendar years.

KEY WORDS: plant macrofossils, lake sediments, dating of aquatic plant successions, Late Glacial, Holocene, Iran

INTRODUCTION

In modern lakes different associations of submerged and floating macrophytes, as well as mire plants, may develop at the same time in various places of one basin, depending on the substrate, bottom relief, availability of plant propagules, and several other factors (Kępczyński & Noryśkiewicz 1998). Similar situations may have occurred in the past, and for palaeoecological investigations it is important to recognize if the analysis of one sediment core (the usual procedure) may provide reliable information about plant palaeo-successions over the entire lake. The studies carried out on Lake Zeribar sediments may contribute to an understanding of this problem.

Lake Zeribar (Fig. 1), situated in an intermontane valley in the Zagros Mountains, SW Iran (35°32′N, 46°07′E), contains sediments over 40 m thick, dating back to about 42 000 radiocarbon years BP at the bottom. The age of the sediments, as well as the location of the lake in an area of crucial significance for the reconstruction of environmental conditions at the time of the emergence of sedentary life and agriculture in the Middle East, has stimulated multidisciplinary studies (among others van Zeist & Wright 1963, Hutchinson & Cowgill 1963, van Zeist 1967, Megard 1967, Wasylikowa 1967, van Zeist & Bottema 1977, 1991, Wright 1993, Snyder et al. 2001, Stevens et al. 2001, Wright & Thorpe 2003, Wasy-

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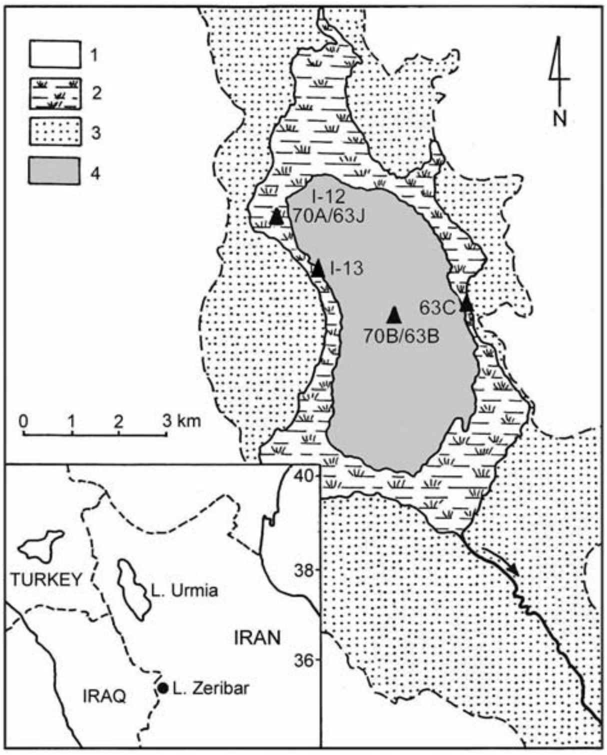

Fig. 1. Lake Zeribar area in the Zagros Mountains. **1** – mountain ridges, **2** – mires, **3** – alluvial fens, **4** – lake. Coring sites are indicated

likowa in press). Regional and local changes of terrestrial vegetation during the last Glaciation and the Holocene were reconstructed by detailed pollen-analytical investigations of two sediment cores, one from the western shore and the other from the centre of the lake (van Zeist & Wright 1963, van Zeist 1967, van Zeist & Bottema 1977, 1991). Pollen and plant macrofossils from the same cores provided information about the development of aquatic and mire-plant communities. Seeds and fruits were also examined from a third core, collected on the east shore (Wasylikowa in press). Analysis of macrofossils shows similar though not quite identical successions of aquatic and marsh plants in all cores. Some of the successional stages seemed to be synchronous in all cores, while the correlation of the others was dubious. The purpose of the present article is to compare the timing of palaeo-succession of lake and mire vegetation as reconstructed from macrofossil analysis of the different sediment cores, in order to answer the question whether the spread of aquatic and mire plants was synchronous over the whole lake. It is not our aim to present a complete description of lake vegetation history, which has been briefly discussed elsewhere (Wasylikowa in press).

MATERIAL AND METHODS

Of the sediment cores studied from Lake Zeribar, only cores 63J from the west shore and 70B from lake centre (Fig. 1) could be used to compare the timing of lake-vegetation development, because only these cores were examined both by pollen and macrofossil analyses and were subjected to radiocarbon dating. They covered the time of the decline of the pleniglacial through the Late Glacial and Holocene. In macrofossil diagrams from both cores a few levels were selected that reflect distinct changes in the succession of aquatic and marsh plants, and their ages were determined with the aid of the calibrated age-depth curves. Macrofossil diagrams were drawn in the POLPAL program (Walanus & Nalepka 1999).

Conventional radiocarbon dates (Tab. 1), eight from core 63J and four from 70B (including one from core 63B, collected from the same spot as 70B), were calibrated with INTCAL98 table (Stuiver et al. 1998). Standard cubic-spline smoothing was applied to obtain continuous calibration curves. The older dates were confirmed with calibration data from Beck et al. (2001) and Hughen et al. (2004). Initially, in the profile 63J one date based on bulk sediment (11 850 ± 120 ^{14}C BP,

Table 1. Radiocarbon dates from Lake Zeribar used for drawing calibrated age-depth curve (for location of cores see Fig. 1)

Core number	Depth in m	^{14}C date BP	Symbol	Material dated	Reference
63J	6.70–7.00	4 010 ± 75	CURL-5788	sedge fruit	H.E.Wright, unpubl.
	14.10–14.20	8 100 ± 160	Y-1432	clay gyttja	van Zeist & Bottema 1977
	16.75–16.80	10 300 ± 50	CURL-5790	plant macroremain	H.E.Wright, unpubl.
	17.10–17.20	11 480 ± 160	Y-1687	clay gyttja with shells	van Zeist & Bottema 1977
	17.45–17.50	12 050 ± 55	CURL-5791	plant macroremain	H.E.Wright, unpubl.
	17.90–18.00	12 750 ± 110	CURL-5792	plant macroremain	H.E.Wright, unpubl.
	18.90–19.00	13 650 ± 160	Y-1686	clay gyttja	van Zeist & Bottema 1977
	25.35–25.45	22 000 ± 500	Y-1431	clay gyttja with shalls	van Zeist & Bottema 1977
63B	7.00–7.10	2 240 ± 150	L-845B	marly clay gyttja	van Zeist & Bottema 1977
70B	9.78–9.93	5 640 ± 70	GrN-7628	calcareous gyttja	van Zeist & Bottema 1977
	11.00–11.15	6 890 ± 80	GrN-7629	calcareous gyttja	van Zeist & Bottema 1977
	13.60–13.75	10 600 ± 100	GrN-7630	calcareous gyttja with shells	van Zeist & Bottema 1977

16.10–16.20 m) was removed from consideration as an obvious outlier. Later, however, when the preliminary calibration curve was obtained, it appeared that also the AMS date 4010 ± 75 ^{14}C BP (6.70–7.00 m) from 63J, based on a sedge fruit, had to be excluded (for explanation see below).

On the basis of probability density functions for the calibrated ages and the average depth for each ^{14}C sample, the provisional age-depth curves were obtained for both cores (Fig. 2). The method of calculation for each curve was as follows. According to the Monte Carlo method, from the probability distributions, "point" dates were drawn, i.e. one value of age BP. The smooth curve of cubic splines was fitted to points defined by depth and age. The curve connects exactly the points. About a thousand of such curves, for different sets of generated point dates were obtained. The best one was then selected, i.e. the curve of the lowest possible curvature and the highest possible probability of the corresponding point dates. The curvature is defined here as the departure from a straight line measured independently in many consecutive short distances and then summed up. How well the obtained curve fits the radiocarbon dates is measured by the parameter, which may be called the likelihood, by analogy with the standard statistical likelihood L. Here likelihood is the product of the density of probability for the actual values of generated point dates. So the higher the likelihood, the higher is the probability of a given set of dates. On the other hand, the age-depth relation should be as smooth as possible, i.e. the curve should have low curvature. The best line is the one with the highest likelihood and the lowest curvature. Since radiocarbon dates are

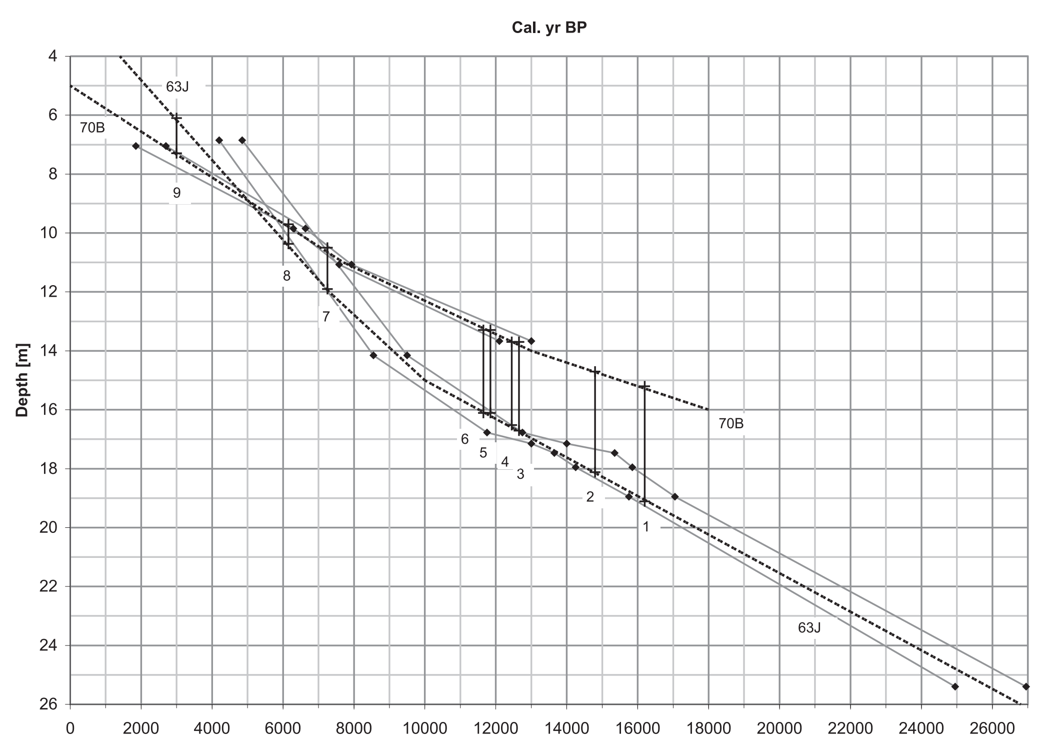

Fig. 2. Age-depth curves for cores 63J and 70B from Lake Zeribar. 1–9 pollen time-stratigraphic markers (for explanations see Tab. 2)

Table 2. Pollen time-stratigraphic markers Nos 1–9 in diagrams from cores 63J and 70B/63B. Depth from van Zeist & Bottema (1977), calibrated age BP according to the age-depth curve (this paper)

Pollen time-stratigraphic markers		Core 63J		Core 70B/63B	
		Sample depth (m)	Cal. yr BP	Sample depth (m)	Cal. yr BP
Plantago lanceolata type in PAZ 7c	9	6.1	2 900	7.3	3 000
Quercus peak in PAZ 7a	8	10.36	6 100	9.29	5 500
Fraxinus peak at top of PAZ 5	7	11.9	7 200	10.49	7 100
Chenopodiaceae decrease in PAZ 5	6	16.11	11 700	13.29	11 800
Artemisia decrease in PAZ 5	5	16.11	11 700	13.29	11 800
Artemisia uppermost peak in PAZ 4	4	16.52	12 300	13.7	12 500
Chenopodiaceae uppermost peak in PAZ 4	3	16.7	12 600	13.7	12 500
Artemisia first decrease in PAZ 4	2	18.12	14 600	14.7	14 800
Artemisia uppermost peak in PAZ 3b	1	19.11	16 200	15.2	16 200

well self-consistent (after removing one of them), the above-mentioned ideal of obtaining good values of both parameters was achieved.

To increase the precision of dating the information provided by pollen diagrams was used as an additional argument to draw the best age-depth lines. Namely, those variations in the pollen profiles in cores 63J and 70B (van Zeist & Bottema 1977), which are assumed to represent the synchronous changes of regional or local upland vegetation, were used as pollen time-stratigraphic markers. Nine such markers were selected, and the age-depth curves were corrected in such a way that the ages of corresponding markers in the two cores were as close to each other as possible, considering the radiocarbon age probability distributions (Tab. 2).

PALYNOLOGICAL BACKGROUND

The results of pollen analysis were discussed at length by van Zeist and Bottema (1977). A brief summary of upland vegetation history, presented below, is confined to those palaeoecological changes that justify the choice of pollen time-stratigraphic markers used for drawing the age-depth curves. The late pleniglacial (PAZ 3b in Figs 3, 4) of the Lake Zeribar area was characterized by a treeless semi-desert vegetation dominated by Chenopodiaceae and *Artemisia*. The high percentages

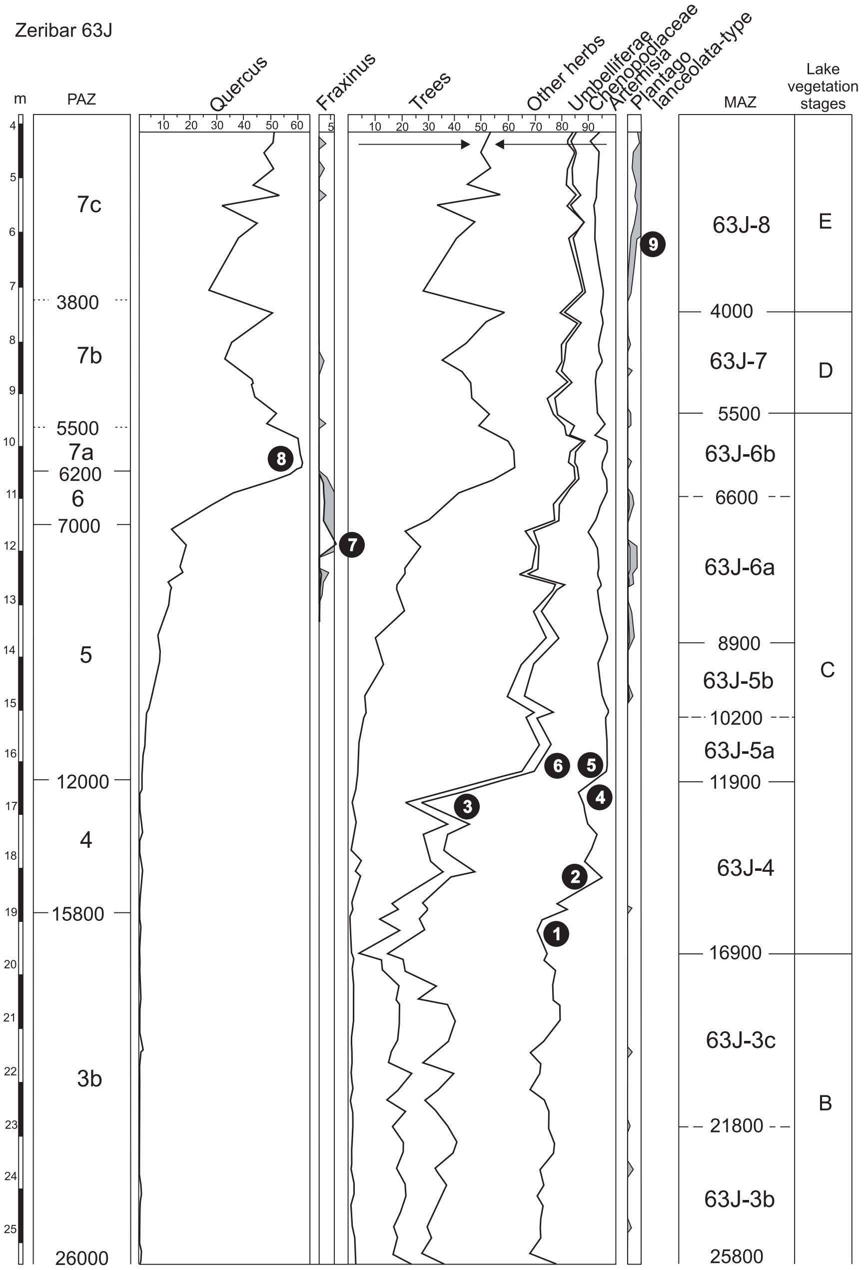

Fig. 3. Simplified pollen diagram from core 63J (from van Zeist & Bottema 1977) showing the position of pollen time-stratigraphic markers 1–9 (Tab. 2). Shaded silhouettes indicate ×10 magnification. Age of pollen (PAZ) and macrofossil (MAZ) assemblage zones in calendar years BP

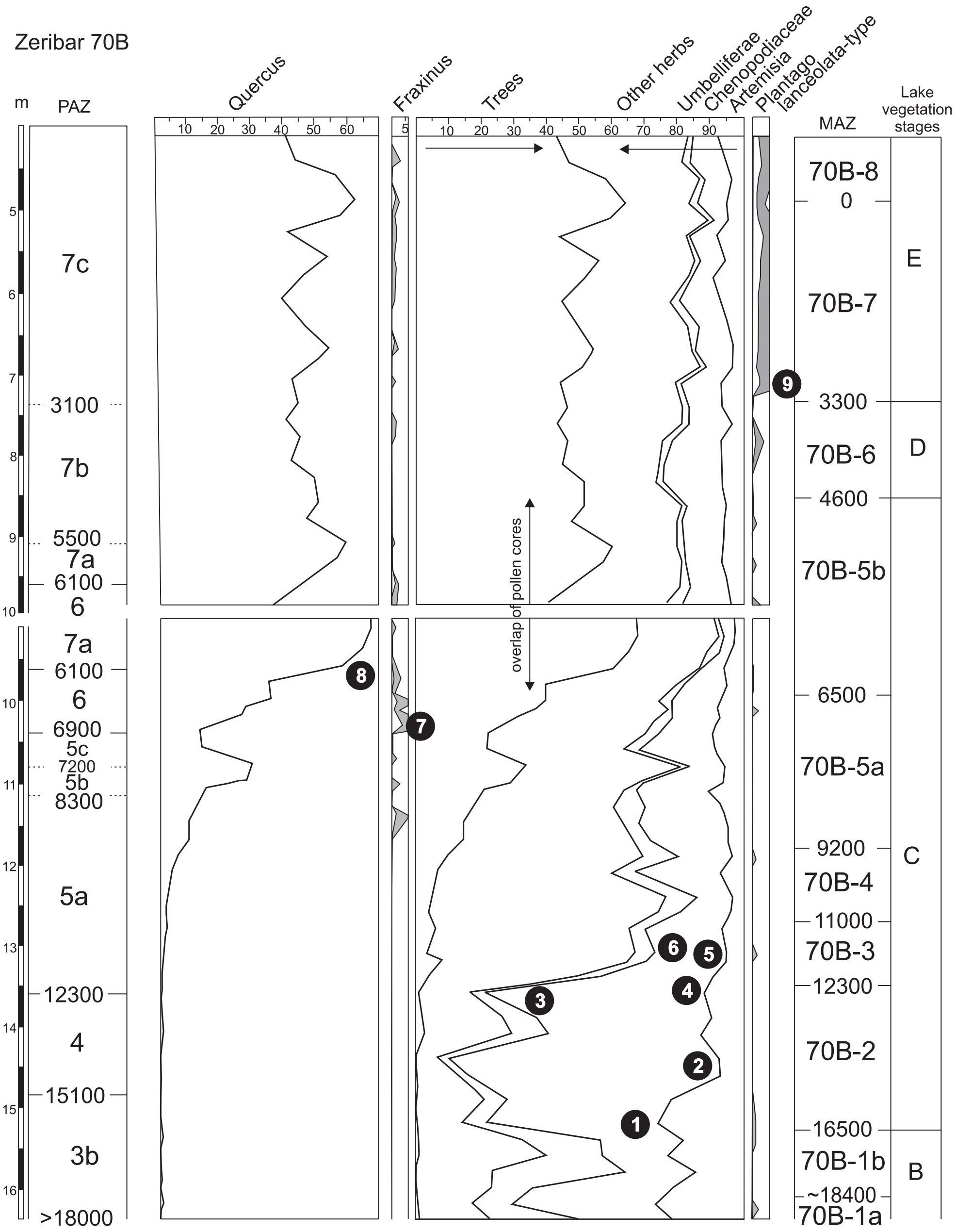

Fig. 4. Simplified pollen diagram from core 70B (from van Zeist & Bottema 1977) showing the position of pollen time-stratigraphic markers 1–9 (Tab. 2). Shaded silhouettes indicate ×10 magnification. Age of pollen (PAZ) and macrofossil (MAZ) assemblage zones in calendar years BP

of these taxa showed several fluctuations in the pleniglacial section of the profiles, and the uppermost culmination of *Artemisia* curve at the top of pollen zone 3b was used as pollen time-stratigraphic marker 1 (Tab. 2, Figs 3, 4). At the transition to the Late Glacial (PAZ 4), when the first *Pistacia* trees probably appeared in the area, the *Artemisia* curve distinctly decreased (pollen marker 2), whereas Chenopodiaceae still remained at a very high level. In the top section of pollen zone 4, corresponding to Younger Dryas time, there was an increase of Chenopodiaceae (pollen marker 3) and *Artemisia* (pollen marker 4), followed by declines of *Artemisia* (pollen marker 5) and Chenopodiaceae (pollen marker 6) at the beginning of the Holocene (PAZ 5). During the Holocene slowly expanding trees first formed an open woodland (or forest-steppe), with *Pistacia*, *Quercus*, and *Amygdalus* (PAZ 5), later followed by a *Quercus* forest (PAZ 6 and 7) similar to that found in less disturbed parts of the Zagros Mountains today. The characteristic increase of *Fraxinus* at the top of pollen zone 5 was used as pollen marker 7, and the culmination of *Quercus* in pollen zone 7a as pollen marker 8. The beginning of continuous curve of *Plantago lanceolata* type, which indicates the increased grazing activity in the surroundings of the lake, was considered pollen marker 9 (Tab. 2. Figs 3, 4). The use of this last marker needs a comment.

The start of *P. lanceolata* type curve in the two cores is palynologically well synchronized and marks the beginning of pollen subzone 7c (van Zeist & Bottema 1977), whereas radiocarbon dates of samples taken just above subzone 7b/7c boundary show the age of 4010 ± 75 ^{14}C BP for 63J and 2240 ± 150 ^{14}C BP for 70B (Figs 5, 6). The dating of this boundary in 63J, based on the calibrated age-depth curve obtained with the ^{14}C date 4010 ± 75 BP included, gave the age by 1700 calendar years older than in 70B. In view of the pollen data this seemed unacceptable and this date was ignored when drawing the calibration curve presented in this paper (Fig. 2). The possible explanation of the discrepancy between the two dates could be that *Carex* fruit, which gave the AMS date 4010 ± 75 (see Tab. 1), was

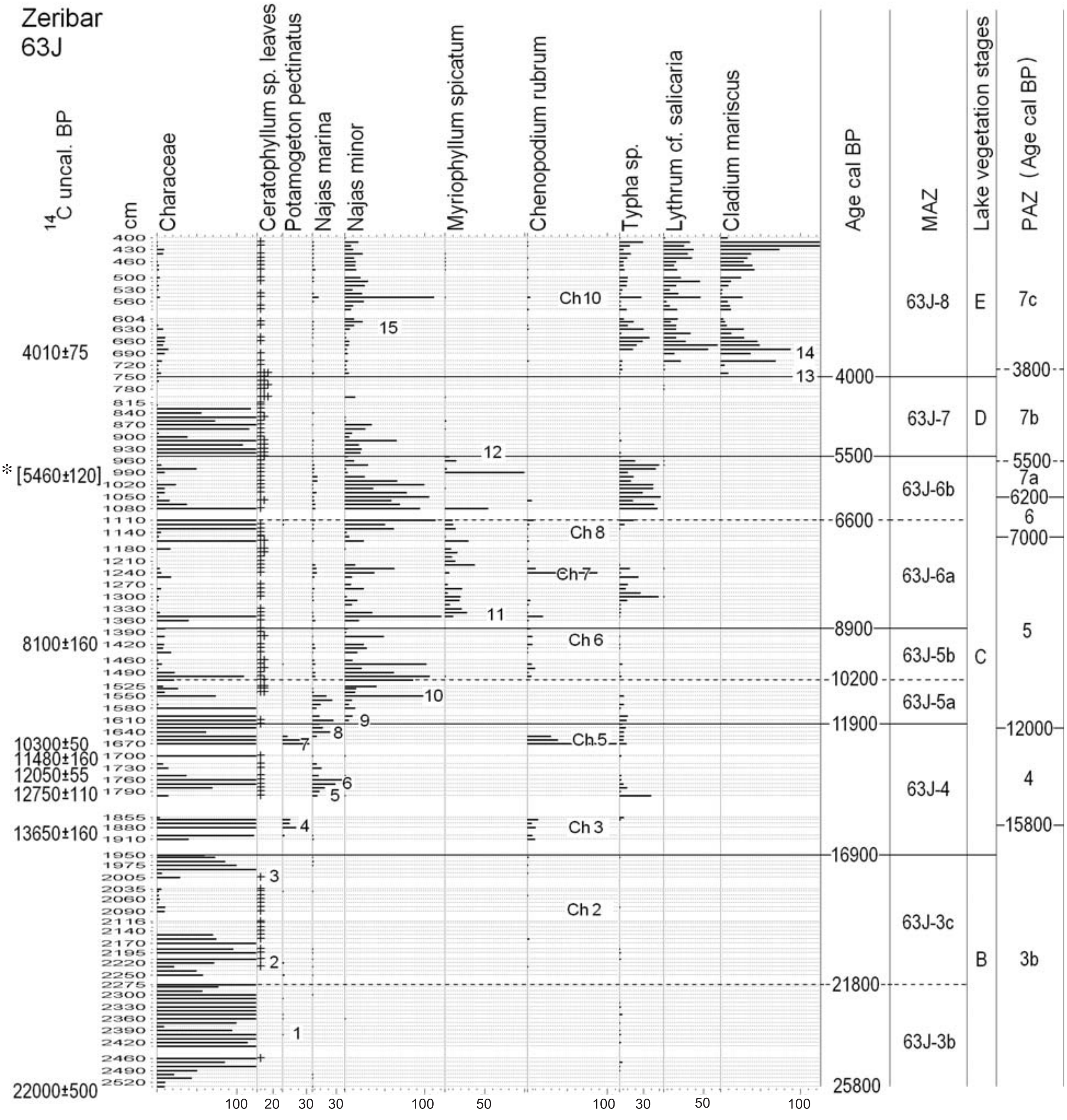

Fig. 5. Plant macrofossil diagram from Lake Zeribar core 63J showing selected plant taxa. 1–15 stages of aquatic and mire plant succession (Tab. 3), Ch2-Ch10 stages of *Chenopodium rubrum* occurrences (Tab. 4). *[ ] – ^{14}C date (Y-934) from core I-13 (see Fig. 1)

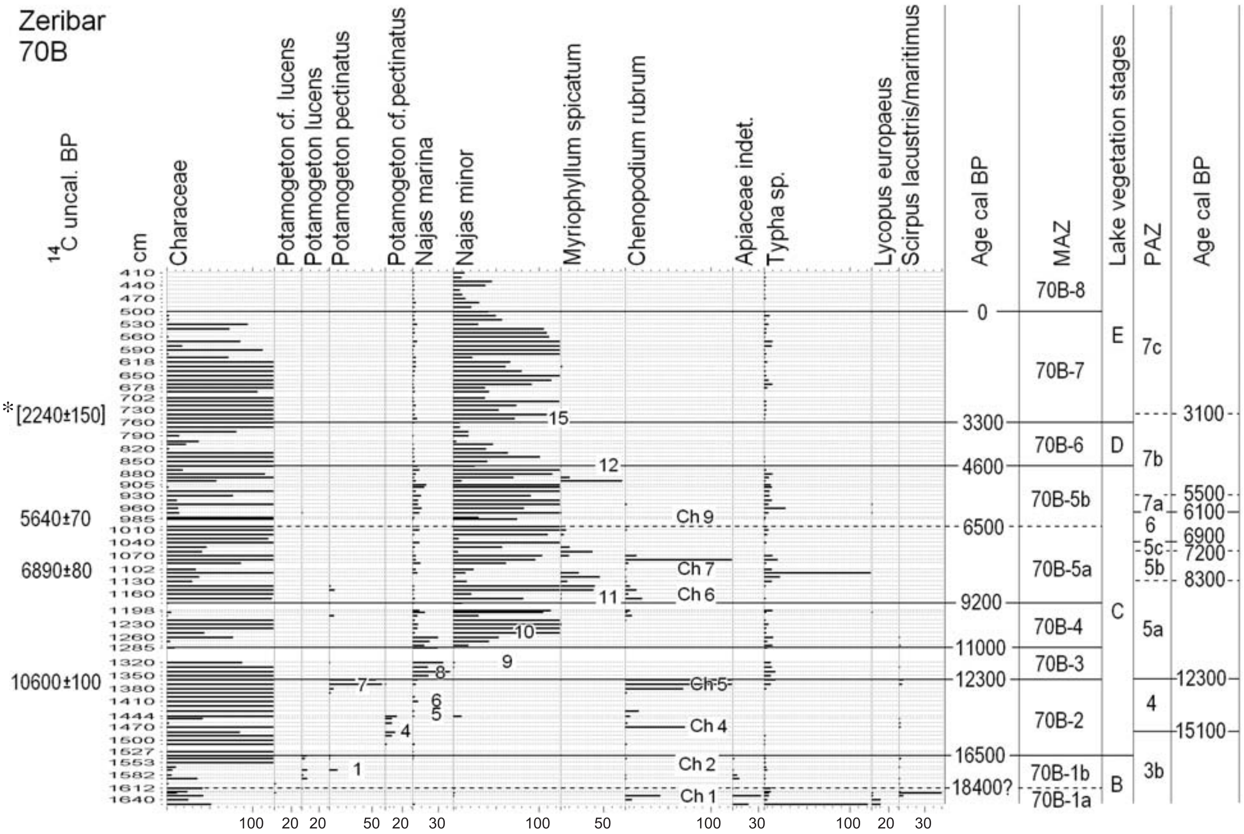

Fig. 6. Plant macrofossil diagram from Lake Zeribar core 70B showing selected plant taxa. 1–15 stages of aquatic and mire plant succession (Tab. 3), Ch1-Ch9 stages of *Chenopodium rubrum* occurrences (Tab. 4). *[ ] – ^{14}C date from core 63B (see Fig. 1)

reworked from older sediments. Such a possibility was also suggested to explain the unreliable AMS dates obtained on sedge fruits from Late Glacial sediments in site Finglas River in Ireland (Turney et al. 2000). The discussed date from Lake Zeribar comes from the horizon showing the start of mire formation at the west shore. Perhaps the edge of the mire floated at times of increased water level, as it happens today, and these fluctuations caused sediment disturbance. Besides, the sediment below this horizon is enriched in mineral material which might come from erosion in the basin. The proposed explanation is, however, not fully satisfactory because the older sediments, which could be the source of redeposited material, contain very few *Carex* fruits.

RESULTS

In plant-macrofossil diagrams from cores 63J and 70B the histograms of frequently and abundantly occurring species show distinct changes, reflecting the beginning, maximum, and decline of their development (Figs 5, 6). In order to answer the question whether the spread of these species occurred contemporaneously at the shore and in the centre of lake the ages of fifteen levels in core 63J and eleven in 70B were read from the age-depth curves (Tab. 3, levels 1–15). The same way of dating was applied to *Chenopodium rubrum* seeds (Tab. 4) and boundaries of macrofossil and pollen assemblage zones (Figs 3–6).

Until about 16 000 cal BP, lake vegetation near the west shore (Fig. 5) and in the centre (Fig. 6) was composed of different plant species. Then between approximately 16 000 and 6000 cal BP similar aquatic communities developed in both places. After 6000 cal BP they were different again. Before about 18 000 cal BP, a rich marsh vegetation existed in the centre of the lake (Fig. 6, MAZ 70B-1a), while at the west shore submerged and floating aquatics predominated (Fig. 5, MAZ 63J-3b, 3c). The middle period (16 000–6000 cal BP) was characterized by the presence of the same species of aquatic plants in both places, but their first appearances and their culminations did not always occur at the same time (Tab. 3). *Potamogeton pectinatus* achieved its first cul-

Table 3. The age of the main stages of aquatic and mire plant succession in macrofossil diagrams 63J and 70B. 1–15 successional stages

Successional stages		Core 63J		Core 70B		Synchronous
		Depth m	Cal. yr BP	Depth m	Cal. yr BP	levels
Najas minor increase	15	6.3	3100	7.5	3200	
Marsh increase	14	6.9	3500	missing		
Marsh start	13	7.5	4000	missing		
Myriophyllum spicatum end	12	9.4	5400	8.6	4600	
Myriophyllum spicatum start	11	13.5	8700	11.7	9000	*
Najas minor first culmination	10	15.5	10 800	12.5	10 400	*
Najas minor start	9	16.1	11 700	13.2	11 600	*
Najas marina culmination	8	16.4	12 100	13.4	12 000	*
Potamogeton pectinatus culmination	7	16.7	12 600	13.7	12 500	*
Najas marina culmination	6	17.7	14 200	14.1	13 300	
Najas marina start	5	18.0	14 600	14.4	14 200	*
Potamogeton pectinatus culmination	4	18.8	15 800	14.8	15 100	
Ceratophyllum demersum end	3	20.0	17 700	missing		
Ceratophyllum demersum start	2	22.2	21 000	no sediment		
Potamogeton pectinatus start	1	24.0	23 800	15.7	17 300	

Table 4. Dating of main levels (Ch1–Ch10) of the occurrence of *Chenopodium rubrum* seeds in cores 63J and 70B

Characteristics of dated levels		Core 63J		Core 70B		Synchronous levels
		Depth m	Cal. yrs BP	Depth m	Cal. yrs BP	
Traces	Ch10	7.10–4.10	3700–1500	missing		
Traces	Ch9	missing		10.10–9.50	6600–5800	
Low continuous	Ch8	12.20–10.60	7500–6300	missing		
Culmination	Ch7	12.50–12.40	7800–7600	10.90	7500	*
Medium continuous	Ch6	15.00–13.10	10 000–8300	12.20–11.00	9800–7800	*
Culmination	Ch5	16.70–16.50	12 600–12 300	13.70–13.50	12 500–12 100	*
Culmination	Ch4	missing		14.70–14.33	14 800–13 900	
Culmination	Ch3	19.10–18.55	16 200–15 400	missing		
Low continuous	Ch2	22.20–19.50	21 000–16 900	16.10–15.10	ca. 18 000–15 800	*
Culmination	Ch1	missing		16.40–16.30	> ca. 18 000	

mination in core 63J some 700 years earlier than in 70B (about 15 800 and 15 100 cal BP respectively; marker 4, Tab. 3). In 63J the beginning of the continuous presence of *Najas marina* (marker 5), dated to about 14 600 cal BP, was soon followed by its first culmination (marker 6) about 14 200 cal BP, while in 70B this species appeared about 14 200 cal BP and culminated as late as 13 300 cal BP. Further development of these two species was probably contemporaneous in both places, *P. pectinatus* culminated for the second time around 12 600–12 500 cal BP (marker 7, Tab. 3), and *N. marina* (marker 8) about 12 100–12 000 cal BP. Also the beginning of continuous curves of *N. minor* (11 700–11 600 cal BP, marker 9) can be treated as contemporaneous as well as their first culminations (10 800–10 400 cal BP, marker 10), and possibly also the beginning of the spread of *Myriophyllum spicatum* (8700–9000 cal BP, marker 11). *M spicatum* persisted until ca. 4600 cal BP in the central part of the lake (marker 12), where the new culmination of *Najas minor* took place about 3200 cal BP (marker 15). At the west shore *M. spicatum* almost disappeared as early as 5400 cal BP and starting from about 4000–3500 cal BP marsh plants became dominant among macrofossils (markers 13, 14, Tab. 3). The spread of *N. minor* recorded in 70B about 3200 cal BP, was reflected in 63J by slight increase of its seed numbers about 3100 cal BP.

The occurrence of *Chenopodium rubrum* seeds in Lake Zeribar sediments was considered an indicator of periods of lower water level, because this species is able to colonize the exposed muddy lake shores. For this reason it was interesting to date levels with higher seed numbers of this chenopod, which were noted in both cores in several sections of the Late Glacial and Holocene. Scattered seeds, which were found in older sediments at the west shore (core 70A, Wasylikowa in press) indicate that the species was present throughout the pleniglacial. The first post-pleniglacial increase of *C. rubrum* seeds, which occurred in core 70B before ca. 18 000 cal BP (Ch1, Tab. 4, Fig. 6), had no counterpart in 63J, where the spread of this plant occurred as late as 16 200–15 400 cal BP (Ch3, Tab. 4, Fig. 5). The second culmination in 70B, between 14 800 and 13 900 cal BP (Ch4, Tab. 4, Fig. 6), was not recorded in 63J. High numbers of seeds in 70B levels dated to 12 500–12 100 cal BP, correspond to those dated in 63J to 12 600–12 300 cal BP (Ch5). Between about 10 000 and 7800 cal BP chenopod seeds occurred continuously, but in small numbers, in both cores (Ch6). The last episode of abundant spread of this species around the lake occurred about 7800–7500 cal BP (Ch7). After that date only sparse seeds were found to the top of the sediment in core 63J (Ch8, Ch10), and in 70B they disappeared completely after about 5800 cal BP (Ch9, Tab. 4).

DISCUSSION

In an attempt to determine the time of spread of short-lived plants such as aquatic annual and even perennial species, it is important to recognize the accuracy of the method applied, which is limited by several factors. First, most of the macrofossil samples from Lake Zeribar contained 10 cm sections of sediment cores. If an average rate of sedimentation is roughly estimated at ca. 10 cm per 100 years, macrofossils from each individual sample might have been growing for any period of unknown duration within this time range. Second, the Zeribar cores have relatively few ^{14}C dates, considering the long period involved, and many of them are based on calcareous sediments. Besides, calibrated dates always represent a range of time and not a single date and the dating of processes that occurred before 18 000 cal BP is uncertain because the calibration of ^{14}C dates older than ca. 13 000 BP is under debate and drawing age-depth curves involves a certain discretion. In addition, the evaluation about which levels in a pollen or macrofossil diagram are the best expressions of inferred synchronous palaeoecological changes is slightly subjective, and the reading of the depth of selected levels on the calibrated age-depth curve may not be exact. This difficulty is particularly well illustrated by the time-stratigraphic pollen marker 8, based on oak culmination, which is noted in pollen diagrams in several samples, and the selection of one or the other highly influences its date. All these shortcomings of the method bear upon our results.

The different lake vegetation indicated by the macrofossil diagrams (and reflected also in the pollen diagrams) from the west shore and the lake centre for the late pleniglacial until about 16 500 cal BP suggests that the configuration of the lake bottom must have been different from present. Before ca. 18 400 cal BP in the centre of the lake (70B) marsh plants prevailed among macrofossils, including *Typha* sp., *Scirpus lacustris*/*maritimus*, *Lycopus europaeus*, some Apiaceae, Brassicaceae, and several other species (Fig. 6, MAZ 70B-1a), suggesting the development of reedswamp-type communities nearby. Periodically low water level is confirmed by the spread of *Chenopodium rubrum* (Ch1, Tab. 4, Fig. 6). About 17 500–17 300 cal BP submerged aquatics appeared, first *Potamogeton lucens* and later *P. pectinatus*, which were accompanied by *Lemna* sp., *Hippuris vulgaris,* and *Batrachium* sp. indicating the continuation of shallow-water conditions until ca. 16 500 cal BP (MAZ 70B-1b). Marsh plants were almost absent in the sediments of the same age at the west shore (Fig. 5, MAZ 63J-3b, 3c), where aquatic vegetation was represented by Characeae, abundant *Ceratophyllum* sp. leaves and a few fruits of *Potamogeton pectinatus* and *Najas marina,* species adapted to survive in a relatively shallow water, but unable to stand complete drying up.

The time between about 16 900 and 12 000 cal BP (Fig. 5, MAZ 63J-4; Fig. 6, MAZ 70B-2) is characterized by a few episodes dominated by the same taxa in the two cores. Dating of these episodes suggests that the spread of *Potamogeton pectinatus* and *Najas marina*, which were the main aquatic plants, was almost contemporaneous in the two places, with some variation concerning the start of succession and intensity of occurrence. *N. marina* appeared and dominated for the first time earlier at the west shore than in the centre (markers 5 and 6, Tab. 3), but about 12 000 cal BP it developed abundantly in both places (marker 8, Tab. 3, Figs 5, 6). Likewise *P. pectinatus* probably culminated (marker 4, Tab. 3, Figs 5, 6) for the first time slightly earlier at the west shore (ca. 15 800 cal BP) than in the centre (15 100 cal BP) but achieved its second predominance (marker 7, Tab. 3) in both places at the same time (around 12 600–12 500 cal BP).

The detailed comparison of the vegetational successions in the period between 16 600 and 12 000 cal BP (MAZ 63J-4 and 70B-2, Figs 5, 6) is hampered by the fact that in core 70B the sediments are either more compressed than in 63J (their thickness being 1.77 m in 70B and 3.3 m in 63J) or partly missing due to sedimentation disturbance, which could be caused by lowering of water level. This is indicated by the spread of *Chenopodium rubrum*, starting about 16 200 cal BP (Ch3, Tab. 4), being continued until about 13 900 cal BP (Ch4), and later occurring again between 12 600 and 12 100 cal BP (Ch5). Considering the accuracy of dating, the culminations dated in 63J to 16 200–15 400 cal BP (Ch3) and between 14 800–13 900 cal BP in 70B (Ch4) could partly overlap.

The time between 12 000 and 6000 cal BP was characterized by the synchronous spread of aquatic plants at the western shore and in the centre of the lake. *Najas marina*, *N. minor*, and *Myriophyllum spicatum*, which showed the most distinct successional changes, were accompanied by other species. *Zannichellia palustris* followed the distribution pattern of *M. spicatum* in both places, while Characeae were much more abundant in the centre and *Batrachium* sp., *Typha* sp., and some Cyperaceae species at the west shore.

The conformity between plant succession recorded in the two cores does not mean that the whole lake was occupied all the time by the same plant communities. One should rather visualize the mosaic of patches of different associations, which persisted in one spot for some time (sometimes probably too short to be measured by ^{14}C) and later developed in another place. But considering the lake as an entitity, and neglecting the composite character of the vegetation, we may suppose that the aquatic species discussed here spread in the lake at more or less the same time (with the accuracy allowed by ^{14}C dating). This period of the similar succession of aquatic plants was the time of the expansion of trees, until oak achieved its culmination in the region and formed Zagrosian oak forest (pollen zones 6 and 7a, Figs 3–6).

After that time the lake vegetation was again distinctly different in the two places. The centre of the lake was covered by aquatic communities, while at the west shore, from ca. 4000 cal BP onwards marsh plants expanded, including among others *Typha* sp., *Lythrum* cf. *salicaria*, *Lycopus europaeus*, *Cladium mariscus*, and several other Cyperaceae species. The formation of the marsh belt that surrounds the lake today was also recorded at the top of undated core 63C from the east shore. At that time the configuration of the lake bottom, as well as the lake water depth and the distribution of vegetation types probably resembled the present-day situation.

An additional problem arising from our analyses was the correlation of pollen and macrofossil assemblage zones in cores 63J and 70B using the age-depth curve. The upper boundaries of PAZ 4, 5, 6 and 7a were approximately of the same age in both cores, but for boundaries of 3b/4 and 7b/7c younger dates were obtained in core 70B compared to 63J (Figs 3, 4). Also in the macrofossil diagrams there was a great age difference between the boundaries of MAZ 63J-7 and 70B-6 (Figs 5, 6), which were considered as synchronous on the basis of plant macrofossil assemblages (Wasylikowa in press). This discrepancy is difficult to explain, and some sediment disturbance seems the most likely cause (compare the discussion about the use of *Plantago lanceolata* curve as time-stratigraphic pollen marker 9).

CONCLUSIONS

The general conclusion of our analyses is that aquatic and mire plant successions in various parts of Lake Zeribar were synchronous at certain times but not at others. A similar suggestion concerns the episodes of the spread of *Chenopodium rubrum* on the exposed muddy lake shores. Synchronous changes occurred between approximately 12 600 and 6000 cal BP, while the older and younger periods were characterized by metachronous (perhaps partly overlapping) plant expansions. This means that the distributional patterns of taxa recorded in one sediment core may or may not provide reliable information about the synchronous changes of the vegetation throughout the lake. In the case of Lake Zeribar the small number of ^{14}C dates allowed timing of consecutive successional stages with the accuracy not exceeding 200–300 years at best and lacked the precision required for dating such short-lived phenomena as the development of annual and perennial aquatic and shore plants. If a detailed interpretation and correlation of various events is required an ideal situation would be to study a few sediment cores from one basin, including pollen and macrofossil analyses, supported by a large number of radiocarbon dates and other data, like faunal remains and sediment characteristics.

The way that *Chenopodium rubrum* seeds occur throughout the cores gives evidence that in the lake history there were several phases of low water levels, when this species, which all the time existed in the area, found particularly suitable habitats for abundant growth and fructification. Five such phases were discovered. Two of them, which occurred before 18 000 and about 14 800–13 900 cal BP, were recorded only in core 70B, the third one, dated to 16 200–15 400 cal BP was reflected only in 63J. We may suggest that at that times only some shore segments were exposed. The two other episodes, dated to about 12 600–12 100 and 7800–7500 cal BP, were found in both cores (Ch5 and Ch7, Tab. 3, Figs 5, 6) and probably corresponded to the most pronounced water level lowerings, causing the exposure of large shore portions around the whole lake. Changes of lake water level could have various causes, but in connection with the other data the increased climatic dryness seems the most likely reason (see discussion in Wasylikowa in press).

As far as the dating of the discussed palaeoecological events is concerned, we are convinced that the use of the information obtained from pollen analysis (our pollen time-stratigraphic markers) to supplement the results of radiocarbon dating appeared very helpfull for obtaining better refined calibrated age-depth curves. This allowed to establish approximate ages of vegetation changes registered in individual sediment cores and to cross-correlate these sequences.

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REFERENCES

BECK J.W., RICHARDS D.A., EDWARDS R.L., SILVERMAN B.W., SMART P.L., DONAHUE D.J., HERERRA-OSTERHELD S., BURR, G.S., CALSOYAS L., JULL A.J.T. & BIDDULPH D. 2001. Extremely large variations of atmospheric ^{14}C concentration during the Last Glacial period. Science, 292: 2453–2458.

HUGHEN K., LEHMAN S., SOUTHON J., OVERPACK J., MARCHAL O., HERRING C. & TURNBULL J. 2004. ^{14}C activity and global carbon cycle changes over the past 50 000 years. Science, 303: 202–207.

HUTCHINSON G.E. & COWGILL U.W. 1963. Chemical examination of a core from Lake Zeribar, Iran. Science, 140: 67–69.

KĘPCZYŃSKI K. & NORYŚKIEWICZ A. 1998. Vegetation of the Gostynińskie Lake District: 29–33. In: Ralska-Jasiewiczowa M., Goslar T., Madeyska T. & Starkel L. (eds) Lake Gościąż, central Poland. A monographic study. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

MEGARD R.O. 1967. Late-Quaternary Cladocera of Lake Zeribar, Western Iran. Ecology, 48: 179–189.

SNYDER J.A., WASYLIK K., FRITZ S.C. & WRIGHT H.E. jr. 2001. Diatom-based conductivity reconstruction and palaeoclimatic interpretation of a 40-ka record from Lake Zeribar, Iran. The Holocene, 11(6): 737–745.

STEVENS L.R., WRIGHT H.E., jr. & ITO E. 2001. Changes in seasonality of climate during the Late-glacial and Holocene at Lake Zeribar, Iran. The Holocene, 11(6): 747–755.

STUIVER M., REIMER P.J., BARD E., BECK J.W., BURR G.S., HUGHEN K.A., KROMER B., MCCORMAC F.G., V. D. PLICHT J. & SPURK M. 1998. INTCAL 98 Radiocarbon Age Calibration, 24 000–0 cal BP. Radiocarbon, 40: 1041–1083.

TURNEY C.S.M., COOPE R.G., HARKNESS D.D., LOWE J.J. & WALKER M.J.C. 2000. Implications for the dating of Wisconsinan (Weichselian) Late-Glacial events of systematic radiocarbon age differences between terrestrial plant macrofossils from a site in SW Ireland. Quaternary Research, 53: 114–121.

WALANUS A. & NALEPKA D. 1999. POLPAL program for counting pollen grains, diagrams plotting and numerical analysis. Acta Palaeobot., Suppl. 2: 659–661.

WASYLIKOWA K. 1967. Late Quaternary plant macrofossils from Lake Zeribar, Western Iran. Rev. Palaeobot. Palynol., 2: 313–318.

WASYLIKOWA K. (in press). Palaeoecology of Lake Zeribar, Iran, in the Pleniglacial, Late Glacial, and Holocene reconstructed from plant macrofossils. The Holocene.

WRIGHT H.E., jr., 1963. Pleistocene glaciation in Kurdistan. Eiszeitalter und Gegenwart, 12: 131–164.

WRIGHT H.E., jr., 1993. Environmental determinism in Near Eastern prehistory. Current Anthropology, 34: 458–469.

WRIGHT H.E., jr. & THORPE J.L. 2003. Climatic change and the origin of agriculture in the Near East: 49–62. In: Mackay A., Battarbee R., Birks J. & Oldfield F. (eds) Global change in the Holocene. Arnold, London.

van ZEIST W. 1967. Late Quaternary vegetation history of western Iran. Rev. Palaeobot. Palynol., 2: 301–311.

van ZEIST W. & BOTTEMA S. 1977. Palynological investigations in Western Iran. Palaeohistoria, 19: 19–85.

van ZEIST W. & BOTTEMA S. 1991. Late Quaternary vegetation of the Near East. Beihefte zum Tübinger Atlas des Vorderen Orients, Reihe A, 18: 1–156.

van ZEIST W. & WRIGHT H.E., jr. 1963. Preliminary pollen studies at Lake Zeribar, Zagros Mountains, Southwestern Iran. Science, 140: 65–67.