

Palaeolimnology of Lake Zeribar, Iran, and its climatic implications

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Abstract

Lake Zeribar sediments covering the time period of the last 25,000 years were examined for the contents of seeds, fruits, Characeae, diatoms, and molluscs. Reconstructions of the variations in the lake water level, salinity, and trophy suggest a sequence of climatic changes. Three pronounced stages of low and varying lake-water level occurred ca. 17,700–15,400, 12,600–12,000, and 10,000–6000 cal yr BP. Some water-level changes were correlated with variations in salinity. The most pronounced increase of salinity occurred 17,700–15,700 and 12,600–12,000 cal yr BP, and less distinct ones occurred about 6400–5900 and 2500 cal yr BP. Diatom assemblages indicated a strong increase of lake trophy ca. 20,200 cal yr BP. Between 6000 and 5000 cal yr BP diatoms characteristic of eutrophy increased in core 63J, and at about 3200 cal yr BP a distinct increase in mesotrophic forms occurred in core 70B. The changes in the occurrence of various organisms indicate increased temperatures about 21,000 cal yr BP, between 15,400 and 12,600, about 12,000, and about 11,700 cal yr BP. The reduced occurrence or disappearance of some of them suggest temperature decreases about 17,700–15,400 and 12,600–12,000 cal yr BP.

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Introduction

The Zagros Mountains belong to the West-Asiatic Fertile Crescent, where the transition from the economy based on hunting–gathering to food production took place at the decline of the last glaciation, giving birth to agriculture, which later spread over the whole of Europe. Climatic conditions during the time of the development and expansion of agriculture were, and still are, much discussed in order to understand better the general interdependence of people's behavior and the natural environment. Lake Zeribar sediments, providing a record of climatic variations more than 40,000 years long, have been the subject of multidisciplinary investigations reported in several publications (among others: pollen analysis by van Zeist and

Wright, 1963; van Zeist and Bottema, 1977, 1991; sediment chemistry by Hutchinson and Cogwill, 1963; Cladocera by Megard, 1967; plant macrofossils by Wasylkowa, 1967, 2005; Wasylkowa and Walanus, 2004; diatoms by Snyder et al., 2001; stable isotopes by Stevens et al., 2001). In the present article the emphasis is put on the role of the sedimentary record of aquatic plant macrophytes, diatoms, and snails as indicators of lake trophy, water depth, salinity, and temperature.

The site

Lake Zeribar is situated in the Zagros Mountains, SW Iran (35° 32'N, 46° 07'E), at an elevation of about 1300 m above sea-level, close to the Iraq border (Fig. 1). The lake is dammed by alluvial fans and has a water depth of 4–5 m, with no regular outlet. Thanks to occasional overflows, occurring mostly in winter, the level of electrolytes is kept low, and the water

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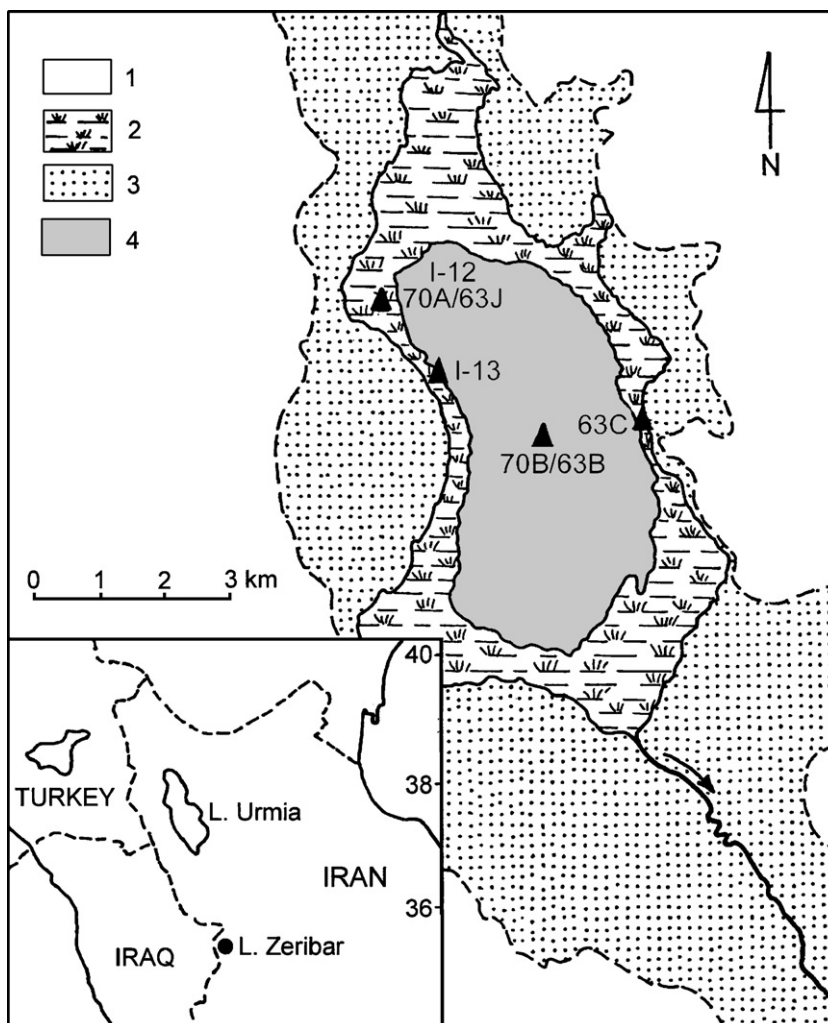


Figure 1. Schematic map of Lake Zeribar. Triangles show coring sites. 1. mountain ridges, 2. mires, 3. alluvial fens, 4. open water (from Wasylikowa and Walanus, 2004).

remains fresh (Löffler, 1961). The lake is about 4.5 km long and 2 km wide and is surrounded by a belt of mire vegetation, partly forming a floating mat (van Zeist and Bottema, 1977). Drier parts of the valley are used for grazing and cereal cultivation. Estimated meteorological data are as follows: annual precipitation ca. 600–800 mm, mean January temperature 2°C, and mean July temperature 28°C (van Zeist and Wright, 1963). The lake freezes over only during very severe winters, and ice cover may last 40–50 days (Löffler, 1961). The hills surrounding the lake are covered with oak scrub. An open oak forest degraded by grazing, constitutes the regional vegetation of the area (van Zeist and Bottema, 1977).

Methods

Cores were taken in 1963 and 1970 by H.E. Wright, Jr. and co-workers with a modified Livingstone piston sampler of 5 cm diameter. Only core 63J from the west shore and 70B from the centre of the lake are discussed in the present paper (Fig. 1). They were analysed for plant macrofossils (K.W.), diatoms (A.W.), and Characeae (A.H.), while pilot samples used for the

examination of molluscs (A.S.W.) came from core 70A, which is a downward continuation of 63J. Each core segment was divided lengthwise into two halves, and one half was used for sampling while the other one was stored. For macrofossil analysis an almost continuous sampling was applied, and Characeae were picked from the same samples as seeds and fruits. Diatom samples were analysed every 20–50 cm. The results are presented in diagrams based on calibrated time scales (A. Wa.) and drawn in the POLPAL program (Walanus and Nalepka, 1999). In plant macrofossil and Characeae diagrams, bars indicate the number of specimens in a constant volume (ca. 100 cm³) (for more details see Wasylikowa, 2005). Diatoms and molluscs are presented as percentages of the total. Sediment signatures follow Troels-Smith (1955).

The age-depth curves

The material dated included eight sediment samples (clay gyttja and calcareous clay gyttja) and four samples of plant macroremains (Wasylikowa, 2005; Wasylikowa and Walanus, 2004). Conventional radiocarbon dates, eight from core 63J and

four from 70B (including one from core 63J, collected from the same site as 70B), were calibrated with the INTCAL98 table (Stuiver et al., 1998). Standard cubic-spline smoothing was applied to obtain continuous calibration curves. In the profile 63J one date based on bulk sediment $11,850 \pm 120$ ^{14}C yr BP (depth 16.10–16.20 m) and one AMS date (*Cladium* fruit) 4010 ± 75 ^{14}C yr BP (6.70–7.00 m) were removed from consideration as obvious outliers. The information provided by pollen diagrams was used as an additional constraint to increase the precision of the age-depth lines (Fig. 2). Nine so called time-stratigraphic pollen markers, showing synchronous changes of regional or local upland vegetation, were selected in pollen diagrams 63J and 70B. They included a few culminations and depressions of pollen curves of *Artemisia* and *Atriplex*-type, peaks of *Quercus* and *Fraxinus*, and the beginning of a continuous curve of *Plantago lanceolata*. The age-depth curves were corrected in such a way that the ages of corresponding markers in cores 63J and 70B were as close to each other as possible (for more explanation see Wasylikowa and Walanus, 2004).

Aquatic and marsh flora of higher plants

The results of plant macrofossil studies were discussed at some length by Wasylikowa (2005; see also Wasylikowa and Walanus, 2004), and a more detailed description is in preparation. In the following text only the main changes of aquatic vegetation are described.

25,500–17,700 cal yr BP

From 25,500 to 21,000 cal yr BP charophytes (mainly *Chara tomentosa*) predominate among the aquatic plants at the west

shore (core 63J, Fig. 3). The other taxa (e.g. *Potamogeton pectinatus*) occur in very small numbers. Between 21,000 and 17,700 cal yr BP, *Ceratophyllum demersum* appears abundantly, and the frequency of *Chara* decreases. *C. demersum* is a relatively warmth-demanding species (Julin and Luther, 1959; Ellenberg et al., 1992), and its occurrence in the sediments of the European Late Glacial is usually considered as an indicator of increased temperature. Approximately at the same time (ca. 19,500–18,400 cal yr BP) in the present-day lake centre (core 70B, Fig. 4) marsh vegetation develops, composed of *Scirpus* cf. *lacustris*, *Typha* sp., and Apiaceae, and *Chenopodium rubrum* is present. Marsh plants indicate shallow water at the mid-lake site, and *C. rubrum* suggests periodic water-level fluctuations. This species belongs to so-called drawdown plants, which expand on water shores after an abrupt lowering of water level (Hejný, 1960; Salisbury, 1970). The replacement of marsh and emerged shore plants by aquatic macrophytes, such as *Potamogeton lucens*, *Lemna* sp., *Hippuris vulgaris*, and *Batrachium* sp., dated to about 18,400 cal yr BP, indicates the increase of lake-water level. The similar difference in the aquatic and marsh flora of the western and middle parts of the lake is reflected in the pollen diagrams (van Zeist and Bottema, 1977).

17,700–15,400 cal yr BP

About 17,700 cal yr BP, *Ceratophyllum demersum* disappears, Characeae predominate, and *Najas marina* appears in small numbers (Fig. 3). About 15,800 cal yr BP *Potamogeton pectinatus* becomes an important constituent of aquatic communities, a halophytic species *Salicornia europaea* appears in the lake (Figs. 3 and 4), and *Chenopodium rubrum* spreads on the lake shore. This phase, which lasted until about 15,400 cal yr BP, is best recorded in core 63J (Fig. 3). The

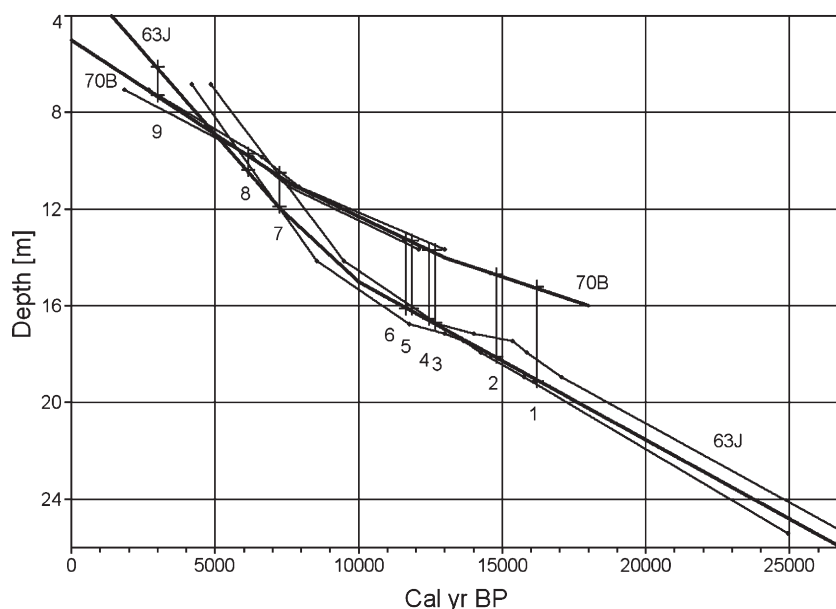


Figure 2. Age-depth curves for cores 63J and 70B from Lake Zeribar (from Wasylikowa and Walanus, 2004). 1–9 pollen time-stratigraphic markers: 1. *Artemisia* uppermost peak in pollen assemblage zone (PAZ) 3b, 2. *Artemisia* first decrease in PAZ 4, 3. *Atriplex*-type uppermost peak in PAZ 4, 4. *Artemisia* uppermost peak in PAZ 4, 5. *Artemisia* decrease in PAZ 5, 6. *Atriplex*-type decrease in PAZ 5, 7. *Fraxinus* peak at top of PAZ 5, 8. *Quercus* peak in PAZ 7a, 9. beginning of continuous curve of *Plantago lanceolata*-type in PAZ 7c. For PAZ see Figure 10.

Zeribar 63J

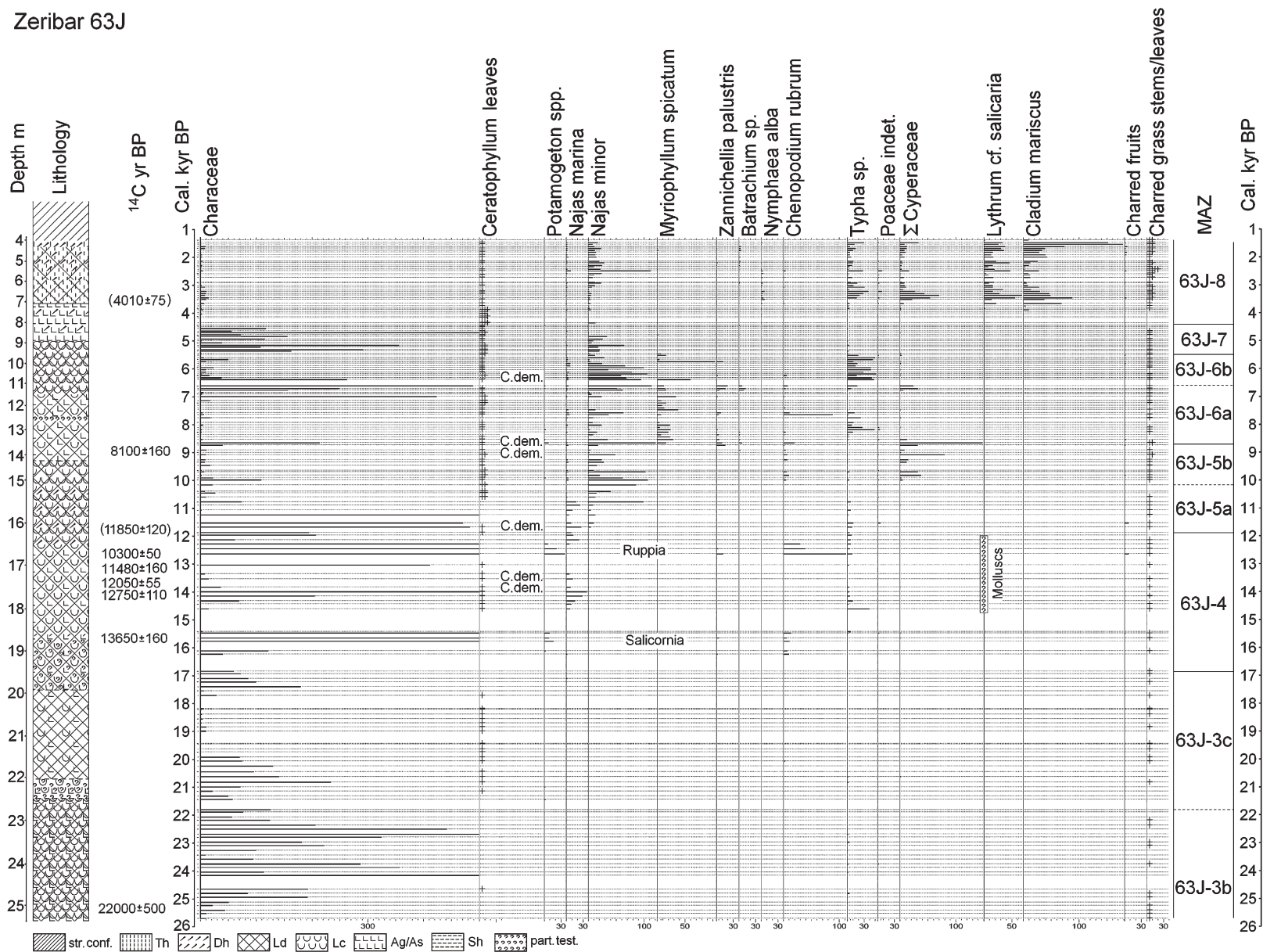


Figure 3. Plant-macrofossil diagram from core 63J, west shore of Lake Zeribar. Selected taxa. *Potamogeton* spp. includes mostly *P. pectinatus*. C. dem.—*Ceratophyllum demersum* fruits, *Ruppia*—*R. maritima* fruits, *Salicornia*—*S. europaea* seeds. MAZ—macrofossil assemblage zones according to Wasylkova (2005). The position of the diagram of molluscs (Fig. 9) is indicated. Sediment symbols simplified from Troels-Smith (1955): str. conf.—disturbed layer, Th—*Turfia herbacea*, Dh—*Detritus herbosus*, Ld—*Limus detrituosus*, Lc—*Limus calcareus*, Ag/As—*Argilla granosa*/*Argilla steatodes*, Sh—*Substantia humosa*, part. test.—mollusc shells.

Zeribar 70B

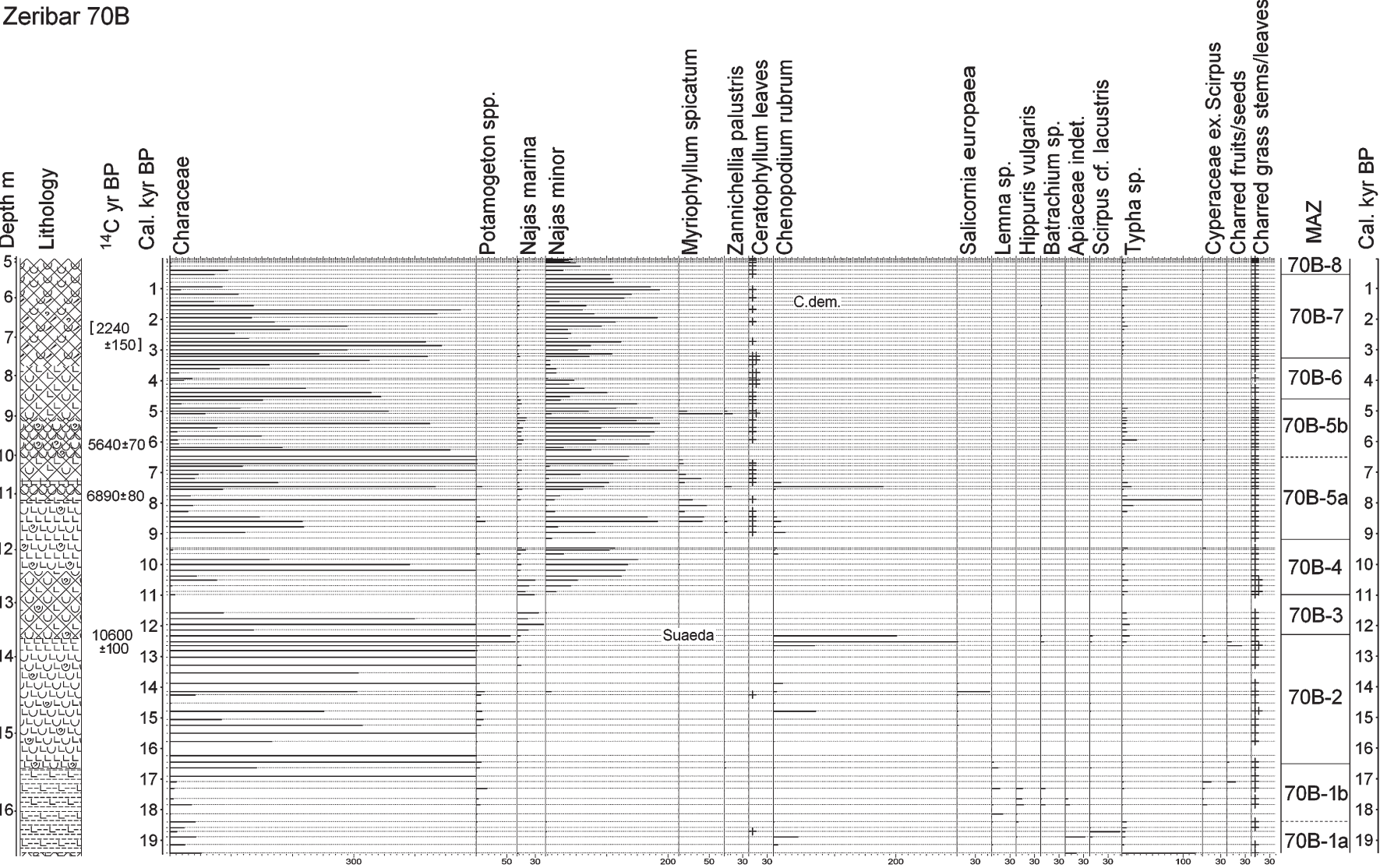


Figure 4. Plant-macrofossil diagram from core 70B, central part of Lake Zeribar. Selected taxa. Suaeda—*Suaeda* sp. seed. For other explanations see Figure 3.

spread of *C. rubrum* indicates seasonal water-level fluctuations, while the spread of *Salicornia europaea* may be connected with increased water salinization. Ecological properties of *P. pectinatus* allow this species to survive both the short-lasting emergence and the rise of salinity (Luther, 1951; Podbielkowski and Tomaszewicz, 1996).

15,400–12,600 cal yr BP

At the west shore *Ceratophyllum demersum* and *Najas marina* replace *Potamogeton pectinatus*, and *Chenopodium rubrum* disappears (Fig. 3). *N. marina* has slightly smaller temperature demands than *C. demersum*, but according to Hejný (1960) it is relatively thermophilous. The spread of these two species may thus indicate a slight temperature increase. The reduction of habitats suitable for *C. rubrum* was probably caused by the more stable lake-water level, favoring the growth of *N. marina*, which, contrary to *Potamogeton pectinatus*, cannot survive even temporary desiccation (Luther, 1951; Podbielkowski and Tomaszewicz, 1996). The continuous occurrence of *Salicornia europaea* (Fig. 4) indicates a certain degree of salinity.

12,600–12,000 cal yr BP

The change of lake vegetation consists of the replacement of *Najas marina* and *Ceratophyllum demersum* by *Potamogeton pectinatus* and Characeae and the appearance of the two new halophytic species *Ruppia maritima* (Fig. 3) and *Suaeda* sp. (Fig. 4). The limitation in the growth of relatively thermophilous aquatics *N. marina* and *C. demersum* suggests a decrease of temperature. The spread of halophytes may result from increased water salinity as a consequence of water-level lowering indicated by frequent occurrence of *Chenopodium rubrum* seeds in both cores.

12,000–8700 cal yr BP

About 11,700 cal yr BP *Najas minor* appears as a new important component of aquatic communities and becomes dominant from ca. 11,000/10,500 cal yr BP. Since that time, in both cores, seeds of this species distinctly predominate over those of *N. marina* and, with minor fluctuations, appear with high frequency and abundance to the top of the profiles (Figs. 3 and 4). This very distinct change in the composition of aquatic macrophytes may reflect an important change in the palaeoecological conditions of the lake. Both *Najas* species are annuals, which reproduce from seeds. They grow in eutrophic, often alkaline waters, at a depth from less than 1 m down to 3–4 m and do not survive complete drying (Luther, 1951; Podbielkowski and Tomaszewicz, 1996). *N. minor* is more warmth-demanding than *N. marina*, and its expansion may indicate particularly warm and long summers because as an annual it is not sensitive to winter temperatures (Bennike et al., 2001). Furthermore, *N. minor* does not tolerate an increased amount of salt (Ellenberg et al., 1992; Bennike et al., 2001). The replacement of *N. marina* by *N. minor* may thus indicate an

increase of temperature and a change from brackish- to fresh-water conditions, or at least a decreased water salinity. This suggestion is in agreement with the conclusions drawn from pollen data, which indicate increased temperature from about 12,000 cal yr BP. The disappearance of *Chenopodium rubrum* seeds about 12,000 cal yr BP may be a sign of the beginning of a period of more or less stable lake-water level. Such a situation lasted until about 10,000 cal yr BP, when this species appeared again, suggesting the onset of an episode of fluctuating water level. This time no indicators of increased salinity were present among aquatic macrophytes.

8700–5500 cal yr BP

The lake vegetation during this time interval differs from that of preceding interval by the spread of *Myriophyllum spicatum* and relatively frequent occurrence of *Zannichellia palustris*, both recorded in profiles 63J and 70B (Figs. 3 and 4). *Najas minor* and *Ceratophyllum demersum* continue their presence at both sites, while Characeae and *N. marina* are more abundant in the central core (Fig. 4). The period dated to ca. 8700–5500 cal yr BP is characterized by the richest vegetation of aquatic plants. At the west shore marsh vegetation with *Typha* sp. and grasses begins to develop (Fig. 3). *Chenopodium rubrum* seeds appear irregularly in both cores until about 6500 cal yr BP, indicating water-level fluctuations particularly well marked about 7800–7500 cal yr BP.

5500–0 cal yr BP

About 5400 cal yr BP in core 63J and 5000 cal yr BP in 70B *Myriophyllum spicatum* loses its significance and never regains it again. At the same time, or soon after that, several other aquatic and mire plants decrease or disappear. The only species that probably was not decimated was *Ceratophyllum demersum*, represented by abundant leaves. This change of aquatic vegetation, which is best seen at the west shore, is associated with an increase of mineral fraction in the sediment (Stevens et al., 2001). About 4000 cal yr BP mire vegetation begins to develop, and about 3500 a marsh belt, similar in species composition to the present-day one, was already well established on the west shore (Fig. 3). In the centre of the lake the decrease in the number of macrofossils of aquatic plants is most conspicuous slightly later, between 4000 and 3200 cal yr BP, and is followed by the new spread of *Najas minor* and Characeae (Fig. 4), while the development of the marsh along the shore is only poorly reflected. The temporary decrease of marsh plants synchronous with an increase of *Najas minor* about 2500 cal yr BP, noticeable in the core from the western sector, indicates that changes of water level occurred until present time.

Diatoms

Counts of diatoms were made by Kazimierz Wasylík (unpubl.). In the present work his counts were verified, the diatom nomenclature was updated, and some problematic taxa

(ca. 20) were identified. The results served as the basis for the diatom diagrams that present a vertical distribution of different ecological diatom groups. The following criteria were used for the diatom groups: habitat, salinity, trophic, and pH. The light microscope (LM) diatom counts were processed with OMNI-DIA v. 3.2 software (Lecointe et al., 1993).

In the entire flora of Lake Zeribar cores only a few species of centric diatoms occur. Included in this group are e.g. *Cyclotella ocellata* Pantocsek (fresh in Figs. 5 and 6) and *Stephanodiscus hantzschii* Grunow (fresh in Figs. 5 and 6), with the former species as the more abundant (up to 40%). Our diatom ecological groups are based on OMNIS data base, and in this data set *C. ocellata* is considered a tychoplanktonic species originating from the periphyton. Therefore our diagrams do not include this species in the plankton group. As a result plankton content in our diatom diagrams, unlike those in Snyder et al. (2001), is very low. The only exception is in core 70B, in which the uppermost sample includes increased plankton content. It should be noted that Wasyluk (1975) in his paper on recent

diatom flora of Lake Zeribar observed *C. ocellata* in the plankton and in the bottom sediments. However, according to his observations a characteristic feature of the phytoplankton of Lake Zeribar was the occurrence of only a few species. The sediments of Lake Zeribar contain the interesting planktonic diatom flora represented by *Chaetoceros* spp. resting spores (brackish in Figs. 5 and 6) typical for saline lakes world wide. The appearance of e.g. *Chaetoceros elmorei* and *Ch. muelleri* is considered as an indicator of saline waters (Fritz et al., 1999). Both taxa occur in the Lake Zeribar sediments, but they were not included in original counts by K. Wasyluk. This feature is now analysed and will be discussed elsewhere (Witkowski et al., in preparation).

25,700–17,700 cal yr BP

The diatom flora of this time interval occurs in core 63J (Fig. 5) and in the lowest part of core 70B (Fig. 6). However, in the latter core the diatom record is incomplete, and diatoms

Zeribar 63J

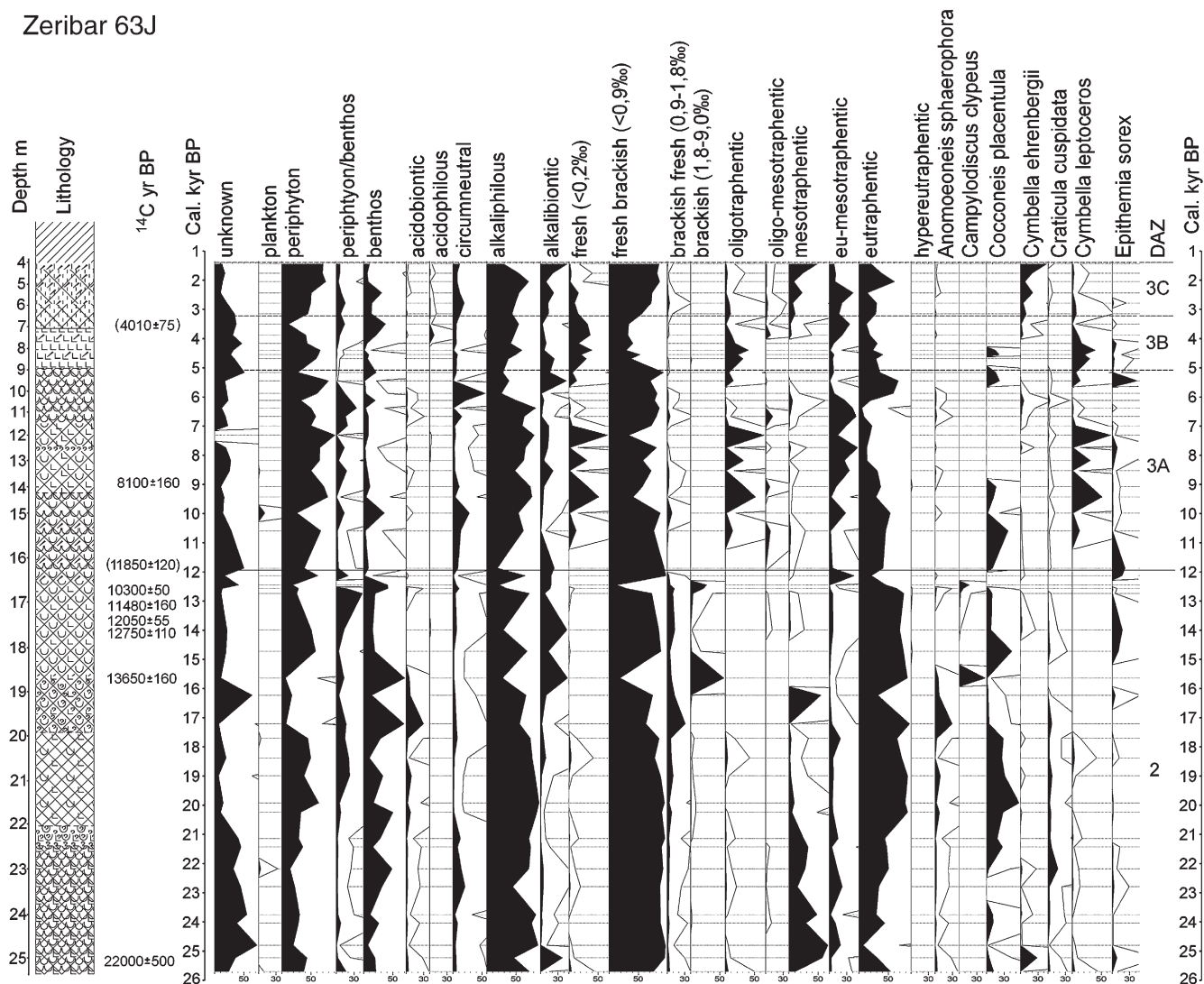


Figure 5. Diatoms from core 63J, west shore of Lake Zeribar. Distribution of diatom ecological groups and selected taxa. DAZ—diatom assemblage zones. For sediment symbols see Figure 3.

Zeribar 70B

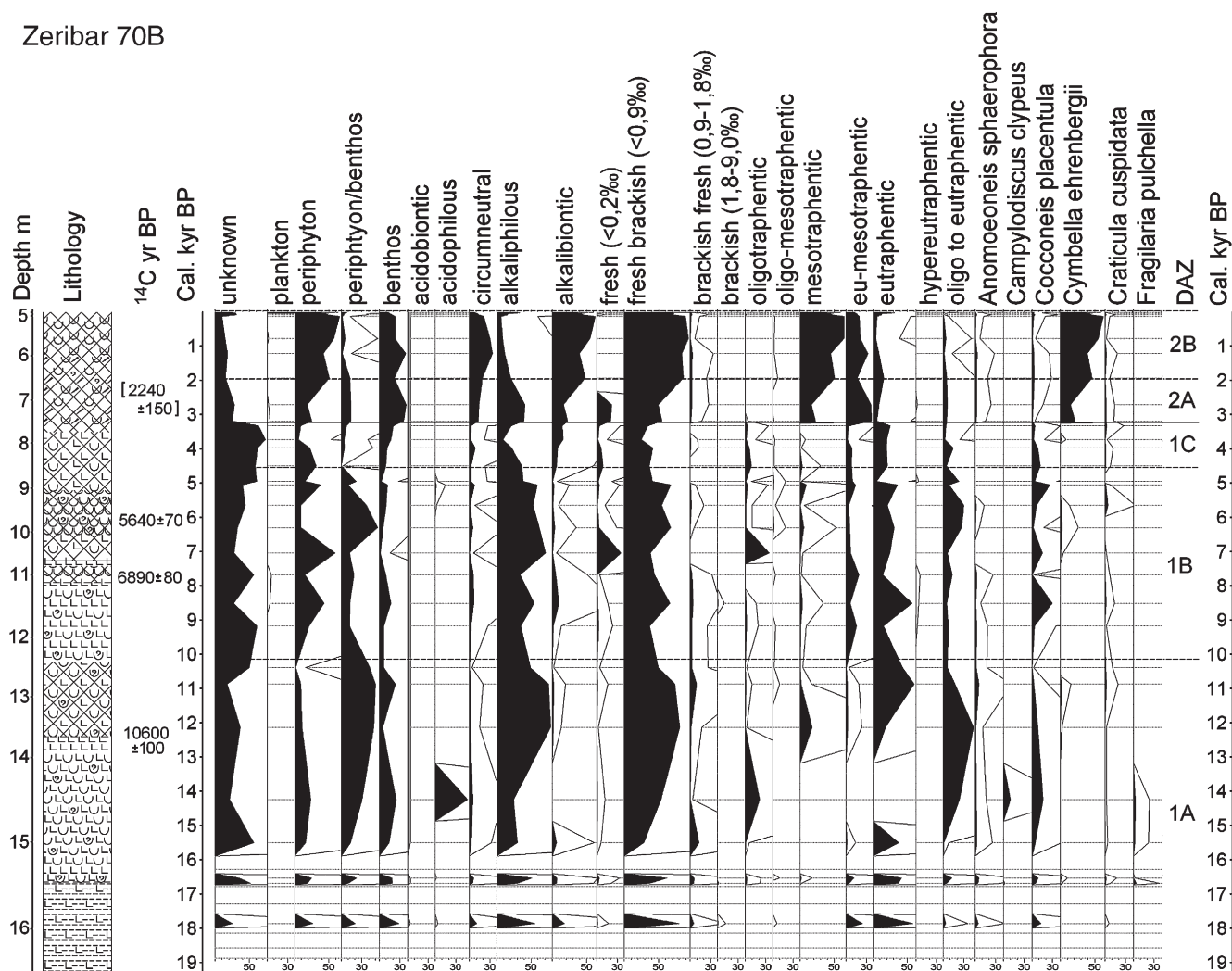


Figure 6. Diatoms from core 70B, central part of Lake Zeribar. Distribution of diatom ecological groups and selected taxa. DAZ—diatom assemblage zones. For sediment symbols see Figure 3.

occurred only in the sample dated to ca. 17,880 cal yr BP. Indistinct fluctuations in diatom ecological groups in core 63J are interpreted as an indication of relatively stable environmental conditions in Lake Zeribar. In both cores studied the diatom flora is strongly dominated by benthic forms. Distribution of diatom ecological groups occurring in these sediments indicates that waters of Lake Zeribar during that period were of very high conductivity. This is indicated by the dominance of halophilous diatoms (fresh brackish in Figs. 5 and 6) and the permanent occurrence of brackish-water taxa (brackish fresh and brackish in Figs. 5 and 6), although the increased contents of brackish-water species were recorded only in core 63J (Fig. 5). In this respect the occurrence of *Anomoeoneis sphaerophora* (brackish in Figs. 5 and 6) in the whole of the sediment profile deposited during that period is remarkable. *A. sphaerophora* is a cosmopolitan species typical for moderate to high conductivity waters, but also abundant in inland saline waters and brackish waters of lagoons located along the Baltic Sea coasts (e.g. Krammer and Lange-Bertalot, 1986; Snoeijs and Vilbaste, 1994). The diatom flora occurring in the sediment of that period shows a distinct bipartition with respect to trophic condition.

Change from sediment characterized predominantly by mesotraphentic forms (in the lowest part of the core) to eutraphentic ones occurred at ca. 20,200 cal yr BP (Fig. 5).

17,700–15,500 cal yr BP

This time interval of the Lake Zeribar history is characterized by pronounced changes in water chemistry. In both cores studied the diatom flora is represented by the highest percentages of brackish-water species. The hitherto occurring *A. sphaerophora* reached its highest relative frequency (in core 63J), and it was associated with *Campylodiscus clypeus* (brackish in Figs. 5 and 6). The latter species occurs in inland waters with high conductivity, inland saline waters, and weakly brackish waters of the Baltic Sea and the North Sea coasts (Krammer and Lange-Bertalot, 1988; Snoeijs, 1993). It is noteworthy that the appearance of a single peak of *C. clypeus* in core 70B is dated to 14,200 cal yr BP, while in core 63J it occurs as a single peak at the limit of this time interval and in a few samples from the following time interval. The distribution of *C. clypeus* and lower frequencies of *A. sphaerophora* in core 70B

(Fig. 6) than in core 63J (Fig. 5) may indicate differences in water chemistry of the lake's central (70B) and coastal parts (core 63J). Apparently the diatom flora of both cores indicates saline waters, but in the coastal area the water conductivity must have been distinctly higher than in the lake centre. One of the factors affecting the water chemistry might have been lowered water level. This interpretation is supported by distinct domination of benthic diatom species. Trophic and pH conditions remained unchanged in comparison to the limit of the preceding time interval.

15,500–10,900 cal yr BP

In core 63J this period is marked by relatively permanent presence of increased percentages of brackish-water forms even despite near disappearance of *A. sphaerophora* (Fig. 5), while in core 70B the contents of brackish-water forms are lower, and *C. chlypeus* occurs as a single peak dated to 14,260 cal yr BP (Fig. 6). The trophic conditions remained unchanged, with strong domination of eutraphentic species. Changes in water chemistry are also marked by two distinct peaks in alkalibiontic species corresponding to the decrease in alkaliphilous ones.

10,900–5000 cal yr BP

The diatom flora of this interval is for the first time characterized by increased contents of fresh-water species (core 63J) and low percentages of brackish-water species in both cores. The last, distinct peak of brackish-water forms (core 63J) is dated to ca. 6000 cal yr BP and is associated with decreasing frequency of fresh-water species (Fig. 5). Frequencies of *A. sphaerophora* are low, and in some samples this species was not recorded at all. A very strong increase in taxa characteristic of eutrophic waters between 6000 and 5000 cal yr BP in core 63J is remarkable.

5500–3900 cal yr BP

This period is marked by the near disappearance of brackish-water forms including *A. sphaerophora* and relatively high contents of fresh-water species and increase of alkalibiontic forms. Its termination is marked in both cores by increase in mesotrophic forms.

3900–0 cal yr BP

Changes in water chemistry result in strong decrease in fresh-water forms and in halophilous and brackish-water species (more pronounced in 70B) and distinct increase in mesotraphentic and alkalibiontic forms (especially in 70B).

Charophyceae

The preliminary results of the analysis of Charophyceae oospores recovered from core 63J demonstrate the presence of abundant specimens belonging to over 10 taxa from the genus *Chara* (not all identified to the species level) and only few

specimens belonging to *Nitellopsis obtusa*, *Nitella flexilis*, and *Nitella* sp. (Fig. 7). The predominance of *Chara* species and the abundance of their oospores indicate that the lake belonged to a harmonious (meso- or eutrophic) lake type with alkaline water.

In core 63J oospores of *Chara tomentosa* dominated in the lower section of the profile, dated to 25,200–21,000 cal yr BP. Large accumulation of oospores of this species in several samples suggests that it developed in a relatively shallow part of the littoral zone. *Chara tomentosa* is a species of wide geographic distribution (Krause, 1997; Ling et al., 2000) and broad ecological amplitude. Optimum water depth for its development is 2–5(6) m, but it may grow in waters from 0.5 to 30 m deep (Hass, 1994; Podbielkowski and Tomaszewicz, 1996), however, in deep waters sexual reproduction is limited (Hirs, 2004). According to Sviridenko (2000) it occurs most often in fresh-water lakes, particularly in large and deep ones. It is also found in shallow and even periodically dry basins (Schmidt et al., 1996). In unpolluted mesotrophic and eutrophic lakes it may form dense phytocoenoses covering 75–100% of the surface. The species prefers alkaline waters with pH 7.2–7.8 (up to 9.2), and it may grow in brackish-waters (Schmidt et al., 1996; Krause, 1997).

About 20,600 cal yr BP in core 63J *Chara globularis*, *C. contraria*, and *C. hispida* appeared, while *C. tomentosa* was still abundant. This change in the flora of charophytes may suggest that water level decreased, because *C. hispida* is an aggregate taxon that grows well in shallow-water reservoirs. It develops in oligo- and mesotrophic waters with pH 7.0–8.4 (optimum at 7.2–8.0) (Hass, 1994; Podbielkowski and Tomaszewicz, 1996; Schmidt et al., 1996). This hypothesis is supported also by the appearance of a greater number of *C. contraria* oospores. *C. contraria* is a cosmopolitan species that occurs outside the tropical zone, mainly in the Northern Hemisphere. It was noted, among others, from Morocco, Egypt (Krause, 1997), and Iraq (Blazencic and Temnisova-Topalova, 1991; Kłosowski et al., 2001). It usually grows in fresh, rarely brackish, waters, alkaline, with pH 7.0–8.0 (8.4), at a depth of a few centimetres down to 7 (or even 30) m (Dąmbska, 1964). However, dense phytocoenoses formed by this species occur most often in shallower places (Dąmbska, 1966). The changes of charophyte flora described above preceded the period dated to ca. 19,700–17,500 cal yr BP, during which charophyte oospores were very rare.

About 17,400 cal yr BP oospores of *Chara globularis*, *C. contraria*, and *C. tomentosa* appeared again more abundantly. The last mentioned species disappeared from the lake about 16,200 cal yr BP, when one oospore of *C. zeylanica* was found for the first time. *C. zeylanica* was recorded also in samples dated at ca. 15,700 and 12,600 cal yr BP. *Chara zeylanica* nowadays grows all over the world in tropical zone (Proctor et al., 1971, cited after Soulié-Märsche, 1999), usually in permanent lakes (Proctor, 1990). In Africa, Asia, and Australia it occurs also in temporary seasonal ponds, but there sexual reproduction is much reduced (Soulié-Märsche, 1999). According to Guerlesquin (1971) its modern range is conditioned by mean summer temperature required for sexual reproduction, which should not fall much below 25°C.

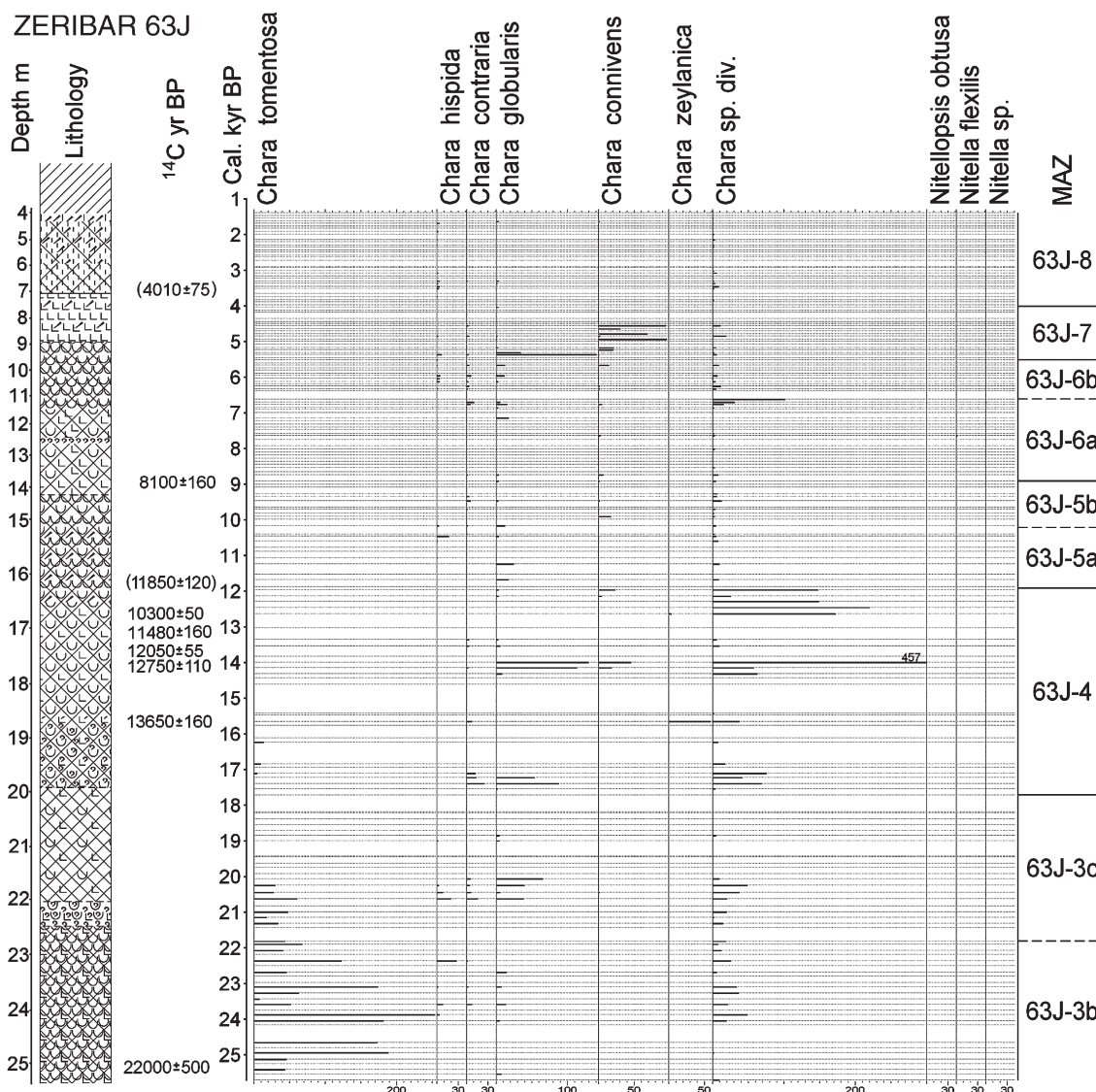


Figure 7. Preliminary diagram of Characeae oospores from core 63J, west shore of Lake Zeribar. Selected taxa. For explanations see Figure 3.

Between ca. 14,300 and 14,000 cal yr BP numerous oospores of *C. globularis* and *C. connivens* were recorded, as well as a few other charophytes that were not identified to the species level. The increased species diversity of charophyte flora was observed also between 12,600 and 12,000 cal yr BP (at least 5 new taxa were encountered). The enrichment of the charophyte flora indicates that the relatively great changes of palaeoecological conditions most probably took place in Lake Zeribar in these periods.

Between 11,200 and 6700 cal yr BP charophyte oospores were infrequent and belonged mainly to *C. globularis*, *C. connivens*, *C. contraria*, and *C. hispida*. A slight increase in their number occurred only about 10,000, 8700, and 7000 cal yr BP.

Numerous oospores were recorded again between 6800 and 6400 and between 5400 and 4600 cal yr BP. In the older of these episodes they belonged to undetermined *Chara* species that were accompanied by *C. contraria* and *C. globularis*. The younger episode was characterized by the dominance of *C. connivens*, which is a thermophilous species, most frequently

encountered in temporary water reservoirs in southern Europe, Morocco, Algeria, Tunisia, and Egypt. It has been observed in temporary ponds also in the Sahara (Krause, 1997).

Molluscs

Numerous shells of molluscs have been collected from Late Glacial calcareous sediments of Lake Zeribar. They were found in sediment core 70A at a depth 16.00–18.73 m, in light- or dark-grey calcareous clay gyttja and lake marl with plant detritus. The fauna consists of seven species represented by 960 specimens. They have been described from the Near East and Arabia, five of them both in recent and subfossil populations, while the remaining one only from Quaternary sediments.

Oxyloma elegans (Risso, 1826)—land snail, which lives in damp meadows and marshes, on edges of rivers and lakes and even on plants growing in water. It is a holarctic species known from central Asia and Europe including the Mediterranean region.

Planorbis planorbis (Linnaeus, 1758)—hard-water snail typical of small shallow and even temporarily dry water bodies with muddy bottom and vegetation, tolerating water salinity up to 4‰. It is a widely distributed holarctic species noted from Europe, southwestern Asia, and northern Africa, forming differentiated populations described as subspecies (Martin, 1968; Brown, 1980). One of them—*Planorbis planorbis antiochianus* Locard, 1883 was reported from late Pleistocene lake sediments of Syria (Kaiser et al., 1973).

Valvata saulcyi (Bourguignat, 1853)—soft water snail inhabiting stagnant and slowly flowing waters, mainly shallow bays of lakes and rivers with muddy or fine sandy bottoms, described from the Near East and Arabia (Tchernov, 1971; Kaiser et al., 1973). In this area it replaces *Valvata piscinalis*, one of the most common European species. After the shape and size of shells *Valvata saulcyi* is quite similar to *Valvata nilotica* Jickeli, 1874, the snail described from several localities in NE Africa as a component of living or subfossil populations (Gardner, 1932; Martin, 1968; Brown, 1980; Alexandrowicz, 1986, 2001). The relation between both species needs special attention and will be studied further.

Bithynia badiella (Küster, 1853)—hard-water snail living in rivers, lakes, and small water bodies between water plants and on sandy or muddy bottoms. It was noted from several localities in the Near East and Arabia, both as a recent and subfossil species (Huckriede and Wiesemann, 1968; Kaiser et al., 1973). In the described material, besides shells, numerous opercula occur in some samples.

Lymnaea stagnalis (Linnaeus, 1785)—a world-wide holarctic species from rivers, lakes, ponds, and artificial basins with rich vegetation and muddy or sandy bottom.

Gyraulus crista (Linnaeus, 1758)—snail connected with water plants, favoring mainly bays of lakes and rivers as well as small but permanent water basins. It is a holarctic species living in Europe south to the border of the Mediterranean, as well as in

northern and central Asia. It was also found in late Pleistocene sediments of the Tibesti Mountains within the Sahara Desert (Böttcher et al., 1972).

Pisidium casertanum (Poli, 1791)—a cosmopolitan species of a bivalve well adapted to different types of water basins, living not only in friendly but also in hard and even in extreme biotopes.

The species mentioned characterize ecological conditions of the lake but not the age of its deposits. Fluctuations of the climate are not distinctly reflected in the differentiation of the fauna and may be estimated only to a very limited degree. Three species as dominant components of the mollusc assemblages are most useful to indicate changes of habitats, namely shallow or even temporary water basin (*Planorbis planorbis*), the muddy bottom (*Valvata saulcyi*), and more or less rich vegetation (*Bithynia badiella*). Subfossil communities enriched in opercula of *Bithynia* were being accumulated between rooted water plants such as reed and bulrush, as was observed in European populations of *Bithynia tentaculata* (Steenberg, 1917; Alexandrowicz, 1999).

Two main types of the mollusc fauna constitute the succession dated approximately to 14,600–11,600 cal yr BP (Fig. 8). They have been distinguished according to the dominance of the indicator species: *Bithynia badiella* (M-1) and *Valvata saulcyi* (M-2). The earlier episode may be additionally divided according to the variable admixture of *Planorbis planorbis* and *Bithynia*-operculum (M-1a–M-1c). Indices of species differentiation (SWI) of each assemblage represented by selected samples were established according to the Shannon–Weaver formula:

M-1a—the first assemblage with hard-water species: *Bithynia badiella* and *Planorbis planorbis* (SWI=1.10);

M-1b—the fauna composed nearly exclusively of *Bithynia badiella* (SWI=0.44);

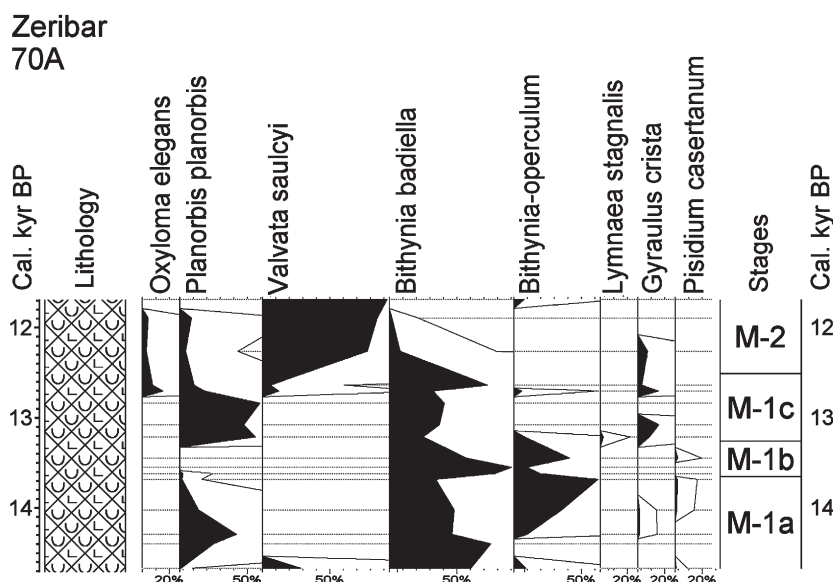


Figure 8. Malacological diagram of Late Pleistocene sediments from core 70A, west shore of Lake Zeribar. M-1a–M-2—assemblages of molluscs described in the text. For correlation with core 63J and sediment symbols see Figure 3.

M-1c—the second assemblage with *Bithynia badiella* and *Planorbis planorbis* (SWI=2.06);

M-2—the fauna dominated by a soft-water snail *Valvata saulcyi* (SWI=0.37).

Changes of the differentiation index (the Shannon–Weaver SWI-index), number of taxa, and dominant components of assemblages reflect living and trophic conditions more or less acceptable to molluscs. The co-occurrence of several species and the value of SWI>1.0 correspond with the mesotrophic water basin, while the fauna composed of one or few taxa with SWI<1 (0.3–0.5) suggests the tendency to nutrient enrichment and eutrophication of the water body.

In the first stage of the described succession the lake was shallow and partly overgrown with water plants (M-1a). The occurrence of *Planorbis planorbis*, as a hard-water species tolerating somewhat higher water salinity, is noteworthy. The impoverishment of the mollusc fauna was presumably connected with the episode of eutrophication (M-1b), but in a short time the fauna becomes richer again and more differentiated, probably due to the amelioration of ecological conditions (M-1c). A considerable content of a species favoring temporary water bodies (*Planorbis planorbis*) as well as symptoms indicating the development of reed or bulrush suggest fluctuations of the shoreline. The occurrence of the holarctic species *Gyraulus crista* may be interpreted as a suggestion of an episodic cooling of the climate.

During the second stage, about 12,300–11,700 cal yr BP, the bottom of the lake was covered with mud, and living conditions became less acceptable for the majority of water molluscs. The domination of *Valvata saulcyi* resembles assemblages that in Central Europe are composed nearly exclusively of *Valvata piscinalis* and occur in the uppermost parts of profiles of lacustrine chalk filling late Pleistocene–early Holocene lakes. Their shells accumulate particularly close to the lower border of the reedswamp belt as a “shell zone” (Schallenzonen—Wasmund, 1926). The admixture of a land snail *Oxyloma elegans* reflects the proximity of the shore. It seems that during this stage Lake Zeribar was gradually filled with sediments enriched in plant detritus.

Discussion

Late Pleistocene 25,700–12,000 cal yr BP

The existence of relatively stable environmental conditions during the time between ca. 25,700 and 21,100 cal yr BP, deduced from smooth curves representing ecological groups of diatoms in core 63J (Fig. 5), is generally confirmed by the little diversified macrophytic flora, which was composed almost entirely of *Chara tomentosa* (Figs. 3, 7). The increase of lake-water trophy about 20,200 cal yr BP, indicated by diatoms, is a little delayed compared to the appearance of *Ceratophyllum demersum* and the decreasing abundance of *Ch. tomentosa* about 21,000 cal yr BP. The change in the charophyte flora (Fig. 7) may be explained by the decreased water level, while the spread of *C. demersum* suggests a slight rise of temperature, which is not reflected in terrestrial plants. According to the

pollen diagram (Fig. 9) a semi-desert vegetation typical for the dry and cold climate was dominant at that time in the Zagros Mountains (van Zeist and Bottema, 1977). *Chenopodium rubrum* seeds found in core 70B (Fig. 4) indicate that water-level fluctuations must have occurred between 19,000 and 18,400 cal yr BP, favoring the spread of this species on exposed lake shores. Intermittent desiccation of the lake shore was probably responsible for poor preservation of diatoms in the lowest section of core 70B. The saline character of the lake is indicated by the presence of halophilous and brackish-water diatoms between ca. 25,700 and 17,700 cal yr BP.

The pronounced increase of lake-water salinity between 17,700 and 15,400 cal yr BP is indicated by high frequencies of brackish-water diatoms, very high reconstructed conductivity (Snyder et al., 2001), and the occurrence of an obligatory halophyte *Salicornia europaea*. Assuming that Lake Zeribar acted as a closed-water basin (Hutchinson and Cogwill, 1963; Wasylukowa, 2005), it is suggested that the increase of salt content was caused by the decrease of water level due to substantial decline of precipitation. The frequent occurrence of *Chenopodium rubrum* indicates an unstable and/or low lake level. The analysis of stable isotopes in core 63J has shown the high $\delta^{18}\text{O}$ values ca. 16,100–15,400 cal yr BP (Stevens et al., 2001), which indicate increased evaporation. The disappearance of *Ceratophyllum demersum* ca. 17,700 cal yr BP was probably caused by the decrease of temperature and an increased salinity. The pollen diagram (Fig. 9) indicates the continued dominance of semi-desert vegetation with *Artemisia* and *Chenopodiaceae* (van Zeist and Bottema, 1977). The appearance of oospores of *Chara zeylanica* in two samples dated to ca. 16,200 and 15,700 cal yr BP (Fig. 7) is somewhat difficult to explain because of the relatively high temperature demands of this species for sexual propagation. Considering the age of this episode Snyder et al. (2001) suggested that it may be correlated with the cold and dry climatic oscillation of Heinrich 1, elsewhere dated to 17,000–15,000 cal yr BP (Bard et al., 2000).

The decrease of brackish-water diatoms about 15,000 cal yr BP and the decline of diatom inferred conductivity ca. 14,600 cal yr BP (Snyder et al., 2001) indicate reduced water salinity. The re-appearance of *Ceratophyllum demersum* and *Najas marina* ca. 14,600–12,600 cal yr BP suggests that there was a warmer oscillation about 15,400–12,600 cal yr BP, recorded in pollen spectra by the decrease of *Artemisia* and a very slight increase of tree pollen curves (Fig. 9). van Zeist and Bottema (1977) suggest that the climate was too dry for oak but that *Pistacia* could start expand slightly in the area. The appearance of *Chara connivens* about 14,300–14,000 cal yr BP is another indicator of increased temperature. The depression of the $\delta^{18}\text{O}$ curve ca. 13,800 cal yr BP may indicate slightly moister climate (Stevens et al., 2001). However, water-level fluctuations occurred seasonally as suggested by the appearance of *Chenopodium rubrum* seeds in the mid-lake core (Fig. 4, 14,800–13,900 cal yr BP) and water salinity is suggested by the low curve of brackish-water diatoms (Fig. 5) and the presence of *Salicornia europaea* (Fig. 4, 15,200–13,900 cal yr BP). The assemblages of molluscs indicates shallow lake water at the west shore with well-developed macrophytic communities. The

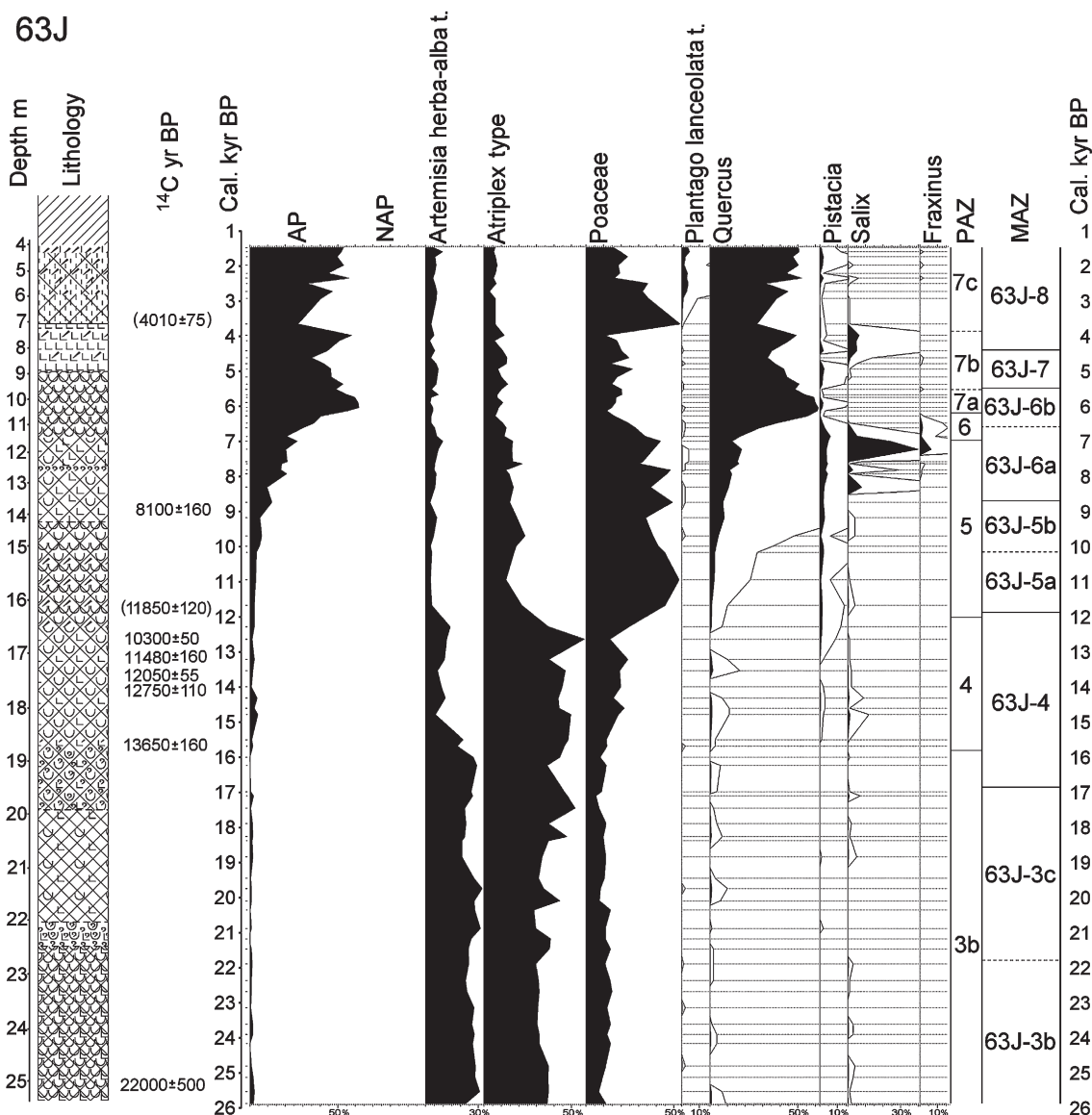


Figure 9. Pollen diagram from core 63J, west shore of Lake Zeribar. Selected curves digitalized from van Zeist and Bottema (1977). PAZ—pollen assemblage zones according to van Zeist and Bottema (1977). For other explanations see Figure 3.

increase of *Bithynia badiella* and the disappearance of other species around 13,500 cal yr BP (stage M-1b) suggest the temporary rise of lake trophy. This episode of milder climate corresponds to the Bølling–Allerød oscillation.

Between 12,600 and 12,000 cal yr BP there appear several indications of a cooler and drier climate. *Ceratophyllum demersum* disappears and *Najas marina* is strongly reduced (Fig. 3). High values of $\delta^{18}\text{O}$ are interpreted as indicators of climatic dryness, which caused low lake-water level and increased salinity (Stevens et al., 2001). Conductivity is very high (Snyder et al., 2001), brackish-water diatoms are present, and show small but distinct culmination (Fig. 5), and halophytic species *Ruppia maritima*, *Salicornia europaea*, and *Suaeda* sp. appear in the lake (Figs. 3 and 4). Seasonally low water levels are documented by the abundant seeds of *Chenopodium rubrum* present in both cores. The occurrence of *Gyraulus crista* in the assemblage of molluscs may suggest the cooling of climate,

while the presence of a land snail *Oxyloma elegans* is in agreement with the reconstructed water-level decrease (Fig. 8). This climatic oscillation, dated here to about 12,600–12,000 cal yr BP, corresponds to the Younger Dryas stadial (Snyder et al., 2001; Stevens et al., 2001; Wright and Thorpe, 2003).

Holocene 12,000–1000 cal yr BP

Changes of the upland vegetation that occurred at the beginning of the Holocene are recorded in the pollen diagram by the decline of *Atriplex*-type and *Artemisia* and the increase of *Poaceae* and tree-pollen curves (Fig. 9). The areas hitherto covered by the semi-desert communities dominated by *Chenopodiaceae* and *Artemisia* were gradually reduced and replaced by communities in which grasses played a more important role and the expansion of trees, mainly *Pistacia*, slowly began. In spite of the improved temperature conditions the development of

woodland was delayed until ca. 7000 cal yr BP, probably due to low effective moisture (van Zeist and Bottema, 1977). Lake vegetation responded to the increased temperature at first, about 12,000 cal yr BP, by the spread of *Najas marina* and *Ceratophyllum demersum* all over the lake and later, about 11,700 cal yr BP, by the appearance of *N. minor*, which soon (ca. 11,000 BP) became the predominant component of aquatic communities (Figs. 3, 4). The spread of *N. minor* could be additionally favored by decreased salinity, which is indicated by the increased frequency of fresh-water diatoms (Figs. 5, 6). More stable water level is suggested by the disappearance of *Chenopodium rubrum*. The decreasing curve of $\delta^{18}\text{O}$ is interpreted as an indication of the increased winter-dominated precipitation (Stevens et al., 2001). This phase of a stable water level ended about 10,000 cal yr BP, and the succeeding period until about 6000–5500 cal yr BP was again characterized by frequent water-level fluctuations, favoring the spread of *C. rubrum* (Figs. 3, 4). Particularly pronounced lowering of lake level occurred about 7800–7500 cal yr BP, creating suitable habitats for *Salix* and *Fraxinus* expansion in the valley (Fig. 9) (van Zeist and Bottema, 1977). Charophyte communities also included species that can grow in shallow water (*Chara globularis*, *C. connivens*, *C. contraria*, and *C. hispida* (Fig. 8). The loss-on-ignition analysis of sediments from core 63J shows an increased content of mineral fraction between ca. 9600 and 6900 cal yr BP, caused probably by increased erosion (Snyder et al., 2001). Drastic variations in the curves for non-combustible fraction, fresh-water diatoms, and the numbers of *C. rubrum* seeds may indicate that this was the time of rapid changes in lake hydrology. There are no indications of the increased water salinity at that time. No halophytes are present among the aquatic macrophytes, brackish-water diatoms are rare, and water conductivity is low (Snyder et al., 2001). Only between 7000 and 6000 cal yr BP the percentages of brackish-water diatoms slightly increase, while those of fresh-water decrease (Fig. 5). It is difficult to present a satisfactory explanation for the decreased lake-levels and increased erosion. The low effective moisture could be the reason, although the absence of increased water-salinity indicators suggests that the occasional lake overflows probably also occurred.

Climate was considered by several authors as a most likely cause of the delayed expansion of trees, and particularly oak, in the Taurus–Zagros Mountains between 11,000 and 6000 cal yr BP (van Zeist and Bottema, 1977; Stevens et al., 2001; Roberts et al., 2001; Wick et al., 2003). Roberts (2002) has paid attention to human activities, which could play some role in the early-Holocene retardation of the expansion of trees. The discovery of charred plant remains in Lake Zeribar sediments brings a new argument to this discussion.

Charred particles of herbaceous plants that were encountered in all sediment cores, in macrofossil samples dated from the Pleniglacial to the present time, indicate that occasional fires, natural or induced by people, occurred somewhere in the area. There were two types of charred remains that might have had different origin. Fairly frequent bigger pieces of stems, including grass culms (up to 15 mm long), and very rare fruits of aquatic plants, such as *Hippuris vulgaris* and *Lemna* sp., could derive

from local marsh vegetation. Small (up to 1 mm long) fragments of awns that probably belonged to grasses could originate from dry-land vegetation or from reed growing in the marsh. These two kinds of charred plants suggest that there could have been at least two different types of burning. In case of marsh or reedswamp vegetation the natural cause of fire seems unlikely. More probably people lighted hearths on the lake shore, and charred particles from abandoned campfires were washed into the lake. This hypothesis assumes that people must have wandered around Lake Zeribar since the Upper Palaeolithic, although it must be admitted that it is not corroborated by archaeological finds from the near region. Another type of burning is indicated by the presence of small awn fragments. If they belonged to grasses growing in the marsh, their origin could be the same as the origin of bigger particles described above. It is interesting, however, that the beginning of continuous appearance of awn fragments in the cores correlates with the increase of grass pollen curve ca. 12,000 BP (Fig. 9), indicating the spread of grass-steppe vegetation at the beginning of the Holocene. The proposed explanation for this coincidence is that patches of grass-steppe were burnt on the surrounding hills and charred awns were transported (by wind and/or water) to the lake. Whether fires were initiated by lightning or by nomadic pastoralists of the Neolithic, exploiting the Zagros highlands for seasonal sheep/goat pasturage (see e.g. Harris, 2002), remains an unresolved problem. As for the Pleistocene, also for the Holocene, there is no evidence of the presence of prehistoric people in the vicinity of Lake Zeribar, but an indirect suggestion may be deduced from the *Plantago lanceolata*-type pollen curve. The continuous curve of this species in the uppermost sections of pollen diagrams (from about 3000 cal yr BP to the present) is considered by van Zeist and Bottema (1977) as evidence of pasturage. Following this interpretation, it is suggested that the increased frequency of *P. lanceolata*-type pollen from about 10,000 cal yr BP (Fig. 9), may indicate the spread of this species in the steppe-like communities due to the disturbance of vegetation by hunters and/or herders with the use of (probably unintentional) fires. In this way the impact of climatic dryness on the spread of woodland could be reinforced by the anthropogenic factor. In this connection it should be noted that the presence of charred fragments of grass epidermis in the early-Holocene sediments of Lake Van was interpreted by Wick et al. (2003) as evidence of natural fires connected with climatic dryness.

The change in diatom flora between 6000 and 5500 cal yr BP (Figs. 5, 6) correlates with higher $\delta^{18}\text{O}$ curve (Stevens et al., 2001), the culmination of *Quercus* pollen curve (Fig. 9) (van Zeist and Bottema, 1977), and the final decrease of *Chenopodium rubrum* frequency among macrofossils (Figs. 3, 4). Almost complete disappearance of brackish-water diatoms (Fig. 5) suggests the existence of fresh-water conditions, which could have been caused by high and stabilized lake level created by wetter climate. The increased spring rains favored the spread of oak, and denser forest cover prevented soil erosion. The input of the mineral fraction to the sediment distinctly decreased. Communities of aquatic macrophytes did not differ much from those of the preceding time.

Between ca. 5500 and 4000 cal yr BP the drastic reduction of aquatic macrophytes can be seen in core 63J (Fig. 3). The increase of the mineral fraction in the sediment (Stevens et al., 2001) suggests that the intensified erosion from the basin could be responsible for the disturbance of aquatic vegetation (Wasylikowa, 2005). Fresh-water diatoms reach high contents (Fig. 5). The pollen diagram shows a decrease of oak pollen curve and an increase of *Salix* about 4500–3800 cal yr BP (Fig. 9). The spread of *Salix* suggests lake-level lowering (Steven et al., 2001), and the poor pollen preservation in the sediment just above this level could result from temporary sediment desiccation (van Zeist and Bottema, 1977). Increased Poaceae pollen curve (Fig. 9) and abundance of macrofossils of several reedswamp plant species (Fig. 3) indicate that ca. 4000 cal yr BP a marsh belt developed around the lake. An increase of aquatic macrophytes recorded in core 63J about 2500 cal yr BP, which correlates with the reduction of marsh plants, reflects an episode of higher lake water level, suggesting that during the last 4000 years variations of water-level occurred irregularly, as effects of precipitation changes, occasional lake overflows and perhaps also human activities reflected by the continuous curve of *Plantago lanceolata*, an indicator species of pasturage (van Zeist and Bottema, 1977).

Conclusions

Lake Zeribar sediments covering the time of the last ca. 25,000 years were examined for the contents of plant macrofossils, diatoms, and mollusc shells. Multiproxy information was obtained about variations in the lake-water level, salinity, and trophic, with some suggestions concerning temperature changes. The results were discussed in the background of regional vegetation changes described by van Zeist and Bottema (1977) on the basis of pollen analysis.

The continuous presence of aquatic macrophytes indicates favorable light conditions during the whole period described in this article, which suggests that the lake was never very deep. It was not possible to estimate exactly the depth of water, which probably did not exceed a few metres, but the reconstruction of water-level fluctuations was attempted from the spread of *Chenopodium rubrum*, a typical drawdown species that expands on exposed lake shores.

The pronounced decrease and frequent fluctuations of water level took place between about 17,700 and 15,400 cal yr BP. The time between 15,400 and 12,600 cal yr BP was characterized by stable (and/or higher) lake-water level. The next stage of low and fluctuating water level occurred from 12,600 to 12,000 cal yr BP and was followed by a period of fairly stable lake level, lasting to ca. 10,000 cal yr BP. Between ca. 10,000 and 6000 cal yr BP, lake level decreased periodically, making possible the spread of *Chenopodium rubrum* swards. Particularly pronounced shallownings took place about 7800–7500 and 4500–3800 cal yr BP. Less significant fluctuations occurred later.

The high frequency of halophilous (fresh brackish group in Figs. 5 and 6) diatoms indicates that the lake had brackish water through most of its history, but a few episodes with increased salinity could be identified. They are correlated to some degree

with variations in lake-water level. The most pronounced increase of salinity is indicated for the periods 17,700–15,400 and 12,600–12,000 cal yr BP (brackish fresh and brackish groups in Figs. 5 and 6), both associated with distinct drops in lake levels. The other fluctuation of salinity are less clearly reflected in the data, for only diatoms indicate slight increases about 6400–5900 and 2500 cal yr BP. No indications of increased salinity were found in the section dated to 10,000–6000 cal yr BP, which is characterized by the frequent episodes of lowered water level. The increase of salt content may be responsible for the rise of the curves of halophilous diatoms ca. 3000 cal yr BP, recorded in cores from the west shore and from the lake centre.

All species of higher plants found in Lake Zeribar sediments can live in eutrophic and alkaline waters. Variations in lake-trophic can be best inferred from changes in diatom assemblages. An increase is indicated at ca. 20,200 cal yr BP, after which trophic conditions remained unchanged until about 12,000 cal yr BP, when the curve of eutraphentic taxa decreased, but only in core 63J. A strong increase of diatoms characteristic for eutrophic waters was observed between 6000 and 5000 cal yr BP, again only in core 63J. About 3200 cal yr BP a distinct increase of mesotraphentic forms occurred especially in core 70B.

Climatic demands of aquatic macrophytes and of a snail *Gyraulus crista* allow some suggestions concerning thermic conditions during the late Pleistocene and the early Holocene. The appearance of relatively thermophilous taxa of water plants indicate the increased temperatures about 21,000 cal yr BP (*Ceratophyllum demersum*, *Lemna* sp.), between 15,400 and 12,600 cal yr BP (*C. demersum* and *Najas marina*), about 12,000 (*C. demersum* and *N. marina*), and about 11,700 cal yr BP (*N. minor*). The reduced occurrence or disappearance of some of them suggest a temperature decrease between 17,700 and 15,400 cal yr BP (disappearance of *C. demersum*) and 12,600–12,000 cal yr BP (*C. demersum* disappears, *N. marina* is strongly reduced, *Gyraulus crista* becomes more frequent).

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References

- Alexandrowicz, S.W., 1986. Holozäne Molluskengemeinschaften von Qasr el-Sagha. Mitteilungen des Deutschen Archäologischen Instituts. Abteilung Kairo 42, 25–34.
- Alexandrowicz, S.W., 1999. *Bithynia tentaculata* (Linnaeus, 1758) as an indicator of age and deposition environment of Quaternary sediments. Folia Malacologica 7 (2), 79–88.
- Alexandrowicz, S.W., 2001. A mollusc thanatocenosis in the Nile River Valley near Wadi Halfa (N Sudan). Folia Malacologica 9 (1), 39–43.
- Bard, E., Rostek, F., Turon, J.-L., Gendreau, S., 2000. Hydrological impact of Heinrich events in the subtropical Northeast Atlantic. Science 289, 1321–1324.

- Bennike, O., Jensen, J.B., Lemke, W., 2001. Late Quaternary records of *Najas* spp. (Najadaceae) from the southwestern Baltic Region. Review of Palaeobotany and Palynology 114, 259–267.
- Blazencic, J., Temnisova-Topalova, D., 1991. Charophyta from Babylon (Republic of Iraq). Kryptogamie, Algologia 12, 289–300.
- Böttcher, U., Ergenzinger, P.J., Jaecel, S.H., Kaiser, K., 1972. Quartäre Seebildungen und ihre Mollusken-Inhalte im Tibesti-Gebirge und seinen Rahmenbereichen der zentralen Sahara. Zeitschrift Geomorphologie 16 (2), 182–234.
- Brown, D.S., 1980. Freshwater Snails of Africa and their Medical Importance. Taylor and Francis Ltd., London.
- Dąbbska, I., 1964. Charophyta-ramienice. In: Starmach, K. (Ed.), Flora Ślaskowodna Polski, Państwowe Wydawnictwo Naukowe, Warszawa.
- Dąbbska, I., 1966. Zbiorowiska ramienic Polski. PTPN, Wyd. Mat.-Przyr. Prace Komisji Biologicznej 31 (3), 1–76.
- Ellenberg, H., Weber, H.E., Düll, R., Wirth, V., Werner, W., Paulissen, D., 1992. Zeigerwerte von Pflanzen in Mitteleuropa. Erich Goltze KG, Göttingen.
- Fritz, S.C., Cumming, B.F., Gasse, F., Laird, K.R., 1999. Diatoms as indicators of hydrologic and climatic change in saline lakes. In: Stoermer, E.F., Smol, J.P. (Eds.), The Diatoms: Applications for Environmental and Earth Sciences. Cambridge Univ. Press, London, pp. 41–72.
- Gardner, E.W., 1932. Some lacustrine Mollusca from the Fayum Depression. Memoires de l'Institut d'Egypte 18, 3–123.
- Guerlesquin, M., 1971. Recherches sur *Chara zeylanica* Klein ex Wild. (Charophycees) d'Afrique occidentale. Revue Algologique, nouvelle serie 10, 231–247.
- Harris, D.R., 2002 (1999). Development of the agro-pastoral economy in the Fertile Crescent during the Pre-Pottery Neolithic period. In: Capper, R.T.J., Bottema, S. (Eds.), The Dawn of Farming in the Near East. Studies in Early Near Eastern Production, Subsistence, and Environment 6, Berlin, Ex Oriente, pp. 67–83.
- Hass, J.N., 1994. First identification key for charophyte oospores from central Europe. European Journal of Phycology 29, 227–235.
- Hejny, S., 1960. Ökologische Charakteristik der Wasser- und Sumpfpflanzen in den Slowakischen Tiefebene (Donau- und Theissgebiet). Verlag der Slowakischen Akademie der Wissenschaften, Bratislava.
- Hirs, E., 2004. Struktura populacji *Chara tomentosa* L. w jeziorach Pojezierza Mazurskiego. Praca doktorska Uniwersytetu Warmińsko-Mazurskiego, Olsztyn (unpubl. doctor dissertation).
- Huckriede, R., Wiesemann, G., 1968. Der jungpleistocäne Pluvial-See von Al Jafr und weitere Daten zum Quartär Jordaniens. Geologica et Palaeontologica 2, 73–95.
- Hutchinson, G.E., Cogwill, U.M., 1963. Chemical examination of a core from Lake Zeribar, Iran. Science 140, 68–70.
- Julin, E., Luther, H., 1959. Om blomning och fruktsättning hos *Ceratophyllum demersum* i Fennoskandien. Botaniska Notiser 112 (3), 321–338.
- Kaiser, K., Kempf, E.K., Leroi-Gourhan, A., Schütt, H., 1973. Quartärstratigraphische Untersuchungen aus dem Damascus Becken und seiner Umgebung. Zeitschrift für Geomorphologie 17 (3), 263–353.
- Kłosowski, S., Szerbowski, J.A., Bartel, R., 2001. Flora in lakes Tharthar, Habbaniya and Razzazah. Archives Polish Fisheries 9 (Suppl. 1), 75–91.
- Krammer, K., Lange-Bertalot, H., 1986. Bacillariophyceae: 1. Teil: Naviculaeae. In: Ettl, H., Gerloff, J., Heynig, H., Mollenhauer, D. (Eds.), Süßwasserflora von Mitteleuropa. 2. G. Fischer, Stuttgart and New York.
- Krammer, K., Lange-Bertalot, H., 1988. Bacillariophyceae: 2. Teil: Bacillariaceae, Epithemiaceae, Surirellaceae. In: Ettl, H., Gerloff, J., Heynig, H., Mollenhauer, D. (Eds.), Süßwasserflora von Mitteleuropa. 2. G. Fischer, Stuttgart and New York.
- Krause, W., 1997. Charales (Charophyceae). In: Ettl, H., Gärtner, G., Hernig, H., Mollenhauer, D. (Eds.), Süßwasserflora von Mitteleuropa. Gustav Fischer, Jena-Stuttgart-Lübeck-Ulm.
- Lecointe, C., Coste, M., Prygiel, J., 1993. "Omnidia": software for taxonomy, calculation of diatom indices and inventories management. Hydrobiologia 269/270, 509–513.
- Ling, Y.-J., Xie, S.-L., Langangen, A., 2000. Charales of China. Nova Hedwigia 71, 69–94.
- Löffler, H., 1961. Beiträge zur Kenntnis der Iranischen Binnengewässer II. International Review of Hydrobiology 46, 309–406.
- Luther, H., 1951. Verbreitung und Ökologie der höheren Wasserpflanzen im Brackwasser der Ekenäs-Gegend in Südfinnland: 2. Spezieller Teil. Acta Botanica Fennica 50, 1–370.
- Martin, F., 1968. Pleistocene molluscs from the Sudanese Nubia. In: Wendorf, F. (Ed.), The Prehistory of Nubia. Southern Methodist Univ. Press, Dallas.
- Megard, R.O., 1967. Late-Quaternary Cladocera of Lake Zeribar, Western Iran. Ecology 48, 179–189.
- Podbielkowski, Z., Tomaszewicz, H., 1996. Zarys hydrobotaniki. Wydawnictwo Naukowe PWN, Warszawa.
- Proctor, V.W., 1990. Characeae of Llano Estacado (Texas and adjacent New Mexico) playas. Journal of Biogeography 17, 75–84.
- Roberts, N., 2002. Did prehistoric landscape management retard the post-glacial spread of woodland in Southwest Asia? Antiquity 76, 1002–10010.
- Roberts, N., Reed, J.M., Leng, J.M., Kuzucuoglu, C., Fontugne, M., Bertaux, J., Woldring, H., Bottema, S., Black, S., Hunt, E., Karabiyikoglu, M., 2001. The tempo of Holocene climatic change in the eastern Mediterranean region: new high-resolution crater-lake sediment data from central Turkey. The Holocene 11, 721–736.
- Salisbury, E., 1970. The pioneer vegetation of exposed muds and its biological features. Philosophical transactions of the Royal Society of London. Series B, Biological Sciences 259 (829), 207–255.
- Schmidt, D., van de Weyer, K., Krause, W., Kies, L., Garniel, A., Geissler, A., Gutowski, A., Samietz, R., Schütz, W., Vahle, H.-Ch., Vöge, M., Wolff, P., Melzer, A., 1996. Rote Liste der Armleuchteralgen (Charophyceae) Deutschlands. Sch.-R. f. Vegetationskunde 28, 547–576.
- Snøeij, P., 1993. Intercalibration and distribution of diatom species in the Baltic Sea. The Baltic Marine Biologist Publication, 1. 16a. Opulus Press, Uppsala.
- Snøeij, P., Vilbaste, S., 1994. Intercalibration and distribution of diatom species in the Baltic Sea. The Baltic Marine Biologist Publication, 2. 16b. Opulus Press, Uppsala.
- Snyder, J.A., Wasylik, K., Fritz, S.C., Wright Jr., H.E., 2001. Diatom-based conductivity reconstruction and palaeoclimatic interpretation of a 40-ka record from Lake Zeribar, Iran. The Holocene 11, 737–745.
- Soulié-Märsche, I., 1999. Extant gyrogonite populations of *Chara zeylanica* and *Chara haitensis*: implications for taxonomy and palaeoecology. Australian Journal of Botany 47, 371–382.
- Steenberg, C.M., 1917. Furesøens molluskenfauna. Kongelige Danske Videnskabs Selskabs Skrifter 8, 78–200.
- Stevens, L.R., Wright Jr., H.E., Ito, E., 2001. Changes in seasonality of climate during the Late-glacial and Holocene at Lake Zeribar, Iran. The Holocene 11, 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. INTCAL98 Radiocarbon age calibration, 24,000–0 cal BP. Radiocarbon 40, 1041–1083.
- Sviridenko, B.F., 2000. Flora and vegetation of reservoirs of North Kazakhstan. Omsk Pedagogical University, Omsk.
- Tchernov, E., 1971. Freshwater molluscs of the Sinai Peninsula. Israel Journal of Zoology 20, 209–211.
- Troels-Smith, J., 1955. Karakterisering af løse jordarter. Danmarks Geologiske Undersøgelse 4/3 (10), 38–73.
- 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 Jr., H.E., 1963. Preliminary pollen studies at Lake Zeribar, Zagros Mountains, Southwestern Iran. Science 140, 65–67.
- Walanus, A., Nalepka, D., 1999. POLPAL program for counting pollen grains, diagrams plotting and numerical analysis. Proceedings 5th EPPC. Acta Palaeobotanica, pp. 659–661 (Supplement 2).
- Wasmund, E., 1926. Biocoenose und Thanatocoenose. Archiv für Hydrobiologie 17, 1–116.
- Wasylik, K., 1975. Notes on the freshwater algae of Iran. Fragmenta Floristica et Geobotanica 21, 369–397.
- Wasylikowa, K., 1967. Late Quaternary plant macrofossils from Lake Zeribar, Western Iran. Review of Palaeobotany and Palynology 2, 313–318.
- Wasylikowa, K., 2005. Paleoeecology of Lake Zeribar, Iran, in the Pleniglacial, Late Glacial, and Holocene reconstructed from plant macrofossils. The Holocene 15, 720–735.

- Wasylikowa, K., Walanus, A., 2004. Timing of aquatic and marsh plant successions in various parts of Lake Zeribar, Iran, during the Late Glacial and Holocene. *Acta Palaeobotanica* 44, 129–140.
- Wick, L., Lemke, G., Sturm, M., 2003. Evidence of Late Glacial and Holocene climatic change and human impact in eastern Anatolia: high-resolution pollen, charcoal, isotopic and geochemical records from the laminated sediments of Lake Van, Turkey. *The Holocene* 13, 665–675.
- Wright Jr., H.E., Thorpe, J.L., 2003. Climatic change and the origin of agriculture in the Near East. In: Mackay, A., Battarbee, R., Birks, J., Oldfield, F. (Eds.), *Global Change in the Holocene*. Arnold, London, pp. 49–62.