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Holocene palaeoecology and human–environmental interactions at the coastal Black Sea Lake Durankulak, northeastern Bulgaria

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ABSTRACT

The environmental changes (vegetation history, human impact and land use, influence of the Black Sea) in the area of Lake Durankulak, northeastern Bulgaria, were reconstructed and synthesized for the last ca. 8000 years. The palaeoecological information derived from various proxies (pollen, plant macrofossils, molluscs, sediments) was compared on a regional scale with the evidence from the nearby coastal lakes Shabla–Ezeretz and Bolata. The Early Holocene xerothermic steppe vegetation, dominated by Chenopodiaceae, *Artemisia* and Poaceae species, and accompanied by stands of trees in moister habitats, was transformed after 6000 cal. BP into a forest-steppe, comprising oak woods with *Carpinus betulus*, *Ulmus*, *Tilia*, *Acer*. This vegetation pattern has been periodically modified, depleted and replaced by arable land or xerothermic herbaceous communities enriched with anthropophytes and ruderals, particularly after the intensification of human activities since 3300 cal. BP. The archaeobotanical evidence from the region has provided valuable information about the occupation phases and subsistence strategy of the local people since the Late Neolithic (5300 cal. BC/7250 cal. BP). Periods with cultivation of cereals (*Triticum*, *Hordeum*) and/or stock-breeding activity were interrupted by abandonment of the settlements and the arable land due to unfavourable environmental changes. The periodical connection/isolation of Lake Durankulak with the Black Sea and the periods of marine influence were recorded by changes in the composition of the fossil molluscan fauna and the lithology of the sediments, and chronologically confirmed by radiocarbon dates. The development of the coastal lakes throughout the largest part of the Holocene has been also considerably influenced by the fluctuations of the Black Sea level.

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1. Introduction

The Holocene vegetation history, human impact and palaeoenvironment of the northern Bulgarian Black Sea coastal area have continuously attracted the interest of researchers during recent decades. Pollen diagrams spanning the last ca. 8000 years were published from the coastal lakes Durankulak (Bozilova and Tonkov, 1985, 1998; Marinova, 2003; Marinova and Atanassova, 2006), Shabla–Ezeretz (Filipova, 1985) and Bolata (Tonkov et al., 2011) (Fig. 1). In broad lines, the earliest palynological evidence derived from Lake Durankulak (Bozilova and Tonkov, 1985) indicated a steppe phase followed by a forest-steppe, characterized by the presence of groups of deciduous trees. In the course of the last millennia, herbaceous communities, secondary in origin, started to dominate in place of the former deciduous oak forests. In addition, marinopalynological investigations from the western sector of the Black Sea (Fig. 1C) complemented the information from the coastal lakes and showed that during the Lateglacial, and until ca. 8000 cal. BP, the vegetation was dominated by steppe elements, *Artemisia* and Chenopodiaceae in particular (Atanassova, 2005; Filipova-Marinova et al., 2013). The woodstands along the northern coastal area were periodically destroyed during phases of human activity after the first prehistoric settlements were founded in the Late Neolithic near the lakes and limans (Todorova, 1995, 2002; Filipova-Marinova, 2007; Yanko-Hombach et al., 2007; Peev, 2009; Tonkov et al., 2011).

Abundant palaeoecological information from various proxies has been collected from the coastal Lake Durankulak. In the course of the years, study was enriched by the application of pollen analysis, micro-charcoal record, determination of plant

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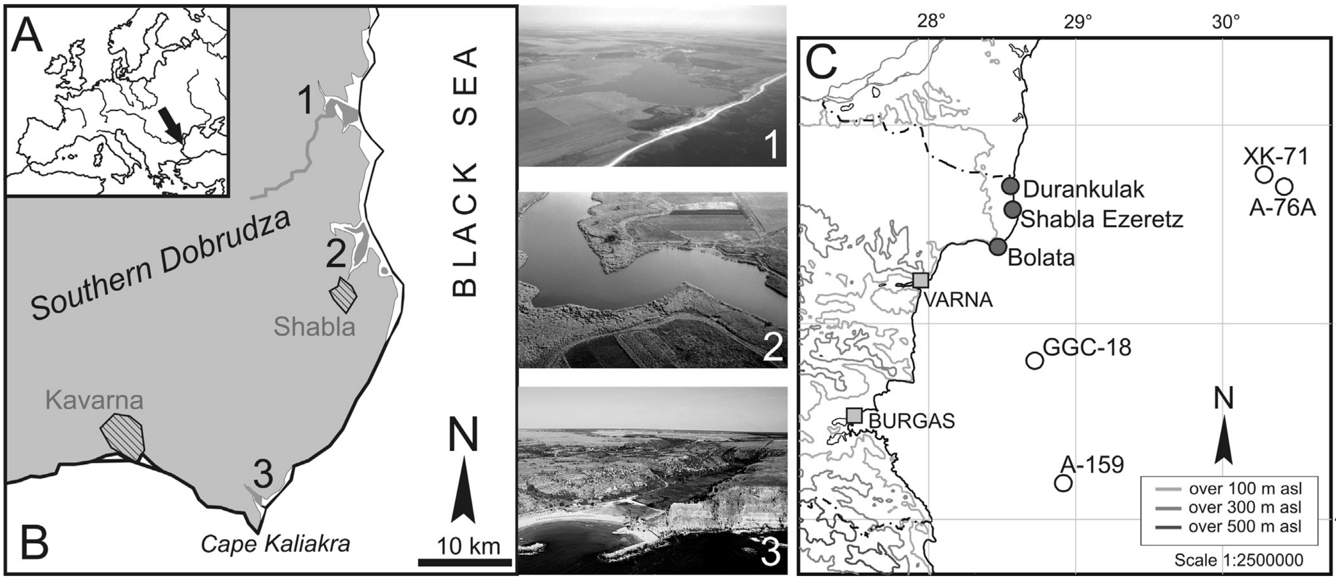

Fig. 1. Study region (1. Lake Durankulak: photo by P. Simeonov, 2. Lake Shabla–Ezeretz: photo by B. Dimitrov, 3. Lake Bolata: photo: http://www.moew.government.bg/cpg/). A. The study area within Europe; B. Location of the pollen cores from coastal lakes in northeastern Bulgaria; C. Bulgarian Black Sea coast and location of coastal lakes (closed circles) and marine pollen cores (open circles) mentioned in the text (XK-71, A-76A, A-159: Atanassova, 2005; GGC-18: Filipova-Marinova et al., 2013).

macroremains and non-pollen palynomorphs, supplemented by radiocarbon dating (Bozilova and Tonkov, 1985, 1998; Marinova, 2003; Marinova and Atanassova, 2006), archaeobotanical finds (Marinova, 2006; Popova, 2009), determination of fossil molluscan (gastropod) fauna (Shopov and Yankova, 1987) and valuable archaeological information since Neolithic time (for most recent overview see Todorova, 2002).

The key location of Lake Durankulak allows detailed tracing of the palaeoenvironmental changes in an area sensitive to climate change and human impact, which has archived the characteristics of the alternation between steppe and forest-steppe, the millennial anthropogenic impact on the surrounding environment and the influence of the Black Sea. The main goal of the paper is to present a reconstruction synthesis of the local and regional vegetation and landscape changes, interactions with the Black Sea and human activity during the largest part of the Holocene, on the basis of the palaeoecological information collected from Lake Durankulak, compared with the available evidence from the nearby coastal lakes Shabla–Ezeretz and Bolata.

2. Study area

Lake Durankulak is the northernmost coastal lake in Southern Dobrudza (Fig. 1) and occupies an area of 3.4 km^2. It is 5.2 km long and 0.2–2 km wide. The lake sediments fill two depressions in Miocene limestone. The maximum water depth reaches 4 m and the lake level is ~40 cm higher than the level of the Black Sea. Two islands exist in the southwestern part of the lake. The larger island has a pear shape, 207 m long and l17 m wide, with an area of 1.8 ha (Fig. 1). The lake is separated from the sea by a sand strip, 100–200 m wide, which is occasionally washed away in stormy weather. The lake is slightly brackish (average salinity is 2‰), oligohalobic and eutrophic, with high pH (8–8.5) (Bozilova and Tonkov, 1998).

The climate in the area is determined by the northeastern continental influence and by the Black Sea. The mean annual precipitation is 440 mm, with 140–170 mm precipitation in late autumn and early winter, while in spring and in summer the rainfall is 100 mm and 125–150 mm, respectively. The thin snow cover is usually blown away by the strong northeasterly winds. The soils around the lake are rich in carbonates and consist of eroded chernozems (Bozilova and Tonkov, 1998).

The southern parts of the Dobrudza phytogeographical region are characterized by the existence of disappearing small fragments of natural forest-steppe vegetation and vast areas of arable land on chernozem soils. Near the coast are remnants of riparian (longoz) forests and terrains occupied by psammophyte, halophyte and hasmophyte vegetation (Bondev, 2002). Around Lake Durankulak, xerothermic herbaceous communities are developed dominated by grasses such as *Chrysopogon gryllus*, *Andropogon ischaemum*, *Agropyrum brandzae* and xerophytes *Artemisia pedemontana*, *Paeonia tenuifolia*, and *Iris pumila*. On the lower terraces and in the ravines near the lake, isolated groups of trees and shrubs are thriving composed of *Ulmus minor*, *Fraxinus excelsior*, *Crataegus monogyna*, *Corylus avellana*, and *Sambucus nigra*. In former times, most of the area with woodstands was cleared for agriculture. The halophytes along the eastern shore of the lake are represented mainly by *Salicornia europaea*, *Limonium gmelinii* and *Aeluropus littoralis* (Bozilova and Tonkov, 1998). South of Lake Durankulak, near the Lake Shabla–Ezeretz and the coast of the Cape Kaliakra area close to the former Lake Bolata, herbaceous steppe and xerothermic assemblages are distributed on a restricted flat limestone territory, dominated by *Agropyron pectiniforme*, *A. brandzae*, *Poa bulbosa*, *Dichantium ischaemum*, *Artemisia pontica*, *Festuca pseudovina*, *Festuca dalmatica*, *Stipa pennata*, *Stipa capillata*, *Adonis vernalis*, *Adonis wolgensis*, and *Jurinea mollis* (Kozuharov et al., 1997; Bondev, 2002; Velchev, 2002).

The steppe vegetation in Dobrudza has been discussed by a number of botanists who had different opinions about its origin. Jordanov (1936) considered the steppe vegetation in northeastern Bulgaria as primary. Stojanov (1941) suggested that the natural vegetation has been forest-steppe, while not excluding the possibility for the existence of primary herbaceous communities.

Based on the palynological evidence, the Holocene vegetation history in the northeastern part of the country revealed that the steppe vegetation was of different origin. Its primary character was confirmed only for a narrow coastal area, particularly around Cape

Kaliakra. After 8000 cal. BP under a forest-steppe phytoclimate, the vegetation was highly modified by anthropogenic impact, its composition being continuously depleted and enriched with ruderals and anthropophytes (Bozilova and Filipova, 1986; Bozilova and Tonkov, 1998; Marinova and Atanassova, 2006; Tonkov et al., 2011).

3. Archaeological background

In Bulgaria the Neolithic period starts at the end of the VIIth millennium BC and continues until ca. 4900 cal. BC (6850 cal. BP), followed by the Eneolithic (or Chalcolithic) period (4900–3800 cal. BC or 6850–5750 cal. BP). The subsequent Bronze Age spans the time interval from ca. 3000 to 1200 cal. BC (4950–3150 cal. BP) (Görsdorf and Boyadziev, 1997).

The human occupation in the coastal area of northeastern Bulgaria commenced during the Late Neolithic (5300–4900 cal. BC or 7250–6850 cal. BP). At Lake Durankulak, a Late Neolithic settlement and an Eneolithic and Bronze Age necropolis were discovered on the southwestern shore (Dimov, 2003) near the places from where cores for pollen analysis were obtained (see Fig. 1 and Table 1 in Marinova and Atanassova, 2006). Some of the Late Eneolithic and Early Bronze Age burials are submerged between the lake shore and the large island. The first inhabitants belonged to the Hamangia culture which existed along the Black Sea coast in Romania and Bulgaria, in the surroundings of the Danube River and the Dobrudza area. On the highest part of the large island, a complex archaeological site dating back to the Early Eneolithic (4750–4450 cal. BC or 6700–6400 cal. BP) was excavated. It comprises cultural layers from the Late Bronze Age (15th–14th centuries BC) and Mediaeval (Proto-Bulgarian) settlements (900–1000 AD), and a Thracian sanctuary (1-st century BC). Evidence for settlement activities on the large island from the end of the Eneolithic to the Early Bronze Age is lacking (Todorova, 2002).

In the course of the first millennium BC, Gethic tribes inhabited the territory of Dobrudza. Subsequently this coastal area was colonized by the Greeks (700–600 BC) and the Romans (45 BC–284 AD). The network of settlements was destroyed in the 6th–7th centuries AD after the devasting invasions of Slavonic, Proto-Bulgarian and Avaric tribes (see references cited in Tonkov et al., 2011).

4. Material and methods

4.1. Pollen data

For local correlation the percentage pollen diagrams from cores Durankulak-2 (N 43°39′52.50″, E 28°31′46.11″) (Bozilova and Tonkov, 1998) and Durankulak-3 (N 43°39′55.89″, E 28°31′41.41″) (Marinova, 2006) were used. For the regional comparison, the pollen datasets from Lake Shabla–Ezeretz (Filipova, 1985) and from Lake Bolata (Tonkov et al., 2011) were added. The original pollen diagrams with the sedimentological characteristics and the levels of radiometric dating are presented as electronic supplementary material (see Figs. 1–6 in ESM). In the synthetic diagram (Fig. 2), selected pollen taxa relevant for the discussion on the vegetation history in the study area and human–environmental interactions were plotted against the age scale using the software TILIA ver. 1.5.17 (Grimm, 2011), considering the interpretation of the radiocarbon dates presented in the above mentioned publications. Each pollen dataset begins with an AP/NAP curve to illustrate the general tendencies of landscape openness in the respective area. All other taxa are graphically presented as histograms. The values for the main arboreal pollen types representing the forests in the area

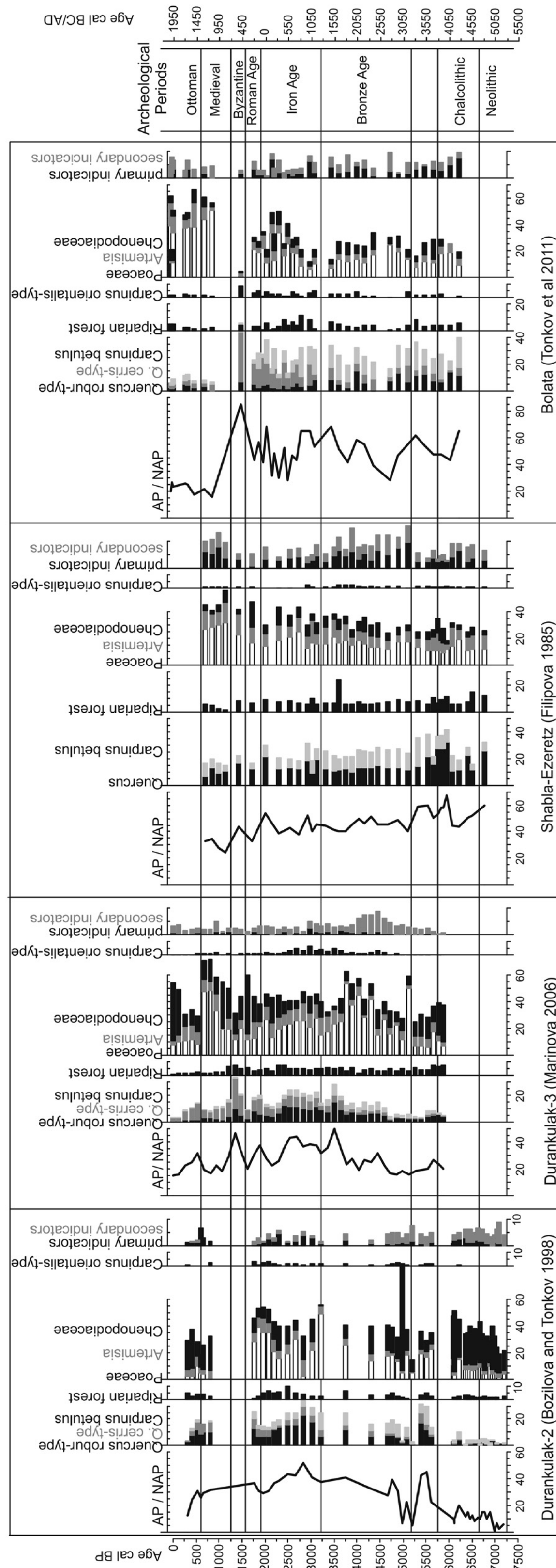

Fig. 2. Correlation of the palynological records from the coastal lakes studied according to their age/depth models.

(*Quercus robur*-type, *Quercus cerris*-type and *Carpinus betulus*) are stacked in order to demonstrate the changes through time of the forest extent. These can be considered with the curve of the riparian forests (longoz) in which all of the potential representatives are included (*Alnus*, *Salix*, *Ulmus*, *F. excelsior*-type, *Hedera*, *Humulus/Cannabis*-type). Comparing this group with the oak woodland could be helpful in estimating the contribution of the alluvial forests to the arboreal component of the vegetation. In regions like the study area, where the dominant vegetation outside the wetlands is steppe and forest-steppe, it appears important to consider the origin of arboreal pollen from local (wetland) or extralocal (forest/steppe) origin. The last arboreal pollen taxon in the dataset is *Carpinus orientalis*-type. Next in the diagrams follow the main steppe components (Poaceae, *Artemisia* and Chenopodiaceae), shown separately. In some cases these taxa also are representative of the local vegetation, such as Chenopodiaceae, originating from the psammophytic communities along the shores, or partly Poaceae originating from the reed formations. The sums of pollen types considered as reliable primary and secondary anthropogenic pollen indicators for the study area (Bozilova and Tonkov, 1990) were stacked. The group of primary anthropogenic indicators included *Triticum*-type, *Hordeum*-type, *Secale*, Cerealia-type, *Juglans*, and *Castanea*. The group of the secondary anthropogenic indicators comprises *Agrostemma githago*-type, *Centaurea cyanus*, *Cirsium*-type, *Plantago lanceolata*, *Plantago major/media*-type, *Polygonum aviculare*-type, *Plantago convolvolus*-type, *Rumex*, *Scleranthus*, *Ranunculus acris*-type, *Convolvolus*, *Malva*-type, *Melampyrum*, *Mercurialis*, and *Urtica*.

4.2. Plant macrofossil remains

From part of the core Durankulak-3, for the period 6000–4300 cal. BP, plant macrofossil evidence was also obtained (Marinova and Atanassova, 2006). This allows a more precise interpretation of the local vegetation development (see Fig. 7 in ESM). This plant macrofossil record indicates continuous presence of open steppe-like vegetation together with representatives of the aquatic and mainly telmatic vegetation. Most of the aquatic macrofossils indicate shallow, meso- to euthrophic water.

Further plant macrofossils comprising fruits and seeds from various wild and cultivated taxa, as well as wood charcoal fragments were recovered from the Late Eneolithic (4450–4200 cal. BC/6400–6150 cal. BP) settlement layers on the large island (Marinova, 2006). The main cultivated plants for the period were emmer (*Triticum dicoccum*) and einkorn (*Triticum monococcum*), followed by free threshing wheat (*Triticum aestivum/durum*) and bitter vetch (*Vicia ervilia*). The finds of free threshing wheat in the study area are represented mainly by single grains and rarely by rachis fragments and occur inland since the Early Neolithic (6100–5900 cal. BC or 8050–7850 cal. BP) (Marinova, 2006). Exceptions from this observation are the storage finds from the Eneolithic period of the Black Sea area, including Durankulak, which also imply more advanced and labour intensive cultivation methods. A diversity of fruits gathered from the surroundings including cornelian cherry and especially different plums was recorded. The seeds of wild-growing plants represent not only the segetal flora, but also ruderal places, open vegetation and wetlands used by the inhabitants of the Late Eneolithic site. The percentage proportions of the wood charcoals (487 fragments extracted from 16 samples) coming from the same site and period are presented on a circle diagram (Fig. 3). It is interesting to note the rather low participation of *Quercus* in the wood directly used by the people at that time. Wood charcoal is dominated by open heliophilous vegetation representatives (*Cornus* sp., *Maloideae*, *Prunus* sp., *Corylus*, etc., in total 35% of the charcoal assemblage) and those most probably coming from the riparian forests (*Fraxinus*, *Ulmus*, *Populus/Salix*, in total 46%).

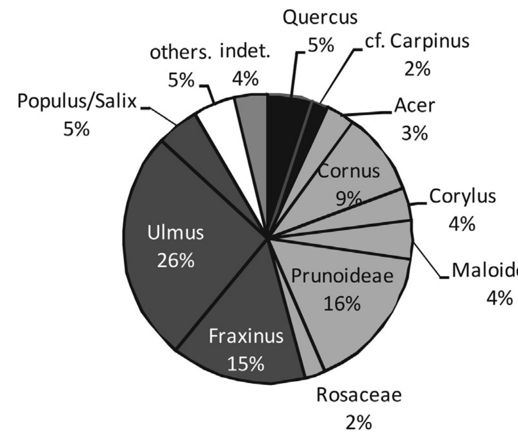

Fig. 3. Percentage proportions of wood charcoal analyzed from the Late Eneolithic layers of the settlement on the large island.

Charred plant macrofossils were also studied from the Late Bronze Age settlement on the large island (Popova, 2009). The study revealed a wide variety of cultivated plants including several cereal crops (*T. dicoccum*, *T. monococcum*, *T.* cf. *spelta*, *T. aestivum*, *Panicum miliaceum*, *Hordeum vulgare*) and also pulses (*Vicia ervilia*). Together with the annual crops, numerous cherry stones (*Prunus avium/cerasus*) suggest the introduction of arboriculture, as also indicated by the palynological evidence. Further fruit remains from *S. nigra* and *Cornus mas* most probably represent gathered plants.

4.3. Fossil molluscan fauna

The content of the fossil molluscan (gastropod) fauna preserved in core Durankulak-2 was analyzed at each 20 cm by Shopov and Yankova (1987) parallel to the samples for pollen analysis. It comprises a wide range of species of diverse ecological groups – terrestrial, freshwater, brackish, to typical marine. The analysis was focused on the freshwater, the terrestrial and the most common semi-freshwater gastropods. Their presence through time was interpreted in connection with the periodical interactions of Lake Durankulak with the Black Sea and the changes in the lithological composition of the lake sediments (see Fig. 8 in ESM).

5. Results and discussion

The chronological parallelisation of the main palaeoecological lines of evidence allows an overview and synthesis (Fig. 4).

5.1. Local vegetation history

The palynological evidence from core Durankulak-2 dates to ca. 7300 cal. BP (Bozilova and Tonkov, 1998). At that time, the vegetation surrounding the lake was extensively dominated by Chenopodiaceae species (possibly from *Atriplex*, *Salsola*, *Chenopodium*, etc.) with various representatives of Asteraceae (*Artemisia*, *Achillea*, *Centaurea*, etc.) and Poaceae. The high participation of chenopods reflects their role in saline coastal habitats. The character of the local vegetation could be described as a xerothermic steppe dominated by herbs (Poaceae, *Artemisia*, Asteraceae, Chenopodiaceae, *Adonis*, Apiaceae) and scattered isolated groups of deciduous trees and shrubs (*Quercus*, *Corylus*, *Carpinus betulus*). The low level of precipitation combined with the first human activities in the

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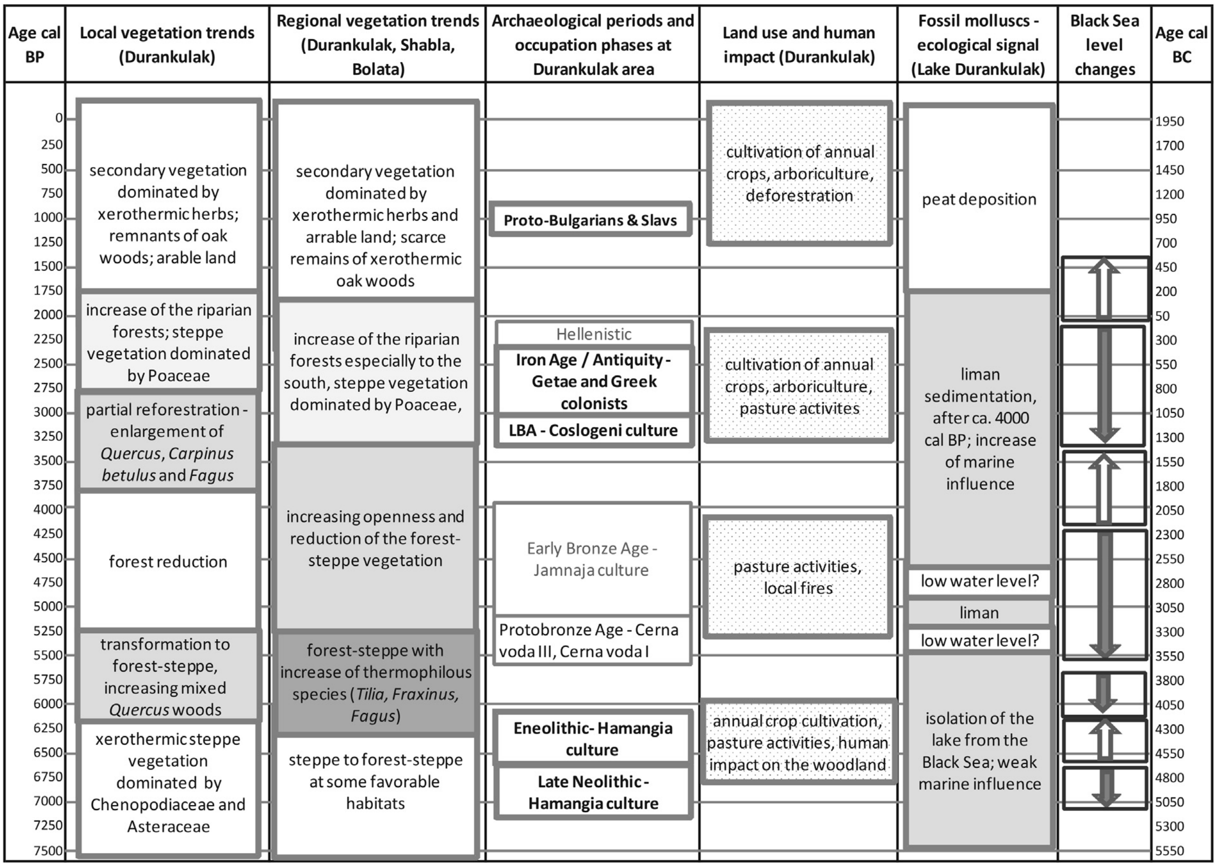

Fig. 4. Correlation scheme of the main tendencies of vegetation development, land use and human impact, ecological signals of fossil molluscs at Lake Durankulak area with the regional vegetation development, archaeological chronology in Dobrudza (Bojadjiev, 1992; Todorova, 2002) and the changes in the Black Sea water level (the occupation phases on the Large Island of Lake Durankulak are marked in bold; the arrows pointing down indicate periods of lower sea levels and those pointing higher sea levels; LBA – Late Bronze Age).

region contributed to further reduction of the woodstands and expansion of the species growing on saline terrains. Along the streams running into the lake and in moister ravines were distributed patches of riparian forests composed of *Alnus*, *Ulmus*, *Fraxinus*, and *Salix*. After ca. 6300 cal. BP during the Mid/Late Eneolithic the primary anthropogenic pollen indicators (Cerealia-type, *Hordeum*-type, *Triticum*-type) increased, together with the secondary indicators, pointing to the development of early human occupation in the study area.

Subsequently, after 6000 cal. BP *Quercus*, *Carpinus betulus* and to a lesser extent the other deciduous trees such as *Ulmus*, *Tilia*, *F. excelsior* started to gain importance. In the course of several centuries the vegetation was gradually transformed into a forest-steppe and the share of Chenopodiaceae and *Artemisia* significantly declined, chiefly in favour of Poaceae. Around 5000–5300 cal. BP a pronounced reduction of the forests was recorded in both pollen profiles, particularly in core Durankulak-2. This short-term expansion of the steppe elements was favoured by increasing drought after the abandonment of the arable land by the local population (Bozilova and Filipova, 1986). Another possible explanation for the interruption of the human occupation could be the rise of the sea level ca. 5300–5100 cal. BP at the end of the period transitional between the Eneolithic and the Bronze Age (Todorova, 2002).

From 4400 cal. BP to 2300 cal. BP the palynological data confirmed a partial reforestation in the study area, mainly due to the spread of *Quercus* (*robur*- and *cerris*-type), followed by *Carpinus betulus* and *Fagus*. The evidence from core Durankulak-3 (Marinova, 2003) pointed to a steady, continuous existence of patches of riparian forests, especially well pronounced around 3000–2000 cal. BP. The herbaceous vegetation continued to occupy large areas on more open places and closer to the seashore, but its composition was dominated by Poaceae species. The plant macrofossils from core Durankulak-3 (*Stipa* sp., *Nesslia panniculata*, *Chenopodium* sp., *Stachys*, etc., see Fig. 7 in ESM) indicated drier conditions. The anthropogenic pollen indicators started to rise, visible in the increase of Cerealia-type, *Triticum*-type, and *Hordeum*-type. Following the age/depth model, this change could be assigned to the Early Bronze Age (Fig. 2). In core Durankulak-3, a peak of the pollen-curve of *Plantago lanceolata* and seeds of *Plantago lanceolata*/*media* occur, indicating pasture activities (Marinova, 2003). In the macrofossil and non-pollen palynomorphs records between 4700 and 4300 cal. BP, a constant presence of eutrophication indicators is visible, which could be related to the human activities in the area (Marinova and Atanassova, 2006).

Since 2000 cal. BP, plant communities highly influenced by humans developed, dominated by herbs, which could be a signal for the widespread of a secondary xerothermic vegetation around the lake, resembling the situation in more recent times. The remnants of oak woods were regularly reduced by the local people and replaced by arable land or xerothermic herbs. This continuous reduction of the arboreal vegetation including the patches of riparian forests is parallel to the increase of the anthropogenic pollen indicators, and hence points to the main driving factor for this deforestation phase.

5.2. Regional vegetation history

The general picture of the vegetation along the Bulgarian Black Sea coastal area during the Holocene before ca. 8000 cal. BP was reconstructed from pollen cores off-shore (Fig. 1C). A steppe phase was dominated by xerothermic and halophilous herbaceous communities composed of *Artemisia*, Chenopodiaceae, Asteraceae and Poaceae species (Atanassova, 2005; Filipova-Marinova, 2007; Filipova-Marinova et al., 2013). During the Holocene climatic optimum, a forest-steppe phase emerged and groups of deciduous trees (*Quercus*, *Corylus*, *Tilia*, *Carpinus betulus*) started to expand in favourable habitats. In the Late Holocene, the herbaceous communities began to dominate, enriched by ruderals and anthropophytes. The comparison in the trends of the Holocene vegetation development between the three lakes in the study region makes possible to follow the changes in the arboreal vegetation through time from north to south (Fig. 2).

For the period 6700–6000 cal. BP in the area of Lake Shabla–Ezeretz (Fig. 1), located 20 km south from Lake Durankulak, the arboreal vegetation was denser and composed mainly of *Quercus* species and *Carpinus betulus* (Filipova, 1985; Filipova-Marinova and Bozilova, 1990) (Fig. 2). The percentage proportions of the xerothermic and halophilous herbaceous communities were lower compared to the situation around Lake Durankulak. The patches of riparian forests had greater extent. The main reason for the wider distribution of arboreal vegetation was the local availability of a larger wetland zone which provided more favourable conditions between 6000 cal. BP and 5300 cal. BP when the forest-steppe communities of *Quercus*, *Carpinus betulus* continued to expand on lower terrains and more thermophilous species such as *Tilia*, *Fraxinus*, and *Fagus* appeared. This is also the time span when *Carpinus orientalis* also arrived in this area. The halophilous communities, composed mainly of *Chenopodiaceae* species, slightly widened their distribution along the coastline because of an increase in the salinity of the soils, most probably due to a rise of the Black Sea level. In sheltered valleys and along the ravines with moister conditions, the riparian forests also increased.

In the course of the next two millennia (5300–3300 cal. BP) the palynological record from Lake Shabla–Ezeretz does not indicate any substantial changes in the composition of the surrounding vegetation. It has steadily retained its forest-steppe character with a tendency of a slight increase for the herb component after ca. 4200 cal. BP. The considerable participation of cereal pollen and the secondary anthropogenic indicators indicates that during the Bronze Age, cultivated areas existed around the lake. Afterwards, part of the cultivated land was probably abandoned and colonized by Chenopodiaceae and *Artemisia* species. Since 3300 cal. BP, human impact can be considered as the major factor that has shaped the character of the vegetation in the study area. Starting with the Iron Age, the increasing human impact led to the present physiognomy of the land cover. The forests in the vicinity of Lake Shabla–Ezeretz were periodically reduced and destroyed like were those in the area of Lake Durankulak. The human interference was intensified in historical times (from 700 AD onwards) as indicated in the pollen record through strong decline of the remnants of tree vegetation, including the riparian forests. As a result herbaceous communities dominated by Poaceae and *Artemisia* species and lesser Chenopodiaceae, enriched with ruderals, regained importance.

The former Lake Bolata is the southernmost site investigated in the study region (Fig. 1). It occupies a unique position in a canyon, at the mouth of a small river running into the Black Sea in the vicinity of the Cape Kaliakra peninsula, where a characteristic xerothermic natural vegetation exists. The lake is separated from the sea by a sand strip 50–80 m wide. Lake sediments (grey mud with sand) started to accumulate ca. 6000 years ago when the rising Black Sea level reached the elevation of the bottom of the depression (−7.5 m) (Tonkov et al., 2011) (see Fig. 4 in ESM). By that time, the forests on the slopes of the canyon consisted of different *Quercus* species with participation of *Acer*, *Carpinus orientalis*, *Fraxinus ornus* and *Tilia*. Riparian forests spread alongside the river composed of *Salix*, *Alnus*, *Ulmus*, *Fraxinus*, and *Carpinus betulus.* Comparable to the area of the lakes Durankulak and Shabla–Ezeretz, the vegetation ca. 6000 cal. BP can be also described as a forest-steppe due to the high share (40%) of non-arboreal pollen. However, the latter could have either originated from places close to the sea, from the local vegetation, from the slopes, or from the plateau. Between 5300 and 3300 cal. BP the fluctuations in the pollen curves of the basic tree taxa indicated partial openness of the forests as in the area of Lake Durankulak, followed by some expansion of the herbaceous communities. At this site, the enlargement of the riparian forests after ca. 3300–3200 cal. BP until ca. 2000 cal. BP is very well pronounced. This result confirmed the conclusion derived from the palynological investigations at the coastal Bulgarian Black Sea area (Bozilova and Beug, 1992) that the recent composition of the riparian (longoz) forests has emerged and was shaped during the last three millennia. Since historical times, the arboreal vegetation in the vicinity of Lake Bolata has been heavily destroyed as in other parts along the northern coast, which has led to the expansion of herbaceous communities dominated by Poaceae species and other xerothermic plants.

5.3. Land use and human impact on the vegetation

There are several lines of evidence which could be considered in order to evaluate the human impact on the vegetation and landscape through time. At the Lake Durankulak area, apart from the continuous palynological record, the archaeobotanical evidence from the archaeological sites for some periods could be taken into consideration (Marinova, 2006; Popova, 2009).

The anthropogenic pollen indicators represented in both pollen diagrams from Lake Durankulak provide information about the agricultural and other land use activities of the local people for particular time-intervals (Fig. 2). In northeastern Bulgaria, the cultivated *Triticum* species were introduced and they appeared as the most reliable indicator of human settlement and arable activity (Bozilova and Beug, 1994). The secondary anthropogenic indicators which are also of importance for this area include plants characteristic of open habitats, most of which expand after deforestation, and with the onset of farming were able to colonize terrains with disturbed soils.

The first phase of human influence could be assigned to the Late Neolithic and the Eneolithic periods (5300–4200 cal. BC/7250–6150 cal. BP), indicated by the regular finds of pollen of *Hordeum*-type, some *Triticum*-type and continuous presence of Cerealia-type, all indicative of agriculture in the study area. The archaeobotanical evidence from the Late Eneolithic settlement layers on the large island indicates a broad inventory of cultivated annual crops and collected fruits typical for the period (Marinova, 2006; Popova, 2009). The relatively high quantity of the secondary anthropogenic indicators, particularly *Plantago lanceolata*, may reflect more intensive cattle and ovicaprid husbandry in the open areas but this is difficult to confirm only by pollen studies. However, indication for this is also visible in the non-pollen-palynomorph evidence (indicators of erosion, animal dung, fire) for that period available from Durankulak-3 (Marinova and Atanassova, 2006). Most likely, because of the open character of the landscape, the riparian forests were the main source for obtaining timber, as visible in the corresponding wood charcoal record from the archaeological site (Fig. 3.). Increasing human impact on the landscape is suggested by the archaeological evidence which indicated that the area has become densely settled. Especially, in the first half of the V-th millennium BC, several new settlements were founded, including those near the coastal lakes (Dimov, 2002, 2003; Todorova, 2002; Slavchev, 2004, 2008). Additional information for human activities is provided by graves and surface finds from Balchik, Bozhurets, St. Konstantin, and from the shore of Lake Varna (Ivanov, 1978; Dimov, 2002, 2003; Slavchev, 2004).

Subsequently, only single finds of *Hordeum*-type ca. 3490 cal. BC/5440 cal. BP and *Triticum*-type ca. 3270–3050 cal. BC/5220–5000 cal. BP were recorded, along with *Plantago lanceolata*, *P. aviculare*, *Rumex*, and *Urtica*. These finds precede the rise in Chenopodiaceae which could reflect abandonment of arable land. The higher values for *Plantago lanceolata*, *Taraxacum*-type, *Cirsium*-type and *P. aviculare* may reflect stock-breeding related to the next phase of human activity for the time interval ca. 3400–2700 cal. BC/5350–4650 cal. BP (the period transitional between the Eneolithic and the Bronze Age) confirmed for the core Durankulak-3 also by the evidence from non-pollen palynomorphs (Marinova and Atanassova, 2006). The direct presence of human activity in the surroundings is indicated by the burial mounds on the shore close to the large island (Todorova, 2002).

The archaeopalynological evidence appears rather scarce for the Early and Middle Bronze Age (3400–1650 cal. BC), when the vegetation had a rather open character. However, the tendency of increasing pasture and dung indicators observed for the previous period became enhanced and reached a peak around 2700–2200 cal. BC. During the Late Bronze Age and the Iron Age after ca. 1300 cal. BC, the increase in *Hordeum*-type and *Triticum*-type, together with *Juglans* and *Castanea*, indicates intensification of the human activities and corroborates the archaeological evidence.

In the area of Lake Durankulak, the phases of human occupation and the activities of the local people since the Late Neolithic were connected with the changes in the surrounding environment. The archaeopalynological record from Lake Shabla–Ezeretz (Filipova, 1985; Filipova-Marinova and Bozilova, 1990) revealed that the phases of human occupation were synchronous with those from Lake Durankulak. In the pollen diagram of Shabla–Ezeretz, a continuous curve for *Cerealia*-type pollen and also more regular finds of *Triticum*-type and *Hordeum*-type pollen occurred, indicative of arable farming for the time interval 5300–4000 cal. BC/7250–5950 cal. BP (Late Neolithic and Eneolithic) when continuous settlements and at least two necropolis (Peev, 2008) existed in the surroundings, marked by a decrease between 3450 and 3100 cal. BC/5400 and 5050 cal. BP (the transition to and during the Early Bronze Age), and further increase ca. 3200–2400 cal. BC/4950–4350 cal. BP. The last well-pronounced phase of human occupation started at ca. 700 AD.

In the course of the last 6000 years, the vegetation of the area around the former Lake Bolata can be described as a forest-steppe due to existence of deciduous *Quercus* communities with *Acer*, *Carpinus orientalis*, *Fraxinus ornus*, *Fagus* and *Tilia* on the slopes of the river valley. The archaeological evidence is still incomplete, the existing remains of prehistoric settlements in the canyon are still not excavated, and this imposes difficulties in correlating the limited archaeopalynological record. It was suggested that the oldest occupation phase, documented by peaks in the anthropogenic indicators, had existed ca. 4200–4050 cal. BC/6150–6000 cal. BP, coincident with the Eneolithic human occupation. Subsequently, between 3620 and 3220 cal. BC/5570 and 5170 cal. BP, *Triticum*-type pollen occurs and indicates cereal cultivation near the site in a period corresponding to the Early Bronze Age in the region. The next phase of continuously occurring Cerealia-type pollen is related to the time span 1500 BC–120 AD. The upper part of the pollen core indicates continuous human impact younger than ca. 400 cal. BP (Tonkov et al., 2011).

5.4. Black Sea–coastal lakes interactions

The development of the lakes along the Bulgarian Black Sea coast during the Holocene was influenced also by the fluctuations of the sea level. The analysis of the composition of the fossil molluscan (gastropod) fauna in the sediments of Lake Durankulak provided some evidence for the periodic connections of the lake with the sea (Shopov and Yankova, 1987) (see Fig. 8 in ESM). The application of an age–depth model for core Durankulak-2 made it possible to define more precisely the duration of the changes in the local hydrological regime through time as recorded by the fossil molluscan assemblages, and hence, the deposition of different types of sediments. The first stage of sedimentation (D_1) between 7300 and 5500 cal. BP (600–440 cm) was characterized by the dominance of freshwater (*Valvata cristata*, *Armiger crista*, *Planorbis carinatus*, etc.) and terrestrial gastropods, indicating a stable isolation of the lake from the sea, with occasional weak marine influence as documented by the presence of *Hydrobia ventrosa*, *Cardium edule*, and *Theodoxus palasii*. This stage ended with deposition of clay with indeterminable molluscan detritus, plant remains, single ostracods, and disintegrated rock particles (440–420 cm), pointing to a catastrophical event (5500–5300 cal. BP) when probably most of the basin was dry. Afterwards, the composition of the fossil fauna dominated by *Mytilus lineatus*, *H. ventrosa* and *Cardium edule* suggests a short period (D_2) of liman sedimentation (5300–4900 cal. BP) with constant, though weak connection of the lake with the sea, which ended with deposition of molluscan detritus at ca. 4900–4700 cal. BP. The next stage in liman sedimentation (D_3) continued for 3000 years (4700–1750 cal. BP) in the conditions of an increasing marine influence, particularly after ca. 4000 cal. BP, indicated by the finding of eurohaline gastropods (*H. ventrosa*, *Rissoa splendida*, *Cardium edule*) and typical Black Sea species *Cingulopsis valvatioides*, *Loripes lacteus*, and *Retusa truncalata*. The deposition of *Phragmites* peat in the lake started after 1750 cal. BP when the connection with the sea again became periodic.

It is reasonable to compare the changes in the composition of the molluscan fauna from Lake Durankulak with the general tendencies in the fluctuations of the Black Sea level during the Holocene. According to the review paper of Marinova-Filipova (2007), sea-level changes during the Holocene have been delimited by analyzing terrace complexes along the seashore, locating marine phases that denote sea-lake oscillations, and comparing them with available radiocarbon dates. The constructed paleoeustatic curve of sea-level fluctuations during the last 11,000 years represents a suggestion only; tectonic factors, landslides, erosion, and some differences in the dating make absolute precision impossible. Following this curve, several important transgression/regression phases could be outlined. A steady rise of the sea level began after 7650 cal. BP. until ca. 7000 cal. BP when sandy deposits with typical molluscan fauna of *Mytilus galloprovincialis* and *H. ventrosa* were found, together with *Mytilaster lineatus*, *Corbula maeotica* and *Cardium edule*. The composition and the considerably more widespread occurrence of this assemblage, compared to the others, reflects conditions of an expanding transgression and salinization of the sea in the mid-Holocene, which eventually brought about the final disappearance of Caspian species as the euryhaline marine species rose to dominance. Most probably, this was a result of the influx of Mediterranean waters (Wall and Dale, 1974; Chepalyga, 2002; Ryan et al., 1997, 2003).

For the period 7000–5500 cal. BP, sea-level was rather unstable, experiencing two distinct lowerings at 7000–6500 and 6000–5500 cal. BP, separated by a steep rise from 6500 to 6000 cal. BP. These fluctuations are in accordance with the slight changes in the composition of the fossil molluscan fauna at Lake Durankulak, as for most of this period the lake remained isolated from the sea. With a generally rising sea level during the mid-Holocene, relative falls can also be observed at 6800 cal. BP in Lake Shabla–Ezeretz (Filipova, 1985) and at Lake Varna, where between 4.3 and 5 m in depth a cultural layer dated at 6190 cal. BP was found (Bozilova and Beug, 1994). Along the southern Bulgarian coast, the evidence also confirmed this lowering of the water level as settlements of the Late Eneolithic existed at the sea side at a depth of several meters north of Cape Atia, in the harbors of Sozopol and Kiten (Draganov, 1995; Lazarov, 1996; Todorova, 2002; Filipova-Marinova and Bozilova, 2003; Filipova-Marinova et al., 2011). A series of radiocarbon dates from these sites between 6400 and 6287 cal. BP (4840–4370 cal. BC) are in conformity with the radiocarbon chronology for Bulgarian prehistory (Görsdorf and Boyadziev, 1997).

The rise in sea level after ca. 6500 cal. BP was particularly sharp, and an enlargement of the coastal lakes probably took place. In support for this suggestion is the Eneolithic burial place around Lake Durankulak, where some of the graves are today under water (Todorova, 2002). The present estuarine bay of Varna–Beloslav was turned into a large embayment of the sea, reaching the mouth of the incoming rivers. Fragments of a marine terrace with some fossils survived at an elevation of 5 m close to the town of Beloslav indicating that at the beginning and end of the transgression the natural reservoir was considerably fresher, with an abundance of *Theodoxus pallasi* and *Dreissena polymorpha*. During the transgression, maximum halophilous and thermophilous Mediterranean molluscan species such as *Ostrea edulis* and *M. lineatus* invaded the basin (Krastev et al., 1990).

The catastrophic event at Lake Durankulak ca. 5500–5300 cal. BP when molluscan detritus was deposited and probably large parts of the basin were dry, concides with the observed lower level of the Black Sea at that time (Filipova-Marinova et al., 2011). A relatively low and stable sea level for the period 5500–4200 cal. BP, combined with an increasing drought (Bozilova and Filipova, 1986), had caused not only the isolation of the lakes from the sea, but also lowering of their water level as shown by the example of Lake Durankulak where a peat layer with molluscan detritus (4900–4700 cal. BP) was deposited and diatoms were absent (Bozilova and Tonkov, 1998).

Similarly dry conditions were detected for the period 4720–3990 cal. BP in the northern Black Sea area (Kremenetskiy et al., 1999) and the archaeological remains excavated provided also evidence for a lowering of sea level during that period. Human activity along the western Black Sea coast resumed during the Early Bronze Age and some settlements developed above remains of Late Eneolithic settlements (Sozopol and Varna) while others arose in new locations (Atia, Ropotamo, Kiten, and Akhtopol). According to Kuniholm et al. (1998), a combination of sea-level change and tectonic subsidence is thought to explain why apparent habitation sites are now 5–10 m under water. The next rise in sea level is shown by both the abandonment of the prehistoric Early Bronze Age settlements and the considerable presence of cysts of the typical association of the euryhaline dinoflagellate *Lingulodinium machaerophorum* and the acritarch *Cymathiosphaera globulosa* in marine sediments after 3840 cal. BP. This steep rise in sea level for the period 4200–3500 cal. BP (Filipova-Marinova et al., 2011) is marked by the deposition of peat with molluscan detritus in the coastal lakes as shown at Lake Durankulak. Marine deposits with dated shells of *O. edulis* (3840–3350 cal. BP) can be observed south of Cape Shabla on an abrasion terrace 4 m high as well as in cross-sections through the estuaries of several rivers running into the Black Sea (Krastev et al., 1990).

The subsequent low level of the Black Sea until 1950 cal. BP may have been a result of lower rates of freshwater inflow during the Fanagorian Regression from 3200 to 2300 cal. BP (Chepalyga, 2002). A marked lowering of the water level in the coastal lakes and the accumulation of a thick peat layer also occurred. From this period as well, submerged ancient settlements are found, everywhere at a depth of 4–6 m, with remnants of harbor basins at depths of 8–12 m (Lazarov, 1975).

High precipitation levels in Europe generally coincided with the Nymphaean Transgression which started in the 1st century AD, and maximum sea-level was attained in the late 7th–early 8th century AD (Shilick, 1997). Ports and ancient towns along the coast were flooded. The archaeological evidence suggests higher rainfall and comparatively moist conditions in Europe between 1950 and 1300 cal. BP (Bouzek, 1983; Hay et al., 1991).

6. Conclusions

The analysis and synthesis of the palaeoecological information from Lake Durankulak spanning the last ca. 8000 years, compared with the available data from other coastal lakes in southern Dobrudza region (northeastern Bulgaria), has revealed in detail the basic stages in vegetation and palaeoecological changes, history of human occupation and impact on the environment, and the influence of the Black Sea. The main results from this study can be outlined as follows:

1. The xerothermic steppe vegetation prevailing on large areas during the early Holocene, and dominated by Chenopodiaceae, *Artemisia* and Poacae species, was gradually transformed after 6000 cal. BP into a forest-steppe, comprising oak woods with *Carpinus betulus*, *Ulmus*, *Tilia*, and *Acer*. Patches of riparian forests with *Salix*, *Alnus*, and *F. excelsior* developed in moister ravines and along the rivers running into the Black Sea.
2. The intensification of human activities since 3300 cal. BP can be considered as the primary factor for the periodical destruction and reduction of the oak woodland. Finally, the human impact led to replacement of the forests by arable land or xerothermic herbaceous communities enriched with anthropophytes and ruderals.
3. The evidence of the anthropogenic impact on the vegetation derived from pollen studies and archaeobotanical finds allowed a detailed reconstruction of the occupation phases and subsistence strategies of the local population since the Late Neolithic (5300 cal. BC/7250 cal. BP). Distinct periods of intensive cultivation of cereals (at ca. 5300–4200 cal. BC/7250–6150 cal. BP, 1300–250 cal. BC/3250–2200 cal. BP) and stock-breeding activities (2700–2250 cal. BC/4650–4200 cal. BP) were interrupted by abandonment of the settlements and the arable land caused by increasing drier/colder environmental conditions or sea level changes in the study region.
4. The development of the coastal lakes and their surroundings during the Holocene has been also influenced by the fluctuations in the water level of the Black Sea. In particular, the time interval 7700–5500 cal. BP was characterized by a rather unstable sea level with alternating steep rises and falls.
5. The periodic connection/isolation of Lake Durankulak with the Black Sea and the periods of marine influence were confirmed by the changes in the composition of the fossil molluscan fauna and the lithology of the sediments. The other coastal lakes had also experienced similar changes in their hydrological regime with certain variations as a result of the local environmental characteristics.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.quaint.2013.12.004

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