Quaternary International 465 (2018) 22–36

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Detailed reconstructions of Holocene climate and environmental changes in the Taman Peninsula (Kuban River delta region) and their correlation with rapid sea-level fluctuations of the Black Sea

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A R T I C L E I N F O

Article history:
Received 1 April 2016
Received in revised form
3 August 2017
Accepted 4 August 2017
Available online 23 August 2017

Keywords:
Middle and Late Holocene
NE Black Sea region
Palynological records
^{14}C dating
Climatic and environmental changes
Sea-level fluctuations

A B S T R A C T

The paper presents results of a detailed subdivision of Holocene sediments in the region of the Kuban River delta into climate-stratigraphic units and reconstructions of the vegetation, climate and depositional environment changes on the Taman Peninsula (NE Black Sea region) during the last 7400 years. The reconstructions are based on data from geological-geomorphological and lithological-facies analysis, palynological studies and radiocarbon dating of six sections penetrated by boreholes in various parts of the Kuban River delta. The studied lithological sequences present an assortment of *liman*, fluvial, lacustrine and marsh sediments, as well as subaerial deposits that accumulated in the course of the delta development.

The factual materials thus obtained provided the basis for reconstructing changes in zonal vegetation types and transformations of zonal and intra-zonal formations in the Holocene landscapes of the Taman Peninsula, induced by changes in edaphic conditions and regional climate. Seventeen phases (stages) have been recognized in the evolution of vegetation and climate through the Middle and Late Holocene, and a detailed description is given to every phase. A detailed pollen-climate-chronostratigraphic scheme of the Black Sea level fluctuations over the last 7400 years is proposed.

Steppe and forest-steppe landscapes were dominant on the Taman Peninsula over the greater part of the studied period of the Holocene. The warmest and most arid conditions were typical of the phases dominated by steppes with grass, herb and grass, and pigweed-wormwood (Chenopodiaceae-*Artemisia*) plant communities. Such phases were dated to intervals ~4660–4400, 3780–3430, 2910–2280, 1540–1230 and 900–830/730 cal yr BP. The most humid intervals within the studied period are dated at ~5160–4900, 4400–3780, 2280–1540 cal yr BP. They were distinct because of the dominance of broadleaf (mostly beech-oak-hornbeam) forests. Those humid intervals most likely correspond to the maxima of the Kalamitian, Dzemetinian, and Nimphaean Black Sea transgressions.

The climatic indexes and zonal attribution of the dominant plant communities can be matched with six transgressive and seven regressive sea level fluctuations of various ranks over the last 7400 years. Of the six transgressive stages, one stage was marked by a relatively cool and humid climate, whereas five others occurred under warm and wet conditions. The regressive stages include four phases of relatively warm and dry climate and three periods of dry and relatively cold (or cool) climate.

1. Introduction

The history of the seas bordering the East European Plain to the south has been the subject of thorough investigations for many decades, the specialists' attention having been concentrated both

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http://dx.doi.org/10.1016/j.quaint.2017.08.013
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on the sea coasts and on the water bodies themselves. In the process, abundant information has been collected, including geological, geomorphological, paleontological (mostly on malacofauna), geo-archeological and historical data, complemented with archival materials and radiocarbon dating. The information obtained formed the basis of numerous regional and inter-regional paleogeographic schemes (e.g. Fedorov and Skiba, 1960; Nevessky, 1970; Varuschenko et al., 1980, 1987; Balabanov and Izmailov, 1988). The authors of various schemes often disagree on a number of points, such as the hypsometric position of ancient coastlines, as well as chronological boundaries, amplitude and hierarchical order of the sea level fluctuations (transgressive and regressive) at the transition from the late glacial to post-glacial and through to the modern interglacial epoch. A constructive analysis of various recently developed schemes, together with new or revised curves of sea level fluctuations in the Azov-Black Sea and the Caspian Sea basins during the Holocene, is presented in a number of recently published papers (e.g. Chepalyga, 2002; Balabanov, 2007, 2009; Konikov et al., 2007; Kroonenberg and Hoogendoorn, 2008; Martin and Yanko-Hombach, 2011; Svitoch, 2011, 2012).

Palynological studies of Holocene sequences within the limits of the marine paleo-basins contribute significantly to the understanding of vegetation, climate and sea level history. Until recently (the last 15–20 years), there were only a small number of known Holocene sections in the south of the East European Plain that were studied palynologically and dated by radiocarbon. Quite a few of them were situated close to the coasts of the Caspian Sea, Black Sea and the Sea of Azov, and these provided information needed for a detailed climatic-stratigraphic subdivision of the sequences, permitting reconstructions of detailed vegetation and environmental changes, and potential relationships with climate-controlled sea level fluctuations (Bolikhovskaya, 1990; Bolikhovskaya et al., 1989, 2001; Lavrushin et al., 1991; Spiridonova, 1991; Gerasimenko, 1995, 1997; Kremenetski, 1991; Kremenetski et al., 1999).

The lack or insufficient amount of radiocarbon dates hampered a proper interpretation of many of the palynological records available for some terrestrial Holocene sequences, including those obtained by sea bottom drilling in the Black, Caspian and Azov seas. For example, the results of pollen analysis of the bottom sediments sampled in the Black and Azov seas (Vronsky, 1976, 1984; Isagulova, 1978) as well as of those from the eastern Azov Sea off the Kuban River delta and from the shallow lakes (*liman*) of the coastal plain (Chebanov et al., 1992; Mishchenko, 2002) were interpreted rather schematically. The authors gave only general characteristics of the four main stages in the evolution of the vegetation and climate of the coastal lands, namely the ancient, Early, Middle and Late Holocene. Similarly, the lack or insufficient coverage of absolute dating has hindered development of comprehensive climatic and environmental reconstructions based on palynological studies of the Holocene Caspian sediments. Even so, pollen analysis of bottom sediments from the Caspian Sea, together with data obtained from lacustrine, fluvial and subaerial deposits in the Caspian lowland, provided sufficient information for reconstructing plant communities and climatic parameters of the coastal regions. These include records for the Mangyshlak (Early Holocene) regression, the New Caspian (Novocaspian) maximum transgression (the late Atlantic period of the Middle Holocene) and several phases during the Late Holocene (Abramova, 1971, 1974, 1980, 1985; Vronsky, 1980, 1987). Mathematical methods applied to palynological data allowed quantitative estimates of paleoclimatic parameters to be obtained, including mean annual rainfall, annual temperatures and those of July and January (Abramova and Turmanina, 1988; Bukreeva and Vronsky, 1995).

The recent decade is notable for a sizeable volume of new data on the paleovegetation (based on pollen assemblages) and absolute geochronology of the Holocene obtained from semiarid (i.e. steppe) regions of the northeast coastal regions of the Black and Azov Seas (Bolikhovskaya et al., 2004, 2014a, b; Cordova and Lehman, 2005; Sapelko and Subetto, 2007; Cordova et al., 2011a, b; Krasnorutskaya and Novenko, 2011; Matishov et al., 2011, 2012, 2013; Shumilovskikh et al., 2012; Dyuzhova, 2013). Comparable data are now available from the arid (i.e. desert and semi-desert) regions to the northwest and northeast of the Caspian Sea (Bolikhovskaya, 2011a, 2011b; Bolikhovskaya and Kasimov, 2008, 2010a, b; Richards and Bolikhovskaya, 2010; Richards et al., 2014, 2017) and from offshore (e.g. Leroy et al., 2007, 2013; Leroy, 2010).

This paper presents the main results of a detailed vegetation and climatic-stratigraphic subdivision of Holocene deposits studied at the Kuban River delta (Taman Peninsula, NE Black Sea region). The sequences were minutely subdivided based on data from lithology and facies studies, palynological analysis and radiocarbon dating, performed on the sections considered to be most informative paleogeographically. The work permitted reconstructions of zonal and intra-zonal plant formations in the Holocene landscapes on the Taman Peninsula and vegetation changes that are attributable to variations in edaphic conditions and climate. Data obtained gave us an insight into regional climate patterns in the recent interglacial epoch and elucidated their impact on environmental and topographic conditions on the Black Sea coasts. These data provided the basis for a palyno-climatic-chronostratigraphic scheme and to assess the relationship with climate-controlled fluctuations of Black Sea level over the last ca. 7400 years. The studied cores are of Middle to Late Holocene age and therefore post-date the reconnection of the Black Sea with the Mediterranean Sea around 7500 years ago (Aksu et al., 2002; Marret et al., 2009; Yanko, 1990; Yanko-Hombach, 2007; Filipova-Marinova, 2007; Filipova-Marinova et al., 2013).

The results of our previous studies in the region (Bolikhovskaya et al., 2002, 2004) focused on changes in vegetation, climate and sea level fluctuations within the period of ca. 7000–1000 years BP. Unfortunately, we could not develop a comprehensive scheme of paleoclimatic changes for the last 2500 years because of insufficient geochronological data and an incompleteness of the Late Holocene sections under study. Recently obtained pollen records and absolute dates have now made it possible to consider the evolution of climate and environments throughout the Holocene in more detail, and to define more precisely chronological boundaries of identified stages. The new reconstructions will be instrumental in permitting easier and more accurate correlations between vegetation, landscape and paleoclimatic events recorded in the NE Black Sea region and those in the lower Volga and Akhtuba region of the NW Caspian Lowland (Bolikhovskaya, 2011a, 2011b; Bolikhovskaya and Kasimov, 2010a,b; Richards et al., 2014) (Fig. 1). The new data also offer a clearer view on the significance of climate-controlled fluctuations of the adjacent sea level. The integrated analysis of paleoclimatic events in the maritime regions of the semiarid (e.g. lower Kuban River region) and arid (e.g. lower Volga River region) zones is of great significance in the development and validation of paleogeographic forecasts of future environmental changes in the coastal regions in the south of the East European Plain induced by climate change.

2. The study area, material and methods

2.1. The Kuban River delta and Taman Peninsula modern environments

2.1.1. Geomorphology

The Kuban River has its source close to Mount Elbrus in the

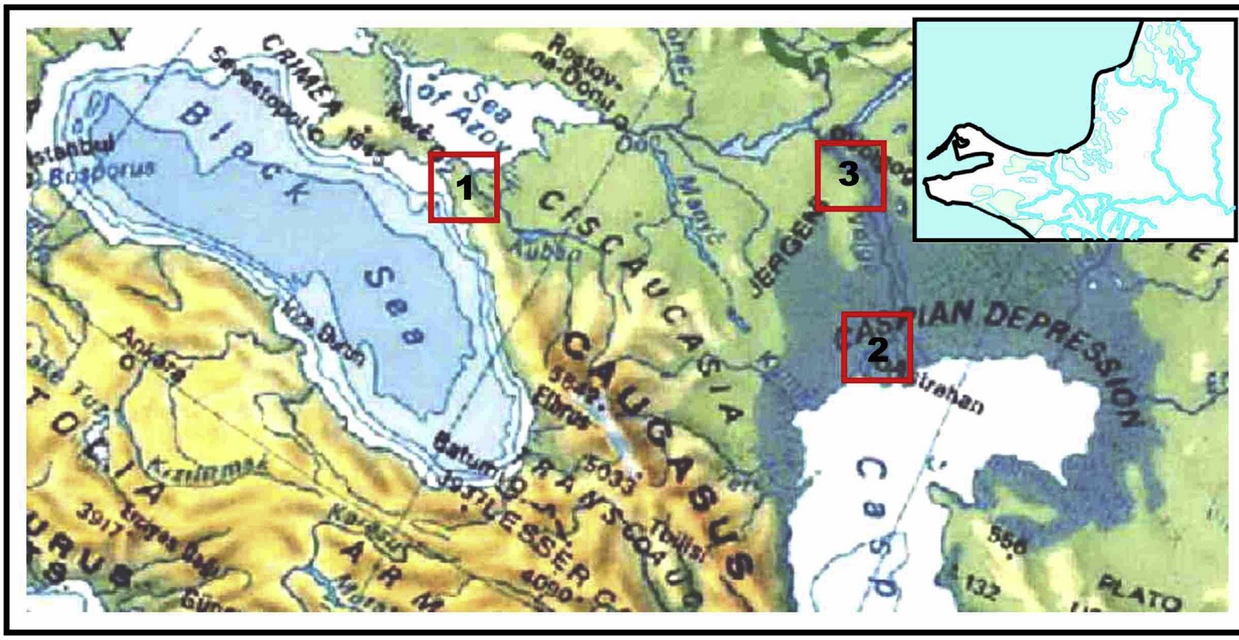

Fig. 1. Location map of the Black Sea and northwestern Caspian Sea regions showing (1) Kuban delta region on the Taman Peninsula; (2) Lower Volga delta region; (3) Solenoe Zajmishche locality in Volga-Akhtuba floodplain region. The inset shows the Taman Peninsula with principal rivers and adjacent land area.

northwestern Caucasus Mountains and flows for around 900 km westwards towards the Taman Peninsula. The Kuban River delta can be classified most closely as a bayhead delta type (cf. Bhattacharya, 2006) in that its discharge is into partially restricted estuarine waters. It is unique because it discharges into two different water bodies: to the north, the outflow is to the Sea of Azov, whereas to the south the outflow is towards the Black Sea. The southern branch is more wave-dominated, with the outflow restricted by the Anapa/Bugaz barrier complex. The Kuban River delta developed in post-glacial times in a marine bay that penetrated deeply into the Western Kuban plain. Due to load transportation by waves and river flow, a few barrier beaches (bars) developed that separated a large lagoon from the Sea of Azov. Over time, the lagoon was gradually filled with river deposits and the lower Kuban delta formed, abounding with *liman*, meandering channels and wetlands. The alluvial-deltaic plain of the lower reaches of the Kuban River is the principal geomorphic unit in the north of the Azov-Kuban lowland. Characteristics of its topography were determined by the geological and tectonic history of the West-Kuban trough, fluctuations of the Azov and Black Sea level in the Holocene and Kuban River runoff. At the maximum of the Black Sea transgression (Bolikhovskaya et al., 2004; Porotov et al., 2004), a large bay with islands of the Taman archipelago existed in place of the modern delta. At the time of the subsequent Phanagorian regression the sea level dropped by up to 5–6 m below that of the present day according to Balabanov (2007) and others.

The southern boundary of the present-day alluvial-deltaic plain passes the base of the eastern slopes of the western Caucasus Range; the lower slopes (130–670 m a.s.l.) of the latter are composed of Neogene sediments and feature erosional relief (Korotaev, 2012) (Fig. 2). At the southwestern boundary of the Kuban delta, on the Taman Peninsula and the adjacent land, predominantly hill and ridge relief developed on Neogene clays, marls and limestones. At least 11 landforms 70–120 m high stretch as continuous ridges or chains of hills from WNW to ESE over 35–40 km. These are eroded anticlinal structures formed by compressional folding and thrusting during the late Cenozoic (Late Pliocene-Quaternary) (Saintot and Angelier, 2000) that are calibrated by magnetostratigraphy and biostratigraphy at the Zheleznyi Rog locality (Krijgsman et al., 2010; Vasiliev et al., 2011; Popov et al., 2016) (Fig. 2). At the eastern boundary of the deltaic plain, between the Beysug and Kuban rivers, there are loess depositional-erosional plains of the Kuban steppe underlain by a thick series of Pliocene brackish-water clays and sands, dissected with small valleys with and without water streams. The plain surface rises gradually southwards from 20 to 70 m a.s.l. A low marine terrace composed of lagoon and *liman* sediments fringes the Azov Sea coasts on the north over a distance of 150 km, from the Achuyev Spit to Peresyp' Girlo. Widely distributed over the region are the so called '*plavni*' – low-lying waterlogged areas (swamps) of the coastal plain that are periodically flooded with river or marine water and overgrown with reed beds. Individual swamps are separated by narrow and gentle-sloped uplifts – remnants of beach ridges 0.3–0.5 m high. There are some structurally controlled elevations rising over the flat alluvial surface (Kuban *plavni*, 0–8 m a.s.l.), their absolute height varying from 20 to 150 m.

The greater portion of the Kuban River delta is typical alluvial-deltaic plain with well distinguishable smaller units, including the youngest delta plain swamp and the older Kuban and Taman deltas. The former occupies the eastern part of the alluvial-deltaic plains in the lowermost reaches of the Kuban River. The Taman delta is in the eastern part of the Taman Peninsula. A noteworthy formation within that unit is an old abandoned channel of the Kuban River; it is traceable over a distance of more than 20 km, from the present-day Kuban channel to Kyzyltash and Vityazev *liman*, as a meander belt 4–11 km wide.

2.1.2. Modern climate and vegetation

The Taman Peninsula, situated within the limits of the steppe zone, is one of the southernmost semiarid regions in Russia. A distinctive feature of the regional deltaic steppe landscapes, with swamps alternating with herb and grass meadows, is the presence of salt-water lakes and numerous *liman* – marine bays partly or completely separated from the sea by depositional spits. The

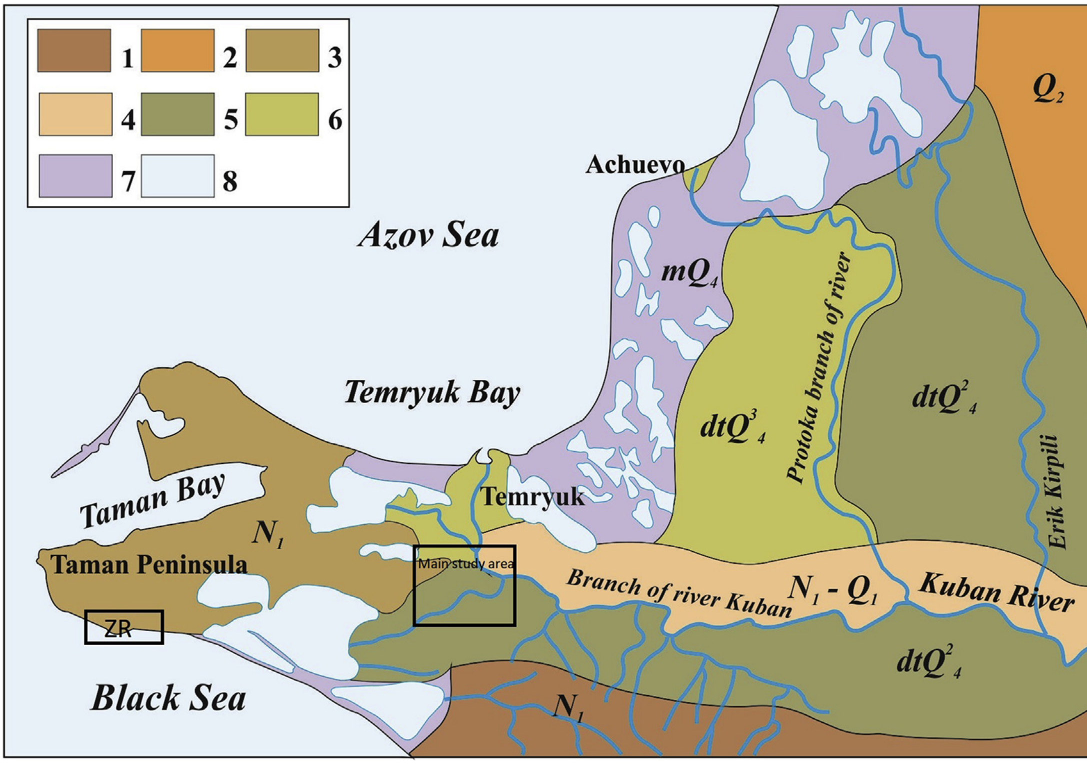

Fig. 2. Schematic and simplified geological and geomorphological map of the Kuban River delta region (modified after Korotaev, 2012). Types of relief: 1 – erosional-denudation of the northwestern Caucasus foothills; 2 – erosional-denudation of the western slope of the Stavropol Arch; 3 – uplifted Neogene ridges and mud volcanoes; 4 – Neogene and Quaternary uplands with mud volcanism; 5 – Middle to Late Holocene alluvial-deltaic plain; 6 – Late Holocene alluvial-deltaic plain; 7 – Holocene coastal marine (*plavni*); 8 – water area of the Black and Azov seas. The inset shows the main study area. ZR = Zheleznyi Rog outcrop locality.

climate is temperate continental, with a relatively mild winter and hot summer. Mean annual rainfall varies from 350 to 430 mm, and mean annual air temperature is about +11 °C (Gvozdetsky, 1963).

The natural vegetation has been essentially disturbed by agricultural activities. A few persisting areas of steppe are dominated by herb and grass and purely grass (sheep's fescue and feather grass) communities alternating with some intra-zonal phytocoenoses typical of floodplains, sands and saline ecotopes. The steppe vegetation is dominated by sod grasses, mostly feather grass (*Stipa Lessingiana*, *S. capillata*) and fescue (*Festuca sulcata*). Herbs are mostly xerophile species (*Adonis wolgensis*, *Medicago romanica*, *Astragalus Henningii, A. novoascanicus*, *Ferula orientalis*, *Seseli compreste*, *Limonium sapertanum*, *Achillea leptophylla* and others) (The vegetation …, 1980). Herbaceous cover is notable for its mosaic structure due to the occurrence of saline soils with typical *solonchak* plants; the latter are dominated by glasswort (*Salicornia*), seablit (*Suaeda*), *Halocnemum*, saltwort (*Salsola soda*), as well as *Artemisia maritima* and some salt-tolerant grasses. On the lake and *liman* coasts there are dense thickets of reed (*Phragmites*), sedges (*Scirpus littoralis*), pondweed (*Potamogeton*), cattail (*Typha*) and watermilfoil (*Myriophyllum*).

Of the trees, only some poplar (*Populus*) and willow (*Salix*) groves persist in the Kuban River delta at present. Some remnants of forests that formerly covered the Kuban delta are found on a hill between two *liman*; the hill is overgrown with thick low forest of oak (*Quercus robur*), elm (*Ulmus carpinifolia*) and lesser amounts of maple (*Acer tataricum*). Further east, in the riverine forests in the lower reaches of the Kuban River and its tributaries, there are willows (*Salix*), poplar (*Populus alba, P. nigra*), elm (*Ulmus foliacea*), ash (*Fraxinus excelsior*), alder (*Alnus glutinosa, A. incana*), with buckthorn (*Rhamnus frangula*), spindle tree (*Euonymus europaea*) and other shrubs in the underbrush. Fairly high ridges on the Kuban floodplain are covered with forests of oak (*Quercus robur*) and ash (*Fraxinus*). Judging from the reconstructed map of broadleaf forests that existed in the lower Kuban valley in the pre-agricultural epoch (Fig. IVa in "The vegetation …, 1980"), the range of the North Caucasian oak forests (mostly of *Quercus petraea*) extended over the Caucasian slopes and foothills and bordered directly on the southeast of the Taman Peninsula. As follows from the pollen data obtained by us on the Holocene dendroflora (see section 4.2), many species belonging to the Holocene broadleaf flora of the Caucasus repeatedly invaded the Taman Peninsula during the intervals of the increased humidity.

2.2. Material and methods

The area where four of the palynologically studied sections are located is within the Middle-Late Holocene alluvial-deltaic sediments at the apex of the Kuban River delta (Figs. 2 and 3a). For the study of lithology and facies composition of the Holocene deposits in the Kuban River delta and the Anapa barrier beach, drilling to a depth of 10–14 m was achieved, and the cores obtained were described and sampled for analyses of granulometry, malacofauna, pollen and spores, as well as ^{14}C dating. The geochronological assignments of the lithofacies complexes were based on the ^{14}C dating of the terrigenous organic matter. The dating was performed in the Laboratory of Geochronology of the Saint Petersburg State University and the dates were calibrated using the IntCal09 calibration curve (Reimer et al., 2009) and CalPal-2007 (Weninger et al., 2007; http://www.calpal.de/); the reservoir effect for the Black Sea basin in the Holocene was estimated at 450 years (Kelletat, 2005). The ^{14}C dates were corrected taking into account

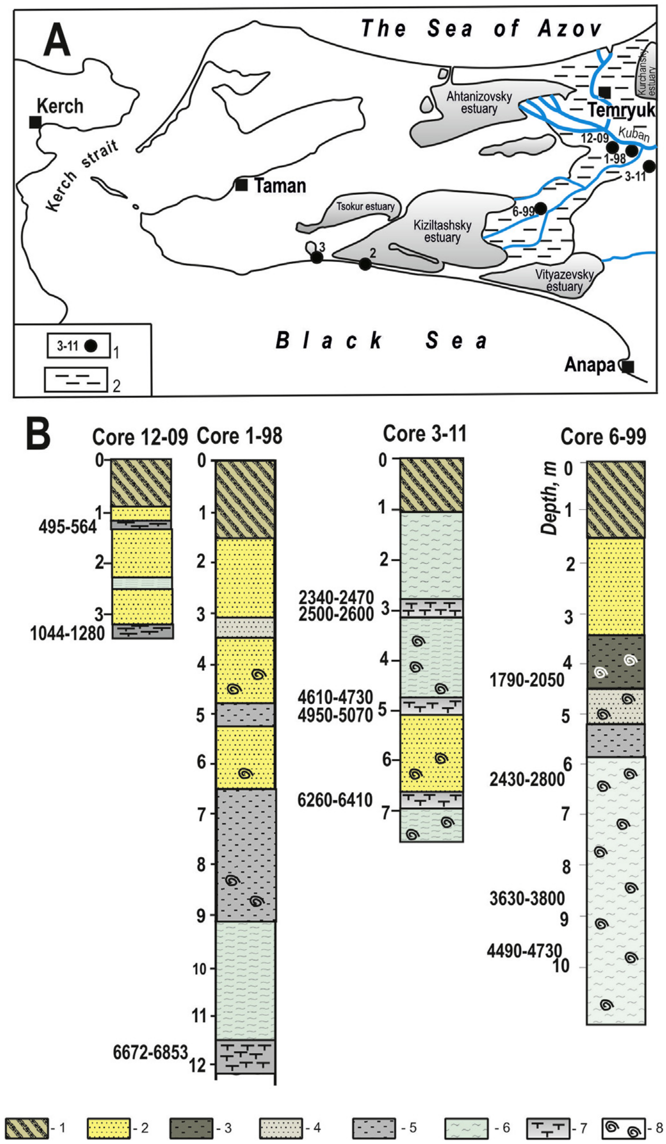

Fig. 3. (A) The location of the studied sequences on the Taman Peninsula: 1 — the locations and core numbers; 2 — the delta of the Kuban River. (B) Lithology and ^{14}C datings (cal yr BP) of sediments penetrated by cores in the area of the delta of the River Kuban, northwestern Black Sea: 1 — sandy loam with interlayers of organic matter; 2 — silty sand; 3 — silty sand gray, dark gray color; 4 — silty sand, fine grained with shell detritus; 5 — silty siltstone, gray, homogeneous; 6 — aleuritic silts, light gray with shells; 7 — lacustrine-deltaic peats and silts; 8 — shells.

the isotopic-geochemical composition of carbon ($^{13}C_{PDB}$).

The standard procedure developed by V.P. Grichuk (Grichuk and Zaklinskaya, 1948) was used for pollen separation from *liman*, lacustrine and marsh deposits; in case of treatment of subaerial and alluvial deposits a version modified by N. Bolikhovskaya was used (Bolikhovskaya, 1995a).

3. Results

At present we have the results of pollen analysis from four boreholes and radiocarbon analyses from six boreholes drilled in various parts of the Kuban River delta (Fig. 3a and b). The studied sequences include *liman*, alluvial, lacustrine and marsh deposits, as well as subaerial sediments formed in the course of the delta development. Holocene deposits studied in boreholes Nos. 1–98, 2, 3–11, 6–99 and 12-09 provided the most representative palynological records of the paleoclimatic events, as may be seen in four pollen diagrams presented in this paper (Figs. 4–7).

The reconstructions are mostly based on the sequence penetrated by borehole 1–98 (Fig. 4). This borehole was positioned in the inner part of the delta, close to the delta apex where the channel divides into two branches, one of them flowing into the Black sea and the other into the Sea of Azov. The sequence includes sediments 12 m thick with a peat horizon at the base no less than 7 thousand years old (5940 ± 50 yr BP; 6853–6672 cal BP) (Fig. 4). The pollen record from the borehole 1-98 section makes it possible to identify 14 stages in vegetation and climate evolution in the interval from ~7000 ^{14}C yr BP to 1000–800 ^{14}C yr BP (from ~7400 to 900–830/730 cal yr BP).

The reconstructions are supported by results of pollen analysis of samples from borehole 6–99 and borehole 2. Borehole 6–99 is ca. 11 m long and was collected near the eastern margin of the Kiziltash *liman*. It contained a sedimentary sequence close in age as well as in lithology and facies composition to the Holocene series known from the central part of the delta (Fig. 5). The middle part of the sequence was dated by radiocarbon to 4330 ± 90–2300 ± 100 ^{14}C yr BP (from 4490 to 4730 to 1790–2050 cal yr BP). Borehole 2 drilled on the Bugaz barrier beach penetrated the outer delta deposits, mostly basal muds overlain by coarse sands and *coquina* that the barrier bar itself is composed of. Pollen data (not shown) characterize the old lagoon sediments dated by ^{14}C to 3–1.5 ka BP interval (Bolikhovskaya et al., 2002; Kaitamba, 2005).

In recent years, palynological and geochronological data have been obtained from three more boreholes – Nos. 3–11, 4–11, and 12-09. The most informative paleogeographically are the pollen records and ^{14}C dates of the sequences from boreholes 3–11 (Fig. 6) and 12-09 (Fig. 7). Palynological data obtained for borehole 3–11 cover the interval approximately from 5520 ± 100 to 2370 ± 50 ^{14}C yr BP (from 6260 to 6410 to 2340–2470 cal yr BP). Pollen spectra recovered from the uppermost part of the borehole 12-09 sequence dated to ~1280–495 cal yr BP, provided information on the latest of the studied phases in the vegetation and climate evolution in the Subatlantic period.

All the samples studied palynologically (except for samples from peat layers) appeared to contain a notable proportion (2–3% of the total sum) of redeposited pollen grains and spores attributable to Neogene (dominant) and Cretaceous (rarer) taxa. Redeposited Pleistocene pollen grains and spores were also present and had mineralized, flattened or severely damaged exines (sporoderm). Most common among the allocthonous palynomorphs are Polypodiaceae spores and pollen of Coniferae, Pinaceae, *Picea, Pinus, Tsuga* (less common), *Juglans, Carya, Pterocarya, Platycarya*, Ericales, *Zelkova, Ulmus, Liquidambar, Ephedra*, Araliaceae, *Sequoia, Metasequoia*, Betulaceae, Fagaceae and others. In all analyzed samples, the pollen spectra include some micro-remains of plants transported by river or by wind over a considerable distance from various regions in the Kuban drainage basin. To obtain a correct interpretation of autochthonous pollen and spores, we utilized pollen and spore data in subrecent samples obtained from different sedimentary facies on the Taman Peninsula, in other regions of the eastern Black Sea coasts, as well as from the North Caucasian forelands and lands adjoining the northwestern and northeastern coast of the Caspian Sea. The studied subrecent spectra are characteristic of forest, forest-steppe, steppe, semidesert and desert plant communities (Isagulova, 1978; Kvavadze and Rukhadze, 1989; Bolikhovskaya, 1995a, 1995b; Mishchenko, 2002; Kaitamba, 2005; Bolikhovskaya and Kasimov, 2008; Dyuzhova, 2013; Richards et al., 2014, 2017). By comparing with the results of the subrecent pollen analyses, we have determined that the spectra recovered from recent deposits of various types adequately reflect the

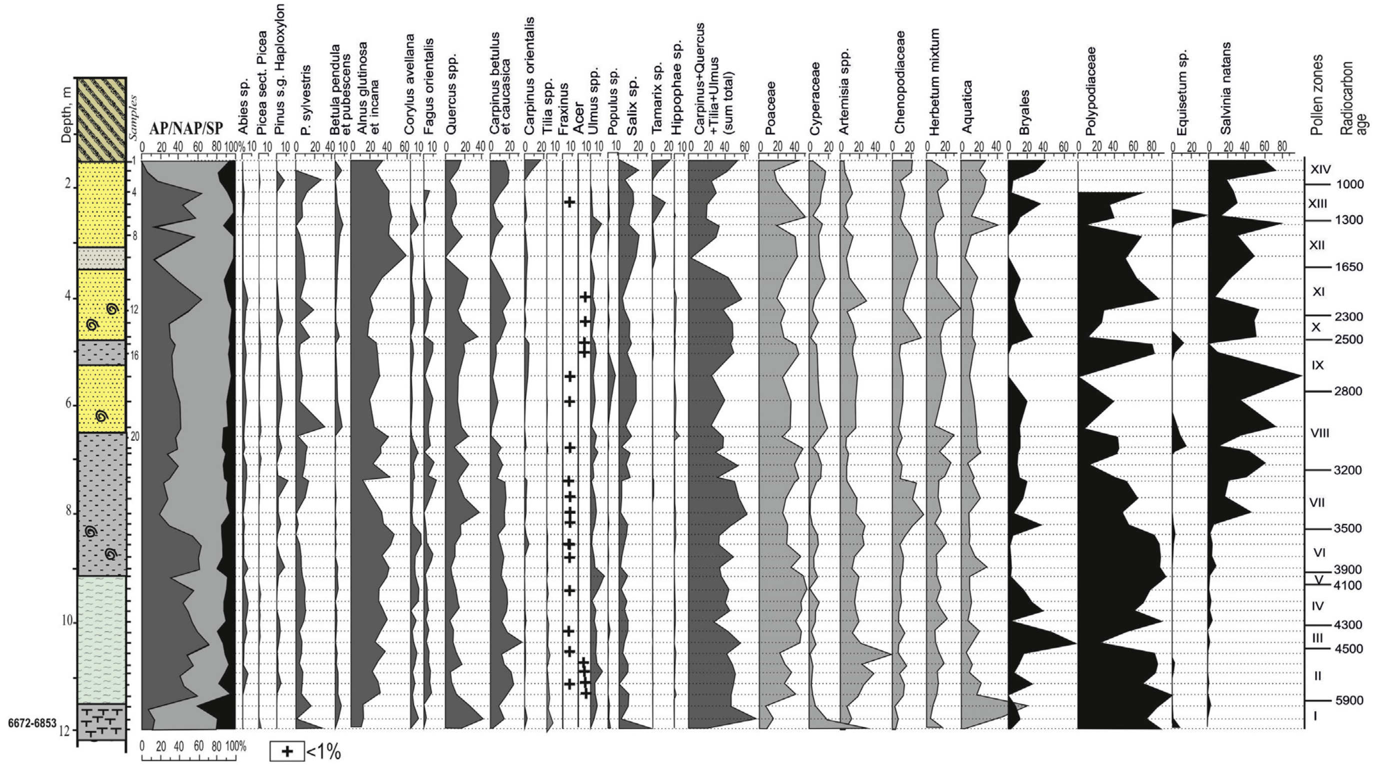

Fig. 4. Pollen and spore percentage diagram of sediments from core 1–98: AP – arboreal pollen (pollen of trees and shrubs); NAP – non-arboreal pollen (pollen of grasses and undershrubs); SP – spores (spores of higher spore plants); + – pollen content less than 1%. Summary column of AP, NAP, SP shown as percentages of total pollen and spore sum. The percentage of each taxon was calculated with respect to: AP taxa as percentage of AP sum, NAP taxa as percentage of NAP sum, SP taxa as percentage of SP sum. Symbols to lithology column are the same as indicated in Fig. 3.

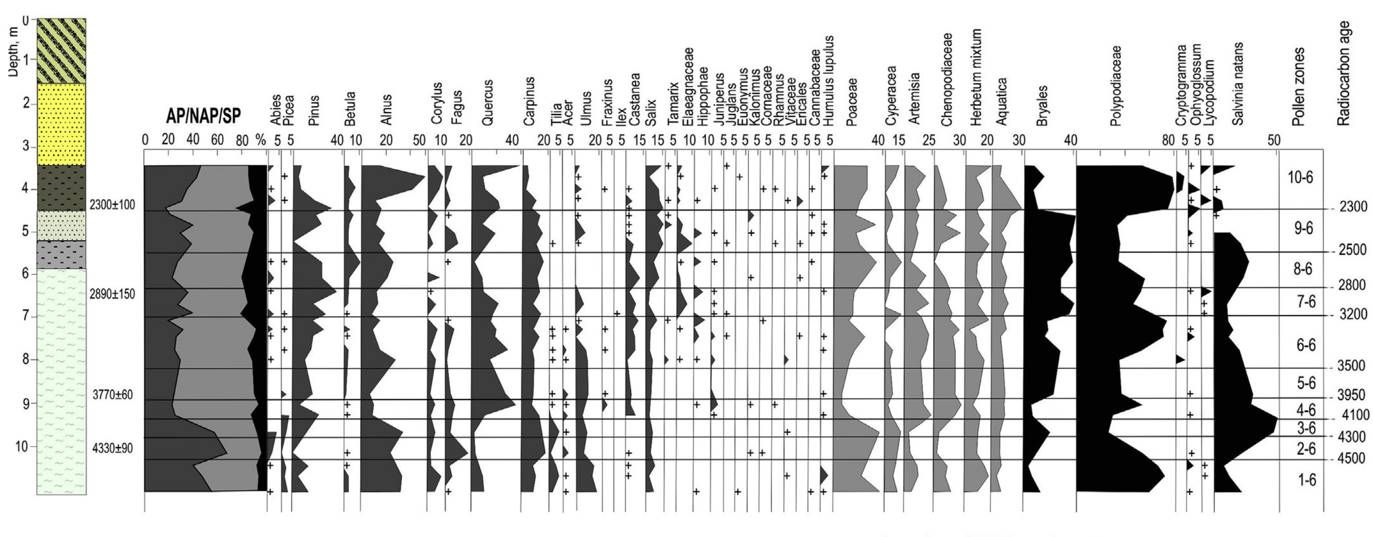

Fig. 5. Pollen and spore percentage diagram of sediments from core 6–99: Symbols to the lithological column and explanations see Figs. 3 and 4.

composition and zonal characteristics of the pollen-producing plant communities, both on the plains and in the mountains. Therefore, the information provided by the pollen assemblages in the borehole samples gives a sound basis for paleo-phytocoenotic reconstruction. Considered together with the radiocarbon dating results (Table 1) and those of the detailed analysis of facies and lithology (Porotov, 2013), they reveal zonal, local and facies-genetic specificity of the Holocene pollen spectra. In this way, we were able to obtain methodologically correct reconstructions for the studied stages in the environmental evolution over ~8000 years (the Middle and Late Holocene) in the Taman Peninsula.

4. Paleogeographic reconstructions of the Taman peninsula and adjacent lands

4.1. Lithostratigraphy and chronology of the delta sediments

The boreholes taken in the deltaic deposits at the Kuban River

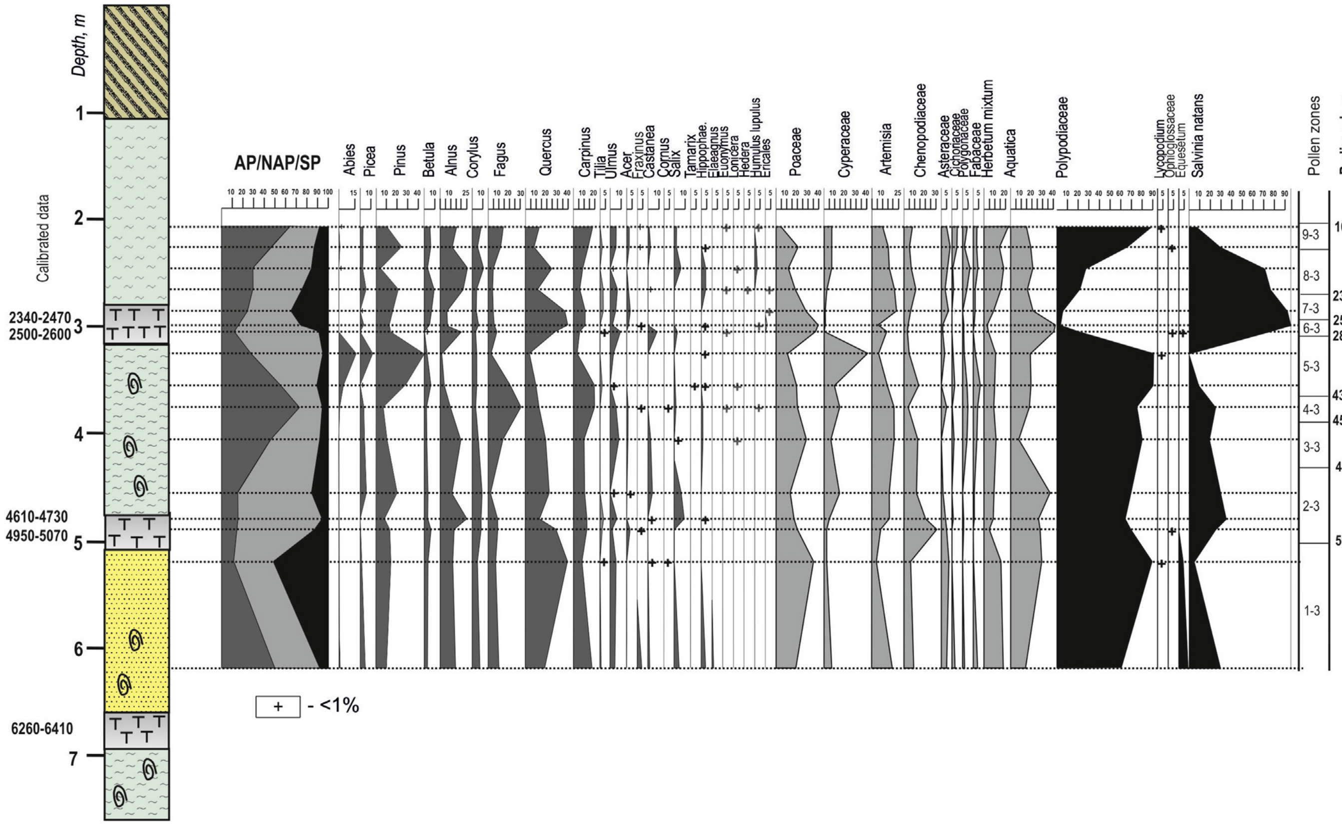

Fig. 6. Pollen and spore percentage diagram of sediments from core 3–11: Symbols to the lithological column and explanations see Figs. 3 and 4.

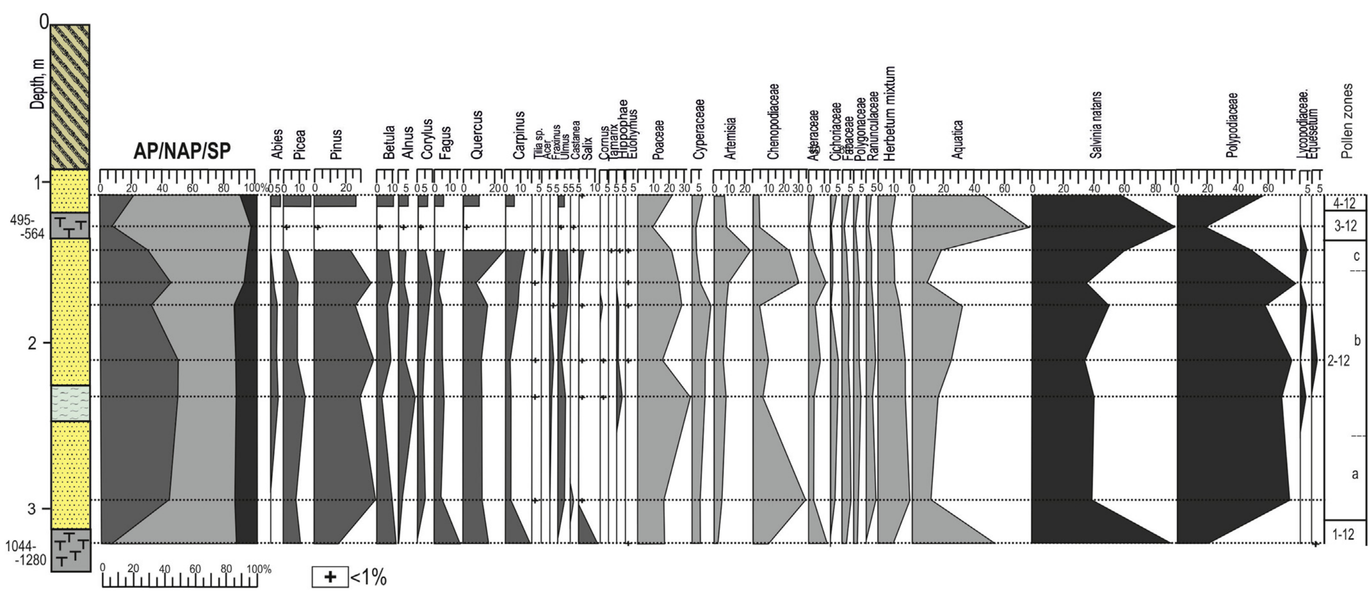

Fig. 7. Pollen and spore percentage diagram of sediments from core 12-09: Symbols to the lithological column and explanations see Figs. 3 and 4.

mouth revealed the Holocene series to be up to 20 m thick and made up of a sequence of rhythmically alternating alluvial sands and silts, *liman* muds and clays, as well as lacustrine and floodplain peats. The sequence shows alluvial and *liman* facies alternating repeatedly, suggesting that the depositional environments changed more than once due to constant migrations of the outer edge of the Kuban delta. The migrations of the delta edge were, in turn, controlled by climate changes and Black Sea level fluctuations. During transgressive phases, the rising sea impounded the river mouth and formed a vast *liman* extending for tens of kilometers upstream. Brackish-water environments are indicated by the presence of *Cerastoderma glaucum* shells in the silt horizons, the species being known to live at salinity no less than 6‰ (Kaplin et al., 2001). The palynological analysis of peat layers penetrated by the

Table 1
List of radiometric ages.

Core, №, Sample	Depth (m), b.s.l.	Lab code	$\delta^{13}C$	Material	Conventional 14C age (yr BP)	Calibrated age 1σ range (yr BP)	References
12–09	1.20–1.30	LU-299	−29.6	Peat	510 ± 80	495–564	authors
12–09	3.20–3.30	LU-6298	−29.0	Peat	1210 ± 160	1044–1280	authors
3-11/6	2.95–3.00	LU-6857	−29.3	Peat	2370 ± 50	2340–2470	authors
3-11/7	3.00–3.05	LU-6858	−27.5	Peat	2570 ± 70	2500–2600	authors
3-11/10	4.95–5.00	LU-6860	−27.8	Peat	4150 ± 60	4610–4730	authors
3-11/12	4.75–4.80	LU-6859	−28.5	Peat	4430 ± 90	4950–5070	authors
3-11/14	6.85–7.00	LU-5831	−27.0	Peat	5520 ± 100	6260–6410	authors
1-98-12	11.50–11.60	GIN-9942	–	Peat	5940 ± 50	6672–6853	authors
[a]DZHI 2/4	−0.50	UGAMS 03178	−27.13	Peat	301 ± 24	305–428	Fouache et al., 2012.
[a]DZHI 2/8	2.10	UGAMS 03179	−26.21	Peat	1015 ± 24	925–955	Fouache et al., 2012.
[a]DZHI 2/10	3.05	UGAMS 04142	0.27	Shell[b]	1937 ± 29	1410–1529	Fouache et al., 2012.
[a]DZHI 2/20	7.30	UGAMS 03180	−2.98	Shell[b]	4790 ± 30	4961–5173	Fouache et al., 2012.
[a]DZHI 2/T1	10.20	UGAMS 03182	−28.30	Peat	5810 ± 37	6563–6666	Fouache et al., 2012.
[a]DZHI 2/T8	10.65	UGAMS 03183	−27.55	Peat	6511 ± 27	7419–7459	Fouache et al., 2012.
[a]DZHI 2/29	12.50	UGAMS 03181	−28.30	Peat	7521 ± 30	8215–8401	Fouache et al., 2012.
6-99/1	4.30–4.40	MSU-1528	–	Shell	2300 ± 100	1790–2050	authors
6-99/2	6.25–6.35	MSU-1529	–	Shell	2890 ± 150	2430–2800	authors
6-99/3	8.70–8.80	MSU-1530	–	Shell	3770 ± 60	3630–3800	authors
6-99/4	9.65–9.75	MSU-1531	–	Shell	4330 ± 90	4490–4730	authors

[a] /Conventional dating with Lab. No.: GIN- Geological Institute, Russian Academy of Sciences; LU – Saint Petersburg State University; MSU- Lomonosov Moscow State University; UGAMS - University of Georgia, Atomic Mass Spectrometry.
[b] For marine carbonates the reservoir age of 408 years was used (see Hughen et al., 2004). 14C ages (Cal BP) were calibrated with CALIB 6.0 using the IntCal09 calibration curve (Reimer et al., 2009). Data from DZHI 2 are included as this core is adjacent to cores 1-98 and 12-09 in the present study.

boreholes at the edges of the valley suggests that peat had accumulated in shallow freshwater lakes (typical of a waterlogged delta). Lakes of that kind tend to develop during periods of very slowly sea level rise, or even lowering; under such conditions the inner parts of *liman* may become dry and pass into wetlands with residual lakes.

Radiocarbon results from the buried peat sequence permits dating of the intervals of peat accumulation at 7152–6887, 6410–6208, 5307–5050, 4409–3998, 2347–2115 cal yr BP (Porotov, 2013). Within the last 2000 years, the peat accumulation traces are dated to 400–590 CE and 1400–1700 CE, equivalent to 1600–1410 and 600–300 cal yr BP respectively. When dating the top and the base of every peat layer, the data obtained made it possible not only to reconstruct sea level fluctuations at the Kuban delta in detail, but also estimate the duration of individual periods of peat accumulation, when the sea level was slowly rising, stagnant or lowering. The accumulation of the lowermost peat layer, now at a depth of 10–12 m below sea level, took about 700 years. As for the duration of the younger peat deposition, it took no more than 350–400 years for every layer. That gave grounds for estimating the length of periods when the rate of the sea level rise was slow enough to permit peat accumulation in shallow water bodies within the delta limits.

4.2. Reconstructions of the vegetation and climate

All the analytical materials thus obtained offer a clearer view of the climate and environment restructuring having taken place on the Taman Peninsula between ~7.4 ka BP and 400 yr BP. There are 17 phases identified in the evolution of vegetation and climate within this interval of the Middle and Late Holocene. It is noteworthy that, in common with most of the East European south, the Taman Peninsula featured much more varied landscapes in the Subboreal and Subatlantic periods than during the previous (Atlantic) period of the Holocene, with seven phases in climate and phytocoenosis evolution identified in the Subboreal period.

4.3. Interval I

The first reconstructed phase was distinguished by the accumulation of peat exposed in borehole 1–98 at a depth of 11.5–12.0 m attributable to the end of the early Atlantic sub-period of the Holocene indicated by the date obtained on the top of the horizon (^{14}C 5940 ± 50 yr BP; 6853–6672 cal yr BP). This phase of marsh accumulation featured herb and grass steppe as the zonal vegetation type on the studied area, indicating a warm and dry climate. The most favorable habitats in the lower Kuban reaches at this time supported hornbeam and oak stands (*Carpinus betulus* and *Quercus robur*) with occasional admixture of beech, lime, elm, poplar and alder. Chenopodiaceae and *Artemisia* communities occupied disturbed grounds and those devoid of soils. Intrazonal hydromorphic paleo-landscapes included willow groves, with meadow and wetland coenoses (dominated by sedges) in the open areas.

4.4. Interval II

The next phase in the vegetation and climate evolution corresponds to approximately 6000 to 4500 ^{14}C yr BP (6730–5160 cal yr BP) late Atlantic to Subboreal period. That interval was marked by an increasingly humid climate, reduced areas of steppe, greater importance of hornbeam, beech and alder in the forest coenoses, and a higher species diversity of trees and shrubs. Under warm and relatively more humid conditions (as compared with the previous period), the studied region was dominated by forest-steppe landscapes. In the forest formations, beech, oak and hornbeam communities prevailed (*Carpinus betulus, C. caucasica, C. orientalis, Quercus robur, Q. petraea, Fagus orientalis*) with admixture of elm (*Ulmus laevis, U. suberosa*), chestnut (*Castanea*), lime (*Tilia cordata, T. caucasica*), ash (*Fraxinus*), maple (*Acer*), Turkish filbert (*Corylus colurna*), hophornbeam (*Ostrya*) and other broadleaf species. In the undergrowth there were *Cornus, Elaeagnus, Rhamnus, Euonymus,* Grossulariaceae among others. Forests growing on hypsometrically lower surfaces were dominated by alder (mostly *Alnus glutinosa*) and willow, with an admixture of poplar (*Populus*), sea-buckthorn (*Hippophae*) and tamarisk (*Tamarix*). Treeless lands were occupied by herb and grass steppes, as well as those dominated by pigweed (Chenopodiaceae) and sagebrush *(Artemisia*).

4.5. Interval III

The increase in humidity noted since late Atlantic times reached its maximum in the phase dated to 4500–4300 ^{14}C yr BP (5160–4900 cal yr BP). That phase manifested the first maximum of increased humidity of the last 7400 years. The Taman Peninsula was almost completely forested, the dominants having been communities of beech, oak and hornbeam or of oak, beech, elm and hornbeam, under conditions of a warm and humid climate. Mixed coniferous-broadleaf stands, groves of alder and willow were also common. Pollen spectra attributed to this interval show a prevalence of *Abies, Pinus* s.g *Haploxylon* and *Pinus sylvestris* in the group of coniferous trees. The palynological record obtained from borehole 3–11 (Fig. 6) distinctly shows this phase of broadleaf dominance and increased humidity.

4.6. Interval IV

Subsequently, during the phase dated to ~4300–4100 ^{14}C yr BP (4900–4660 cal yr BP), the forested area was noticeably reduced, as well as the proportion of broadleaf trees. The composition of dominants in the broadleaf forest and alder communities was mostly the same as in the previous period. The most typical landscapes at the Taman Peninsula at this time were transitional from forest to forest-steppe. A comparative analysis of pollen spectra attributable to this stage in all the studied sections (Fig. 4 – pollen zone IV; Fig. 5 – pollen zone 3–6; Fig. 6 – pollen zone 5-3) suggests that the decrease in the proportion of forest coenosis might have become more pronounced downstream of the Kuban River.

4.7. Interval V

The next, rather short, phase (~4100–3950 ^{14}C yr BP; 4660–4400 cal yr BP) was marked by maximum forest degradation, with open steppe landscapes widespread. Climate conditions were relatively cool and dry. The vegetation of the steppe and coastal areas included mostly grass and herb-grass communities, as well as those of pigweed (Chenopodiaceae) and sagebrush (*Artemisia*). The intra-zonal forests in the lower Kuban valley were dominated by alder and willow stands, with some communities of oak, hornbeam and elm also present. Forests of beech, hornbeam and oak with some lime, ash, maple and chestnut occurred in the most favorable habitats.

4.8. Interval VI

The next phase of the vegetation evolution on the Taman Peninsula (~3950–3500 ^{14}C yr BP; 4400–3780 cal yr BP) was notable as a new period of increasing humidity (the second humidity maximum during the last 7400 years) that promoted restoration of forests in the region. In the automorphic (i.e. well-drained) landscapes, the dominant forests consisted of oak-beech-hornbeam and beech-hornbeam-oak (with elm, lime and ash) associations, as well as with coniferous-broadleaf formations. In river valleys and wetter depressions, alder (*Alnus glutinosa, A. incana*) and willow stands were present in noticeable quantities along with the above mentioned broadleaf forests. The ground cover was mostly composed of various grasses (Poaceae) and herbs (e.g. Polygonaceae, Apiaceae, Lamiaceae, Plantaginaceae, Caryophyllaceae, Brassicaceae, Solanaceae, Rubiaceae, Urticaceae, Valerianaceae, Iridaceae, Scrophulariaceae, Asteraceae etc.). Ferns and fern-allies were dominated by Polypodiaceae (*Athyrium filix-femina, Dryopteris*) among others, including Ophioglossaceae (e.g. *Ophioglossum vulgatum, Botrychium*), *Equisetum* and other spore-bearing plants. Disturbed grounds were colonized by sagebrush (*Artemisia*), pigweed (Chenopodiaceae), hemp (*Cannabis*) and burweed (*Xanthium*). Pollen spectra from the middle part of the interval are characterized by a noticeably reduced proportion of pollen from broadleaf trees, probably indicative of a relatively colder episode within this stage of otherwise mostly warm and humid climate. Subsequently, the forest zone has never expanded onto the Taman Peninsula; since the mid-Subboreal period (~3500 ^{14}C yr BP; 3780 cal yr BP), all the changes in vegetation were manifested as transitions from steppe to forest-steppe and vice versa.

4.9. Interval VII

The next phase in vegetation and climate evolution dated by interpolation to ~3500–3200 ^{14}C yr BP (3780–3430 cal yr BP) corresponds to a new stage of steppe dominance under conditions of a warm and dry climate. This is recorded in the pollen spectra of borehole 1–98 at a depth of 7.5–8.0 m (Fig. 4, pollen zone VII) and is confirmed by the data from borehole 6–99 (Fig. 5, pollen zone 6-6). Forested areas were rather limited and represented by hornbeam and oak stands and alder groves. During this phase, grass communities were dominant and widespread in the open landscapes, together with *Artemisia*, Chenopodiaceae and diverse assemblages of herbs belonging to Fabaceae, Ranunculaceae, Apiaceae, Lamiaceae, Plantaginaceae, Caryophyllaceae, Brassicaceae, Solanaceae, Rubiaceae, Linaceae, Liliaceae, Urticaceae, Valerianaceae, Iridaceae, Scrophulariaceae, Plumbaginaceae, Cichoriaceae, Asteraceae and other families. It is within this interval that the oldest *Cerealia* pollen was found, at a depth of 7.6–7.5 m in borehole 1. The newly obtained ^{14}C data permit to specify the time of the earliest human impact on the environment in the region; in all probability, it was during the second half of the Bronze Age at the earliest.

4.10. Interval VIII

A distinctive feature of the phase dated to the interval of 3200–2800 ^{14}C yr BP (3430–2910 cal yr BP) was the prevalence of forest-steppe landscapes under conditions of colder and wetter climate. The relative cooling is indicated, first of all, by a reduced proportion of broadleaf pollen and the recorded maximua of *Pinus sylvestris* (see Figs. 4 and 5). Forests of beech, hornbeam and oak occupied a rather limited area in the automorphous landscape, *Quercus robur* and *Carpinus caucasica* being the dominant species. Poorly drained areas were still dominated by alder and willow. Steppe and meadow steppe vegetation consisted mostly of herb and grass communities. In common with the previous phase, assemblages of Chenopodiaceae and *Artemisia* were fairly widespread. As the pollen spectra from the Bugaz barrier bar locality show (borehole 2), those assemblages also colonized the maritime zone in the south of the peninsula at that time.

4.11. Interval IX

Characteristics of phytocoenoses and climate during the next phase, dated to the interval of 2800–2500 ^{14}C yr BP (2910–2590 cal yr BP), were inferred from pollen data in all the borehole sections studied. Boreholes 1–98 and 6–99 yielded spectra indicative of herb-grass and sagebrush-pigweed (Chenopodiaceae–*Artemisia*) steppes that were dominant under conditions of warm and dry climate. The most favorable areas on watersheds and in the Pra-Kuban valley were occupied by forests of oak (*Quercus robur, Q. petraea*), hornbeam (*Carpinus betulus, C. orientalis*), beech (*Fagus orientalis*), elm (*Ulmus carpinifolia*), ash (*Fraxinus*), lime (*Tilia cordata*). Communities of beech, hornbeam, and oak were prevalent. Understorey and shrubs consisted of hazel (*Corylus avellana*), tamarisk (*Tamarix*), sea-buckthorn (*Hippophae*), spindle tree (*Euonymus*), jasmine (*Jasminum*), honeysuckle

(*Lonicera*), buckthorn (*Rhamnus*), juniper (*Juniperus*), members of the Grossulariaceae family, as well as grape (*Vitis sylvestris*), hop (*Humulus lupulus*) and other lianas. Alder (*Alnus glutinosa, A. incana*), poplar (*Populus*) and willows (*Salix*) were dominant in the floodplain forests. The pollen spectra are noted for the maximum content of *Cerealia* pollen, which may be indicative not only of floristic, but also of edaphic specificity. It is not inconceivable that the *Cerealia* maxima correspond to the increasing rate of the chernozem formation on the Taman Peninsula. The palynological record from borehole 3–11 (Fig. 6) agrees well with the reconstruction of this phase as it distinctly shows increased steppe elements in pollen zone 6-3.

4.12. Interval X

The final phase of the Subboreal period is dated to ~2500–2300 ^{14}C yr BP (2590–2280 cal yr BP). That interval featured vegetation transitional from steppe to forest-steppe indicating a relatively warm and dry climate.

4.13. Interval XI

The last and most pronounced increase in humidity (the third maximum of moisture supply within the last 7400 years) was recorded by the analytical data from the first phase of the Subatlantic period, dated to ~2300–1650 ^{14}C yr BP (2280–1540 cal yr BP). It is identifiable in phytocoenoses by the transitional from forest-steppe to forest vegetation. During that rather prolonged interval, the forest-steppe and forest communities occurred in close proximity to each other, indicating a relatively warm and wet climate. The pollen and spore assemblages show a highly diversified species composition in the arboreal, as well as in grass and shrub groups. The vegetation in the region at the time of the humidity maximum was dominated by forests of beech (*Fagus orientalis*), oak (*Quercus robur, Q. petraea, Q. pubescens*) and hornbeam (*Carpinus betulus, C. caucasica, C. orientalis*) with an admixture of elm (*Ulmus*), maple (*Acer*), Turkish filbert (*Corylus colurna*) and alder groves (of *Alnus glutinosa, A. incana*). In the grass and dwarf shrub cover there were mostly grasses (Poaceae) and various herbs (e.g. Brassicaceae, Rubiaceae, Ranunculaceae, Fabaceae, Boraginaceae, Lamiaceae, Apiaceae, Papaveraceae, Plantaginaceae, Liliaceae, Dipsacaceae, Polygonaceae, Iridaceae, Solanaceae, Campanulaceae, Caryophyllaceae, Urticaceae, Plumbaginaceae, Asteraceae, Cichoriaceae and others).

4.14. Interval XII

The pollen spectra recovered from sediments formed between ~1650 and 1300 ^{14}C yr BP (1540–1230 cal yr BP) show that the studied region was dominated by herb and grass steppes alternating with those of *Artemisia* and Chenopodiaceae. Meadows were widespread too. Forest ecotopes were drastically reduced in area. These factors suggest that the climate was noticeably drier and cooler. Broadleaf trees completely disappeared by the middle of the stage while at the beginning and towards its end, the areas most favorable for broadleaf forests around the lower Kuban River were occupied by hornbeam and oak stands with admixture of elm (*Ulmus* cf. *suberosa, U.* cf. *foliacea*). Tree stands surrounding water bodies were mostly of alder (*Alnus glutinosa, A. incana*) and willow.

4.15. Interval XIII

The pollen spectra recovered from the deposits dated to ~1300–1000 ^{14}C yr BP (~1230–900 cal yr BP) show that forest-steppe vegetation dominated the areas adjacent to the inner delta of the Kuban River. Forest formations, made up mostly of beech, hornbeam and oak, occupied predominantly interfluves, slopes and locally occurred in the lower Kuban valley in places most favorable for broadleaf tree species. The areas of the steppe, meadow vegetation of grass and herbs, sedge communities and those of *Artemisia* and Chenopodiaceae were notably reduced as compared with the previous interval. These indicate a new phase of climate humidification, though it was less significant than the earlier ones. Tree stands confined to hydromorphous landscapes still had alder and willow as edificators.

4.16. Interval XIV

A relatively short phase dated to ~1000–900/800 ^{14}C yr BP (900–830/730 cal yr BP) coincided with almost complete deforestation and the dominance of steppes with grasses, sagebrush (*Artemisia*) and pigweed (Chenopodiaceae) communities. The AP proportion in pollen spectra is less than 1%. Littoral and aquatic vegetation was dominated by bur-reed (*Sparganium*), cattail (*Typha*), pondweed (*Potamogeton*) and *Salvinia natans* (floating fern). This was the most arid interval in all the considered period of the Holocene and suggests sudden warming and increased aridity throughout the Taman Peninsula.

4.17. New data from borehole 12-09

Pollen spectra newly obtained from the uppermost sedimentary layers penetrated by borehole 12-09 permitted reconstruction of some later phases of vegetation and climate evolution through the Subatlantic period of the Holocene, between approximately 800 and 400 cal yr BP (Fig. 7). Pollen zone 1–12, showing the pollen and spore composition in the peat layer dated by radiocarbon at 900–1000 ^{14}C yr BP, corresponds to the pollen zone XIV identified in borehole 1–98; the latter was noted for the increasing dominance of steppe vegetation in response to increased aridity. This was succeeded by a 200–300 year period with forest-steppe landscapes growing in importance (pollen zone 2–12). Coniferous-broadleaf forests were the dominant constituent of the arboreal vegetation at that time (~830/730–580 cal yr BP) with a considerable proportion of coniferous species made up by pine (*Pinus sylvestris*) and spruce (*Picea*), seemingly due to higher moisture supply. The pollen spectra from the upper part of the sequence in borehole 12-09 indicate a further expansion of open vegetation and landscapes (pollen zones 3–12 and 4–12) where forb-grass steppes adjoined vast meadows and wetlands with cattail, bur-reed etc. Forests were of limited occurrence, with boreal elements (fir, spruce, pine and birch) dominant. The paleoclimatic stage recognizable in this phase in the environmental history of the Taman Peninsula most probably corresponds to the Little Ice Age dated to ~650–150 yr BP, that is approximately between 1350 CE and 1850 CE (Mann et al., 2009).

5. Discussion

5.1. The proxy record and regional correlation of climate change for the last 7.4 ky

The results of a detailed palynological study of deltaic sediments in different parts of the Kuban River delta enabled us to reconstruct a succession of the zonal vegetation types and transformations of the zonal and intra-zonal plant formations in the Holocene landscapes of the Taman Peninsula for the last ~7400 cal yrs (see section 4.2 in this paper). The changes (phases) in the vegetation and environments were controlled by global and regional climatic fluctuations, together with changing edaphic conditions during the

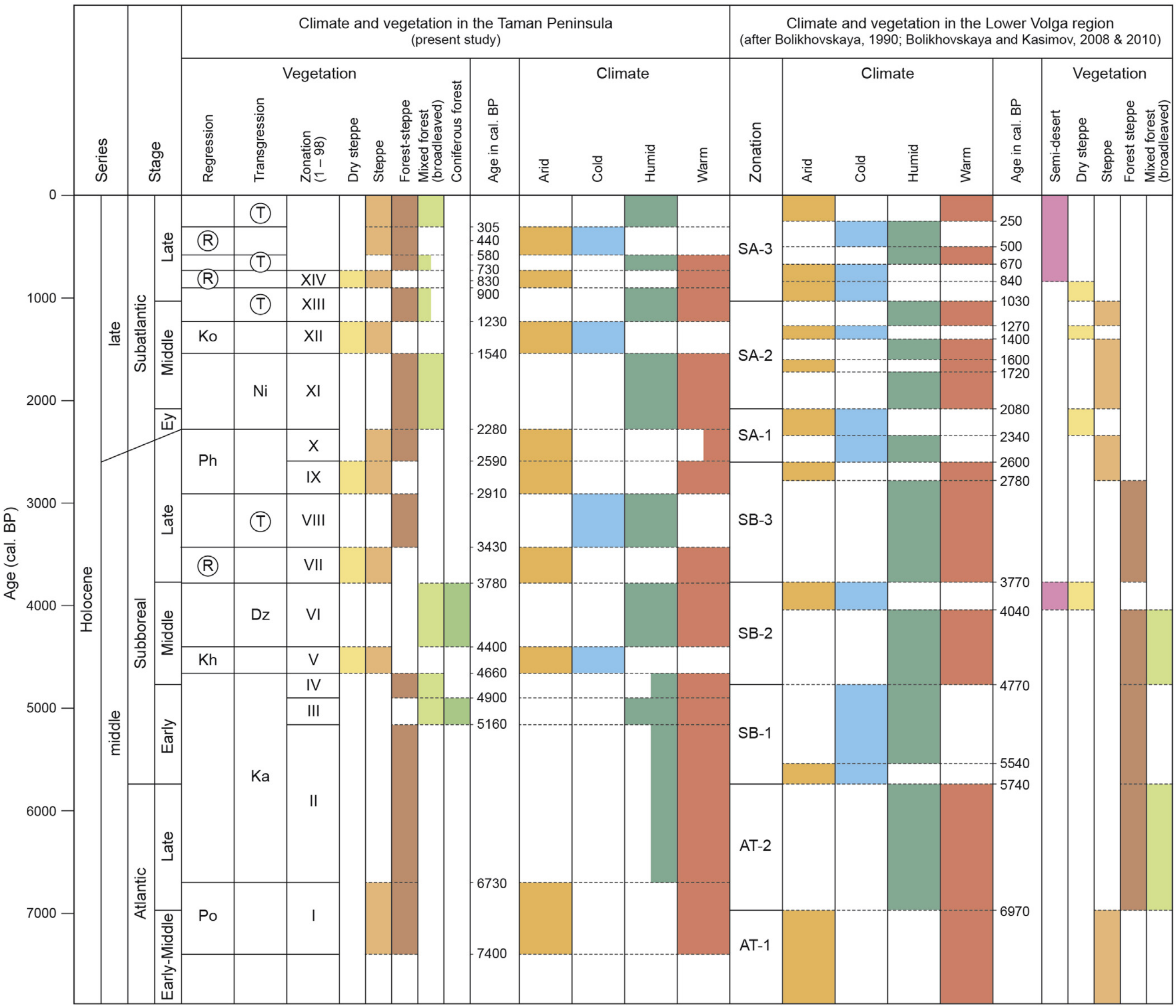

Fig. 8. Comparison of Middle-Late Holocene vegetation and climate reconstructions for the Kuban River delta region (this study) and the Volga-Akhtuba floodplain, NW Caspian lowland region (Solenoe Zajmishche): Po – Pontian regression, Ka – Kalamitian transgression, Kh – Khadzhybeian regression, Dz – Dzemetinian transgression, Ph – Phanagorian regression, Ni – Nimphaean transgression, Ko – Korsunian regression.

Middle and Late Holocene. Steppe and forest-steppe landscapes predominated throughout the Taman Peninsula during the most part of the reconstructed period. The warmest and most arid conditions were marked by the dominance of grass, herb-grass, and pigweed-wormwood (*Artemisia*-Chenopodiaceae) steppes; they existed in the intervals (1) 4100–3950 14C yr BP (~4660–4400 cal yr BP), (2) 3500–3200 14C yr BP (3780–3430 cal yr BP), (3) 2800–2500 14C yr BP (2910–2590 cal yr BP), (4) 1650–1300 14C yr BP (1540–1230 cal yr BP) and (5) 1000–900/800 14C yr BP (900–830/730 cal yr BP).

The more wet periods with predominance of broadleaf (mostly beech, oak and hornbeam) forests are documented for three intervals: 4500–4300 14C yr BP (5160–4900 cal yr BP), 3950–3500 14C yr BP (4400–3780 cal yr BP) and 2300–1650 14C yr BP (2280–1540 cal yr BP). On the whole, the paleoclimatic record for the last ~7.4 cal years constitutes a sequence of relative short-term phases that reflect worldwide climate fluctuations during the Holocene (Mayewski et al., 2004; Martin et al., 2007). It is noteworthy that this paleoclimatic sequence is characterized by partly anisochronous changes in humidity and temperature. The more pronounced phases of climate amelioration (i.e. warming) are associated with synchronous increases of humidity. The intermediate phases are characterized by the multidirectional change in principal climatic feature. Such internal differences between the climatic phases of cooling are reflected by different environmental responses, including changes in vegetation. At the same time, the results of this palynological study on the Taman peninsula show similarity with the principal trends in vegetation development and climate change observed in the northern Pontic steppe (Spiridonova and Lavrushin, 1997; Kotova and Makhortykh, 2010), southwestern Crimea (Gerasimenko, 1997; Cordova and Lehman, 2005; Cordova et al., 2011a, b) and western Georgia (de Klerk et al., 2009; Connor et al., 2007). Conversely, the vegetation and inferred climate changes at Taman are largely out of phase with those interpreted for the lower Volga region by Bolikhovskaya (1990), Bolikhovskaya and Kasimov (2008, 2010a, b) and Richards

Table 2
Holocene vegetation and climatic stages in the Taman Peninsula and their ages according to ^{14}C dating and interpretations of the pollen record, and likely correlations with sea-level fluctuations (N. Bolikhovskaya).

^{14}C and interpreted ages of vegetation and climate stages, years BP		Zonal vegetation (from pollen)	Climate	Correlation with supposed transgressive and regressive phases
Conventional	Calibrated			
	<300 – subrecent	All the subrecent samples (soil, estuary, alluvial) indicate steppes with patches of broadleaf and pine forests	More humid than at present	Trend to transgression
301 ± 24 430 ± 20	580–305/ 440	Herb-grass steppe; locally forests of fir, spruce, pine and birch; meadows and abundant aquatic vegetation	Relatively cool and dry	regression
510 ± 80	830/730 –580	Forest-steppe with a notable presence of mixed coniferous - broadleaf forests	Warm and relatively humid, increasing in humidity	transgression
1000–900/ 800	900–830/ 730	Grass and *Artemisia*-Chenopodiaceae steppe	Increasing aridity and warming	regression
1300–1000	1230 –900	Forest-steppe with patches of beech-hornbeam-oak forests	Relatively humid and warm	transgression
1650–1300	1540 –1230	Dominance of herb-grass and *Artemisia*-Chenopodiaceae steppe; broadleaf tree species disappear almost completely after the middle of this phase	Dry and relatively cold	Korsunian regression
2300–1650	2280 –1540	A combination of broadleaf beech-oak-hornbeam forests and forest-steppe	Warm and humid: 3rd maximum of humidity	Nimphaean transgression
2500–2300	2590 –2280	Vegetation transitional from steppe to forest-steppe	Relatively warm and dry	Phanagorian regression
2800–2500	2910 –2590	Herb-grass and *Artemisia*-Chenopodiaceae steppe	Warm and dry	
3200–2800	3430 –2910	Forest-steppe dominated by steppe and meadow-steppe herb-grass communities; alder and willow forests, small areas of beech-hornbeam-oak forests	Relative cooling and increase in humidity	transgression
3500–3200	3780 –3430	Grass steppe, *Artemisia*-Chenopodiaceae and herb-grass steppes, locally with broadleaf (hornbeam-oak) and alder forests	Warm and dry	regression
3950–3500	4400 –3780	Broadleaved forests (oak-beech-hornbeam and beech-hornbeam-oak) with patches of coniferous and broadleaf stands	Warm and humid: 2nd maximum of humidity	Maximum phase of Dzemetinian transgression
4100–3950	4660 –4400	Grass, herb-grass and *Artemisia*-Chenopodiaceae steppes; floodplain forests of alder, poplar and willow; reduced broadleaf stands of oak-hornbeam-elm	Relative cooling and increasing aridity	regression
4300–4100	4900 –4660	A combination of forest and forest-steppe communities with forests of former edificators	Warm and relatively less humid	Kalamitian transgression
4500–4300	5160 –4900	Broadleaf forests, mainly of beech, oak, and hornbeam, with patches of coniferous- broadleaf stands and alder and willow groves	Warm and humid: 1st maximum of humidity	
5900–4500	6730 –5160	Forest-steppe with patches of beech-oak-hornbeam forests	Warm and relatively more humid	
5940 ± 50 >6500	7400 –6730	Steppe with meadow and marsh communities and patches of hornbeam-oak stands	Warm and dry	Pontian regression

et al. (2014) (Fig. 8.). The differences between the sub-regional climatic reconstructions reflect the variability in the response of various environments to climate change. Adequate documentation of those changes is, however, in many cases limited by the availability and completeness of the sedimentary archives and associated geochronology.

5.2. Climate change and Black Sea level

Despite its long history, the discussion about the relationship between sea level fluctuation and climate changes along the Black Sea coast still remains open, partly due to a paucity of high-resolution records of pollen-climate data and reliable data sets documenting the chronology of coastal evolution in the region. Existing differences between various reconstructions of sea level change were reviewed by Pirazzoli (1991), Balabanov (2007), Martin et al. (2007) and Brückner et al. (2010) using compilations of data from different coastal areas of the Black Sea and including various proxies (geomorphological, sedimentological, archeological) as sea level indicators. A further review by Martin and Yanko-Hombach (2011) concluded that subtle sea level changes have occurred in the Black Sea during the Holocene, partly due to eustatic signals from the Mediterranean, but also as a result of periodically increased freshwater discharge caused by relative shifts in evaporation/precipitation. Interpreted changes are of lesser magnitude (i.e. 1 m or so) than those (~5–10 m) envisaged by Balabanov (2007). Conversely, Fouache et al. (2012) concluded that many estimates of Holocene sea level change in the Black Sea are exaggerated as they do not take into account local tectonics, primarily subsidence.

In this work, we refer to the generalized model of sea level change in the Middle-Late Holocene for the northern sector of Black sea coast as presented by Balabanov (2007), Martin et al. (2007) and Martin and Yanko-Hombach (2011) for correlation with new data from the Kuban delta lowland. On the basis of the reconstructions obtained from pollen records, N.S. Bolikhovskaya developed a pollen-climate-chronostratigraphic summary of climate-controlled sea level fluctuations for the last ~7400 cal years (Table 2; Fig. 8). Starting from the zonal attributes and inferred climatic characteristics of the dominant plant community in each of 17 reconstructed stages, a pollen record of paleoclimatic events has been developed. Furthermore, there is a good correlation with the climatic conditions inferred from the pollen data and phases of sea level change as postulated by Balabanov (2007) and modified by Martin and Yanko-Hombach (2011).

The Black Sea reconstructions (e.g. Balabanov, 2007; Martin et al., 2007; Martin and Yanko-Hombach, 2011) consider that six small amplitude transgressive and seven regressive phases are distinguished for the last 7400 years. When compared with the pollen-climate reconstructions in the present study, of the six transgressive stages one matches a period of relatively cool and humid climate (~3430–2910 cal yr BP) whereas five stages coincide with periods of relatively warm and humid climate: 6730–4660 cal yr BP, most probably corresponding to the Kalamitian transgressive phase; ~4400–3780 cal yr BP, presumably coinciding with the Dzhemetinian maximum transgression; ~2280–1540 cal yr BP correlatable with the Nimphaean transgressive phase; two unassigned phases are dated to ~1230–900 and ~830/730–580 cal yr BP.

Seven regressive stages recognized in the sea level reconstructions identified also provide close matches with our paleoclimatic records. Most probably, these include four intervals with relatively warm and dry climates: ~7400–6730 cal yr BP, supposedly corresponding to the Pontian regression in the scheme by Martin and Yanko-Hombach (2011); ~3780–3430 cal yr BP interval; ~2910–2280 cal yr BP coinciding with the Phanagorian regression recognized by many authors; an unassigned arid period ~900–830/730 cal yr BP. In addition, three periods of dry and relatively cold (or cool) climate have been identified: ~4660–4400 cal yr BP corresponding in all probability to the Khadzhybeian regression in the scheme by A.L. Chepalyga (2002); ~1540–1230 cal yr BP interval, correlatable with the Korsunian regression; ~580–300 cal yr BP interval coinciding with the Little Ice Age.

The obtained records of the pollen-paleoclimatic events are therefore confidently interpreted as evidence supporting the hypothesis that regards regional climatic cyclicity as a significant driving force for low amplitude fluctuations in Black Sea level interpreted (e.g. by Martin et al., 2007) during the Middle-Late Holocene. The close match between our inferred pollen-climate model and interpreted sea level changes suggest definite conformity between the two. The inferred sea level changes are likely to have been small amplitude events that did not always correspond with identical climatic events. The small-scale nature of sea level events, for example at the time of the Holocene climatic optimum (5.0–6.0 ky BP) when transgression of the Black Sea was relatively minor, are partly due to neotectonic subsidence during the Holocene as highlighted by Fouache et al. (2012).

6. Conclusions

The results of multidisciplinary studies performed shed light on vegetation, climatic and environmental dynamics on the Black Sea coasts of the Taman Peninsula. Climatic changes in the Middle and Late Holocene are interpreted against a background of local environmental, geomorphological conditions and sea level fluctuations.

The dynamics of phytocoenotic-climate successions have been recognized for the last ~7400 cal years in the Kuban delta region. Steppe and forest-steppe landscapes persisted during the latter part of the Atlantic and early Subboreal sub-periods of the Holocene between ~7400 and 6730 cal yr BP (steppe) and 6730–5160 cal yr BP (forest steppe). In the subsequent ~5000 cal years, the types of zonal vegetation (i.e. broadleaf forests, forest-steppe and steppe) replaced each other at least 14 times.

For the most part, periods with steppe and forest-steppe vegetation are likely to be associated with mostly warm and dry climates, whereas periods of forest-steppe and forest expansion are likely to be in response to mainly warm and increasingly humid climates.

Despite the complexities of interpreting past sea levels, there is a clearly expressed pattern which suggests a correlation in most cases between warm/dry climatic periods and minor Black Sea regressions, and more humid periods with Black Sea transgressions. These observations support the view that climate was a significant driver in relation to sea levels in the Black Sea during the Middle and Late Holocene, but that eustacy and subsidence were also important factors.

It is evident that vegetation and climatic signals were out of phase between the Taman/Kuban delta region and the lower Volga region. This suggests that regional climatic conditions were more important in driving vegetation change than global-scale climate events. As the link between climate and sea level appears to be strong, it follows that Black Sea and Caspian Sea levels are also likely to be out of phase during the Middle and Late Holocene.

Acknowledgments

This paper is a contribution to RGS Project No 18110, to IGCP 610 Project and to GM Project on theme “Paleoclimates, the natural environment development and long-term prediction of the environmental change”. The authors would like to thank two anonymous referees for constructive comments, which have significantly improved this manuscript.

References

Abramova, T.A., 1971. The results of spore-pollen analysis of modern sediments of the Caspian Sea and Dagestan coast. In: The Spore-pollen Analysis in Geomorphological Researches. Moscow State University Publishing House, Moscow, pp. 106–115 (in Russian).
Abramova, T.A., 1974. Reconstruction of the Paleogeographical Environment of the Quaternary Transgressions and Regressions of the Caspian Sea (On the Data of Paleobotany Investigations) (Thesis of the PhD dissertation). Moscow State University, Moscow, pp. 1–24 (in Russian).
Abramova, T.A., 1980. Change in moisture of the Caspian region during the Holocene identified based on palynological data. In: Fluctuations of Moisture in the Aral-caspian Region in the Holocene. Nauka, Moscow, pp. 71–74 (in Russian).
Abramova, T.A., 1985. Paleogeographical conditions of the Aral-Caspian region in the late Holocene time (by palynological data). In: Relief and Climate. VGO, Moscow, pp. 91–100 (in Russian).
Abramova, T.A., Turmanina, V.I., 1988. Climate change in the Caspian Sea region in the Late Holocene (from palynological, historical, and archival data). In: Holocene Paleoclimates of the European Territory of the USSR. Institute of Geography of the RAS of the USSR, Moscow, pp. 182–191 (in Russian).
Aksu, A.E., Mudie, P.J., Kaminski, M.A., Abrajano, T., Yaşar, D., 2002. Persistent Holocene outflow from the Black Sea to the eastern Mediterranean contradicts Noah's flood hypothesis. GSA Today 12, 4–9.
Balabanov, I.P., 2007. Holocene sea-level changes of the Black Sea. In: Yanko-Hombach, V., Gilbert, A.S., Panin, N., Dolukhanov, P.M. (Eds.), The Black Sea Flood Question: Changes in Coastline, Climate, and Human Settlement. Springer, New York, pp. 711–773.
Balabanov, I.P., 2009. Paleogeographical Prerequisites of Formation of the Modern Environments and the Long-term Forecast of the Holocene Terraces Development on the Black Sea Coast of the Caucasus. Dal'nauka, Vladivostok, p. 350 (in Russian).
Balabanov, I.P., Izmailov, Ya.A., 1988. Sea-level and hydrochemical changes of the Black Sea and Azov Sea during the last 20,000 years. Water Resour. 6, 54–62 (in Russian).
Bhattacharya, J.P., 2006. Deltas. In: Posamentier, H.W., Walker, R.G. (Eds.), Facies Models Revisited. SEPM (Society for Sedimentary Geology, Tulsa, Oklahoma) Special Publication No 84, pp. 237–292.
Bolikhovskaya, N.S., 1990. Palynological indication of environment changes in the Lower Volga region during the last 10,000 years. In: Lebedev, L.I., Maev, E.G. (Eds.), Issues of Geology and Geomorphology of Caspian Sea. Nauka, Moscow, pp. 52–68 (in Russian).
Bolikhovskaya, N.S., 1995a. The Evolution of Loess-paleosol Formation of Northern Eurasia. Moscow University Press, Moscow, p. 270 (in Russian).
Bolikhovskaya, N.S., 1995b. The Pleistocene Periglacial and Interglacial Environments in the East Ciscaucasian Loess Region. VINITI Press (No. 52-B95), Moscow, p. 125 (in Russian).
Bolikhovskaya, N.S., 2011a. Evolution of Climate and Landscapes in the Low Volga Region during the Holocene. Bulletin of Moscow University, pp. 13–27. Series 5. Geography. No 2, (in Russian).
Bolikhovskaya, N.S., 2011b. The pleistocene and Holocene of the North-Western caspian Sea region: climatostratigraphy, correlation and palaeoenvironments. Stratigr. Sedimentol. Oil-Gas Basins, Baku, Azerbaijan 1, 3–30.
Bolikhovskaya, N.S., Gorlov, Ju.V., Kaitamba, M.D., Porotov, A.V., Parunin, O.B., Fouache, E., 2002. Landscape-climate changes in the Taman peninsula during the last 6 thousand years. In: Problems of a History, Philology, Culture. Institute archaeology of RAS, XII, Moscow-Magnitogorsk, pp. 257–271 (in Russian).
Bolikhovskaya, N.S., Gorlov, Ju.V., Porotov, A.V., 2001. Ecological-paleogeographical conditions in the Taman peninsula during the antique epoch and preceding periods of the Holocene. In: Proceedings of the First International Seminar “Pollen as an Indicator of the Environment State and Paleoecological Reconstructions”. VNIGRI, Saint-Petersburg, pp. 33–36 (in Russian).
Bolikhovskaya, N., Kaitamba, M., Porotov, A., Fouache, E., 2004. Chapter 17.

Environmental changes of the Northeastern Black Sea's coastal region during the middle and late Holocene. In: Scott, E.M., et al. (Eds.), Impact of the Environment on Human Migration in Eurasia. Kluwer Academic Publishers, Dordrech, pp. 209–223.

Bolikhovskaya, N.S., Kasimov, N.S., 2008. Landscape and climatic changes in the Lower Volga during the last 10,000 years. In: Bolikhovskaya, N.S., Kaplin, P.A. (Eds.), Problems of Paleogeography and Stratigraphy of the Pleistocene. Issue 2. Faculty of Geography Press, Moscow, pp. 99–117 (in Russian).

Bolikhovskaya, N.S., Kasimov, N.S., 2010a. Environmental and climatic evolution of the lower Volga River region during the last 10 kyrs//the caspian region: environmental consequences of the climate change. In: Proceedings of the International Conference. Moscow, pp. 73–78.

Bolikhovskaya, N.S., Kasimov, N.S., 2010b. The Evolution of Climate and Landscapes of the Lower Volga Region during the Holocene. Geography, Environment, Sustainability, vol. 3. Faculty of Geography of Lomonosov Moscow State University and by the Institute of Geography of RAS, pp. 78–97. No 2.

Bolikhovskaya, N.S., Porotov, A.V., Faustov, S.S., 2014a. Climatic and environmental changes in the Kuban delta (northeastern sector of Black Sea's coastal region) during the last 7.0 ka. Stratigraphy and sedimentology of oil-gas basins. In: Special Issue Devoted to IGCP 610 Second Plenary Conference and Field Trip “From the Caspian to Mediterranean: Environmental Change and Human Response during the Quaternary” (12-20 October 2014, Baku, Azerbaijan). Baku. 2014. No 1, pp. 23–25.

Bolikhovskaya, N.S., Porotov, A.V., Kaitamba, M.D., Faustov, S.S., 2014b. Reconstruction of the Changes of Sedimentation Environments, Vegetation and Climate within the Black Sea Part of the Kuban River Delta Area for the Last 7000 Years. In: Series 5. Geography, vol. 1. Vestnik of Moscow University, pp. 64–74 (in Russian).

Bolikhovskaya, N.S., Varuschenko, A.N., Klimanov, V.A., 1989. New data on geochronology and pollen-stratigraphy of the Holocene sediments of the Lower Volga region//Geochronology of the Quaternary period. In: Abstr. Proceedings. All-Union Conf. Tallinn, p. 50.

Brückner, H., Kelterbaum, D., Marunchak, O., Porotov, A., Vött, A., 2010. The Holocene sea level history since 7500 BP e lessons from the eastern Mediterranean, the Black and Azov seas. Quat. Int. 225, 160–179.

Bukreeva, G.F., Vronsky, V.A., 1995. Palyno-stratigraphy and Paleogeography of the Caspian Sea in the Holocene Based on Paleoclimate Modeling Results//Palynology in Russia. M., V. 2, pp. 12–25.

Chebanov, M.S., Mishchenko, A.A., Shvidchenko, O.I., 1992. Chapter 10. Lake history of Kuban river delta. In: Lake history of the East-european Plain. Saint-Petersburg: Nauka, pp. 204–211 (in Russian).

Chepalyga, A.L., 2002. Chapter 11. The Black Sea. In: Velichko, Editor-in-chief Prof. A.A. (Ed.), Dynamics of Terrestrial Landscape Components and Inland and Marginal Seas of Northern Eurasia during the Last 130 000 Years. Atlas-monograph “Evolution of Landscapes and Climates of Northern Eurasia. Late Pleistocene – Holocene – Elements of Prognosis. II. General Paleogeography”. GEOS, Moscow, pp. 170–182 (in Russian).

Connor, S., Tomas, I., Kvavadze, E., 2007. A 5600-yr history of changing vegetation, sea levels and human impacts from the Black Sea coast of Georgia. Holocene 17, 25–36.

Cordova, C.E., Gerasimenko, N.P., Lehman, P.H., Kliukin, A.A., 2011a. Late pleistocene and Holocene paleoenvironments of Crimea: pollen, soils, geomorphology, and geoarchaeology. In: Buynevich, I.V., Yanko-Hombach, V., Gilbert, A.S., Martin, R.E. (Eds.), Geology and Geoarchaeology of the Black Sea Region: beyond the Flood Hypothesis GSA Special Papers 473. Geological Society of America, Boulder, pp. 133–164.

Cordova, C.E., Lehman, P.H., 2005. Holocene environmental change in southwestern Crimea (Ukraine) in pollen and soil records. Holocene 15, 263–277.

Cordova, C., Gerasimenko, N., Lehman, P., Kliukin, A., 2011b. Late Pleistocene and Holocene Paleoenvironments of Crimea: Pollen, Soils, Geomorphology, and Geoarchaeology. The Geological Society of America, pp. 133–164. Special Paper 473.

de Klerk, P., Haberl, A., Kaffke, A., Krebs, M., Matchutadze, I., Minke, M., Schultz, J., Joosten, H., 2009. Vegetation history and environmental development since ca 6000 cal yr BP in and around Ispani 2 (Kolkheti lowlands, Georgia). Quat. Sci. Rev. 28, 890–910.

Dyuzhova, K.V., 2013. Paleogeographical Reconstructions of the Azov Sea Basin in the Holocene According to Data of Palynological Analysis. Thesis abstract for the degree of candidate of geographical sciences. Murmansk, p. 25 (in Russian).

Fedorov, P.V., Skiba, L.A., 1960. Fluctuations in the levels of the Black Sea and caspian Sea during the Holocene. In: Proceedings of the USSR Academy of Sciences, Geological Series, 1960, N 4, pp. 24–34 (in Russian).

Filipova-Marinova, M., 2007. Archaeological and paleontological evidence of climate dynamics, sea-level change, and coastline migration in the Bulgarian sector of the circum-Pontic region. In: Yanko-Hombach, V., Gilbert, A.S., Panin, N., Dolukhanov, P. (Eds.), The Black Sea Flood Question: Changes in Coastline, Climate, and Human Settlement. Springer, Dordrecht, The Netherlands, pp. 453–481.

Filipova-Marinova, M., Pavlov, D., Coolen, M., Giosan, L., 2013. First high-resolution marinopalynological stratigraphy of Late Quaternary sediments from the central part of the Bulgarian Black Sea area. Quat. Int. 293, 170–183.

Fouache, E., Kelterbaum, D., Brückner, H., Lericolais, G., Porotov, A., 2012. The Late Holocene evolution of the Black Sea – a critical view on the so-called Phanagorian regression. Quat. Int. 266, 162–174.

Gerasimenko, N., 1995. Holocene landscape and climate changes in Southeastern Ukraine. In: climate and environment changes of East Europe during Holocene and late-middle pleistocene. In: Materials for IGU Conference “Global Changes and Geography”. Moscow, August 14–18, 1995, pp. 38–48.

Gerasimenko, N.P., 1997. The natural environment of human habitation in south-eastern Ukraine in the Late Glacial and Holocene (based on the paleographic study of archaeological sites). Arkheologicheskiy al'manakh Archaeol. Alm. 6, 3–64 (in Russian).

Grichuk, V.P., Zaklinskaya, E.D., 1948. The Analysis of Fossil Pollen and Spores and His Application in Paleogeography. Geographgiz, 1948, Moscow, p. 222 (in Russian).

Gvozdetsky, N.A., 1963. Caucasus: a Sketch of the Nature. Geographical State Publishing House, Moscow, p. 264 (in Russian).

Hughen, K.A., Baillie, M.G.L., Bard, E., Bayliss, A., Beck, J.W., Bertrand, C., Blackwell, P.G., Buck, C.E., Burr, G., Cutler, K.B., Damon, P.E., Edwards, R.L., Fairbanks, R.G., Friedrich, M., Guilderson, T.P., Kromer, B., McCormac, F.G., Manning, S., Bronk Ramsey, C., Reimer, P.J., Reimer, R.W., Remmele, S., Southon, J.R., Stuiver, M., Talamo, S., Taylor, F.W., van der Plicht, J., Weyhenmeyer, C.E., 2004. MarineO4. Marine radiocarbon age calibration, 0-26 cal kyr BP. Radiocarbon 46 (3), 1059–1086.

Isagulova, E.Z., 1978. Palynology of the Azov Sea. Naukova Dumka, Kiev, p. 88 (in Russian).

Kaitamba, M.D., 2005. Change of Vegetation in the Eastern Black Sea Region during the Late Neopleistocene and Holocene. Dissertation for the Degree of Candidate of Geographical Sciences. Lomonosov Moscow State University, Moscow, p. 170 (in Russian).

Kaplin, P., Porotov, A., Yanina, T., Gorlov, Y., Fouache, E., 2001. O Vozraste I Uslovijach Formirovaaanija Bugazskoi Peresipi. [The Age of Bugaz Spit and Peculiarity of its Formation] Vestnik Moskovskogo Universiteta. Geografia [Vestnik of Moscow state University, Geography. 2,], pp. 51–57 (in Russian).

Kelletat, D., 2005. A Holocene sea level curve for the eastern Mediterranean from multiple indicators. Z. Geomorphol. Bd. 137 (Supplement), 1–9.

Konikov, E., Likhodedova, O., Pedan, G., 2007. Paleogeographic reconstructions of sea-level change and Coastline migration on the northwestern Black Sea shelf over the past 18 kyr. Quat. Int. 167–168, 49–60.

Korotaev, V.N., 2012. Essays of Geomorphology of River Mouth and Coastal Systems: Selected Works. Faculty of Geography, MSU, Moscow, p. 494 (in Russian).

Kotova, N., Makhortykh, S., 2010. Human adaptation to past climate changes in the northern Pontic steppe. Quat. Int. 220, 88–94.

Krasnorutskaya, K.V., Novenko, E.Yu., 2011. Landscape and climatic reconstruction of the Asov Sea region in the late Holocene based on pollen data of sediments of the Azov Sea. In: Problems of Modern Palynology: Proceedings of the XIIIth Russian Palynological Conference. Syktyvkar, vol. II, pp. 119–123 (in Russian).

Kremenetski, C.V., 1991. Palaeoecology of Earliest Agricultural Tribes of the Russian Plain. Nauka, Moscow, p. 193 (in Russian).

Kremenetski, C.V., Chichagova, O.A., Shishlina, N.I., 1999. Palaeoecological evidence for Holocene vegetation, climate and land-use change in the low Don basin and Kalmyk area, southern Russia. Veg. Hist. Archaeobotany 8, 233–246.

Krijgsman, W., Stoica, M., Vasiliev, I., Popov, V.V., 2010. Rise and fall of the paratethys Sea during the Messinian Salinity crisis. Earth Planet. Sci. Lett. 290, 183–191.

Kroonenberg, S.B., Hoogendoorn, R.M., 2008. Field Excursion to the Volga Delta// Field Excursion to the Volga Delta. An Analogue for Paleo-Volga Deposits. Delft University of Technology, pp. 1–39.

Kvavadze, E.V., Rukhadze, L.P., 1989. The Vegetation and Climate of the Holocene in the Abkhaziya. Metsniereba, Tbilisi, p. 137 (in Russian).

Lavrushin, Yu.A., Spiridonova, E.A., Sulerzhitsky, L.D., 1991. Geological-paleoecological events in the north of the arid zone during the last 10,000 years. In: Geological-paleoecological Environments of the Quaternary. Moscow, 1991, pp. 87–104 (in Russian).

Leroy, S.A.G., 2010. Palaeoenvironmental and Palaeoclimatic Changes in the Caspian Sea Region since the Lateglacial from Palynological Analyses of Marine Sediment Cores. Geography, Environment, Sustainability. Faculty of Geography of Lomonosov Moscow State University and by the Institute of Geography of RAS, pp. 32–41. No 2 (vol. 3).

Leroy, S.A.G., Marret, F., Gibert, E., Chalie, F., Reyss, J.L., Arpe, K., 2007. River inflow and salinity changes in the Caspian Sea during the last 5500 years. Quat. Sci. Rev. 26 (25–28), 3359–3383.

Leroy, S.A.G., Tudryn, A., Chalié, F., López-Merino, L., Gasse, F., 2013. From the Allerød to the mid-Holocene: palynological evidence from the south basin of the Caspian Sea. Quat. Sci. Rev. 78, 77–97.

Mann, M.E., Zhang, Z., Rutherford, S., Bradley, R.S., Hughes, M.K., Shindell, D., Ammann, C., Faluvegi, G., Ni, F., 2009. Global signatures and dynamical origins of the Little Ice age and Medieval climate anomaly. Science 326, 1256–1260.

Marret, F., Mudie, P., Aksu, A., Hiscott, R.N., 2009. A Holocene dinocyst record of a two-step transformation of the Neoeuxinian brackish water lake into the Black Sea. Quat. Int. 197, 72–86.

Martin, R.E., Leorri, E., McLaughlin, P.P., 2007. Holocene sea-level and climate change in the Black Sea: multiple marine incursions and freshwater discharge events. Quat. Int. 167–168, 61–72.

Martin, R.E., Yanko-Hombach, V., 2011. Rapid Holocene sea-level and climate change in the Black Sea: an evaluation of the Balabanov sea-level curve. In: Buynevich, I.V., Yanko-Hombach, V., Gilbert, A.S., Martin, R.E. (Eds.), Geology and Geoarchaeology of the Black Sea Region: beyond the Flood Hypothesis GSA Special Papers 473. Geological Society of America, Boulder, pp. 51–58.

Matishov, G.G., Kovaleva, G.V., Novenko, E.Yu., Krasnorutskaya, K.V., Polshin, V.V.,

2013. Paleogeography of the Sea of Azov region in the Late Holocene (reconstruction by diatom and pollen data from marine sediments). Quat. Int. 284, 123–134.
Matishov, G.G., Novenko, E.Yu., Krasnorutskaya, K.V., 2011. Landscape dynamics of the Asov Sea region in the late Holocene. Vestn. Yuzhnogo Nauchnogo Tsentra 7 (3), 35–43 (in Russian).
Matishov, G.G., Novenko, E.Yu., Krasnorutskaya, K.V., 2012. Climate changes in the Azov sea region in the late Holocene. Dokl. Earth Sci. 444 (No. 3), 1–5 (in Russian).
Mayewski, P.A., Rohling, E.E., Stager, J.C., Karlén, W., Maasch, K.A., Meeker, L.D., Meyerson, E.A., Gasse, F., van Kreveld, S., Holmgren, K., Lee-Thorp, J., Rosqvist, G., Rack, F., Staubwasser, M., Schneider, R.R., Steig, E.J., 2004. Holocene climate variability. Quat. Res. 62, 243–255.
Mishchenko, A.A., 2002. Paleogeography of the Eastern Azov Sea Region in the Holocene (By Palynological Data). Abstract of thesis for the degree of candidate of geographical sciences. Rostov-on-Don, p. 23 (in Russian).
Nevessky, E.N., 1970. Holocene history of the coastal shelf zone of thenUSSR in relation with processes of sedimentation and condition of concentration of useful minerals. Quaternaria 12, 78–88.
Pirazzoli, P.A., 1991. World Atlas of Holocene Sea-level Changes. Elsevier, Amsterdam, p. 300.
Popov, S.V., Rostovtseva, Y.V., Filippova, N.Y., Golovina, L.A., Radionova, E.P., Goncharova, I.A., Vernyhorova, Y.V., Dykan, N.I., Pinchuk, T.N., Iljina, L.B., Koromyslova, A.V., Kozyrenko, T.M., Nikolaeva, I.A., Viskova, L.A., 2016. Paleontology and stratigraphy of the middle–upper Miocene of the taman peninsula: Part 1. Description of key sections and benthic fossil groups. Paleontol. J. 50 (10), 1–168.
Porotov, A.V., 2013. Changes of the Black Sea Level during the Holocene According to Geo-archeological Indicators. In: Series 5. Geography, vol. 1. Vestnik of Moscow University, pp. 76–82 (in Russian).
Porotov, A.V., Gorlov, Yu.V., Yanina, T.A., 2004. Features of development of the Black Sea coast of taman peninsula in the late Holocene. Geomorphology 2, 63–77 (in Russian).
Reimer, P.J., Baillie, M.G.L., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Ramsey, C.B., Buck, C.E., Burr, G.S., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hajdas, I., Heaton, T.J., Hogg, A.G., Hughen, Kaiser, K.F., Kromer, B., McCormac, F.G., Manning, S.W., Reimer, R.W., Richards, D.A., Southon, J.R., Talamo, S., Turney, C.S.M., Plicht von, J., Weyhenmeyer, C.E., 2009. IntCal09 and Marine09 Radiocarbon age calibration curves, 0–50,000 years cal BP. Radiocarbon 51 (4), 1111–1150.
Richards, K., Bolikhovskaya, N.S., 2010. Palynology of pre-Holocene and Holocene shallow cores from the Damchik region of the Volga delta: palynological assemblages, zones, depositional environments and caspian Sea level//the caspian region: environmental consequences of the climate change. In: Proceedings of the International Conference. Geographical Faculty Press, Moscow, pp. 126–129.
Richards, K., Mudie, P., Rochon, A., Athersuch, J., Bolikhovskaya, N.S., Hoogendoorn, R.M., Verlinden, V., 2017. Late Pleistocene to Holocene evolution of the Emba Delta, Kazakhstan, and coastline of the north-eastern Caspian Sea: sediment, ostracods, pollen and dinoflagellate cyst records. Palaeogeogr. Palaeoclimatol. Palaeoecol. 468, 427–452.
Richards, K., Bolikhovskaya, N.S., Hoogendoorn, R.M., Kroonenberg, S.B., Leroy, S.A.G., Athersuch, J., 2014. Reconstructions of deltaic environments from Holocene palynological records in the Volga delta, northern Caspian Sea. Holocene 24 (10), 1226–1252.
Saintot, A., Angelier, J., 2000. Plio-Quaternary paleostress regimes and relation to structural development in the Kertch-Taman peninsulas (Ukraine and Russia). J. Struct. Geol. 22, 1049–1064.
Sapelko, T.V., Subetto, D.A., 2007. Vegetation change reconstruction during the Holocene in the north-western Crimea, based on pollen data. In: Yanko-Hombach, V. (Ed.), Extended Abstracts IGCP 521-481 Joint Meeting and Field Trip, Gelendzhik-kerch, September 8-17, 2007. Rosselkhozakademiya Printing House, Moscow, pp. 135–136.
Shumilovskikh, L.S., Tarasov, P., Arz, H.W., Fleitmann, D., Marret, F., Nowaczyk, N., Plessen, B., Schlütz, F., Behling, H., 2012. Vegetation and environmental dynamics in the southern Black Sea region since 18 kyr BP derived from the marine core 22- GC3. Palaeogeogr. Palaeoclimatol. Palaeoecol. 337/338, 177–193.
Spiridonova, E.A., 1991. The Vegetation Evolution of the Don Drainage-basin in the Late Pleistocene and Holocene (Upper Paleolithic-bronze Time). Nauka, Moscow, p. 221 (in Russian).
Spiridonova, E.A., Lavrushin, Y.A., 1997. Correlation of the Geological and the Paleoecological Events of Holocene of Arctic, Boreal and Arid Zones of East Europe. Quaternary Geology and the Paleogeography of Russia. Russian Academy of Sciences, Moscow, pp. 151–170.
Svitoch, A.A., 2011. The Holocene History of the Caspian Sea and Other Peripheral Basins of European Russia: Comparative Analysis. In: Series 5. Geography, vol. 2. Vestnik of Moscow University, pp. 28–37 (in Russian).
Svitoch, A.A., 2012. General Paleogeography. History of Intercontinental Southern Seas of Russia and Adjacent Territories (Selected Papers. Vol. 2). Lomonosov Moscow state University Press, Moscow, p. 608 (in Russian).
Gribova, S.A., Isachenko, T.I., Lavrenko, E.M. (Eds.), 1980. The Vegetation of the European Part of the USSR. Nauka, Leningrad, p. 429 (in Russian).
Varuschenko, A.N., Varuschenko, S.I., Klige, R.K., 1980. Changes in the caspian Sea level in the late pleistocene-Holocene. In: Moisture Fluctuations of the Aral-caspian Region in the Holocene. Nauka, Moscow, pp. 79–89 (in Russian).
Varuschenko, S.I., Varuschenko, A.N., Klige, R.K., 1987. Changes in the Regime of the Caspian Sea and the Drainage Basins in Paleo-time. Nauka, Moscow, p. 239 (in Russian).
Vasiliev, I., Iosifidi, A., Khramov, A., Krijgsman, W., Kuiper, K., Langereis, C., Popov, V., Stoica, M., Tomsha, V., Yudin, S., 2011. Magnetostratigraphy and radio-isotope dating of upper Miocene-lower Pliocene sedimentary successions of the Black Sea basin (taman peninsula, Russia). Palaeogeogr. Palaeoclimatol. Palaeoecol. 310, 163–175.
Vronsky, V.A., 1976. Marine Palynology of the Southern Seas. Rostov State University, Rostov-on-Don, p. 200 (in Russian).
Vronsky, V.A., 1980. Holocene history of the Caspian Sea from palynological data. In: Fluctuations of Moisture in the Aral-caspian Region in the Holocene. Nauka, Moscow, pp. 74–79 (in Russian).
Vronsky, V.A., 1984. Paleogeography of the Asov Sea in the Holocene. Isvestiya Acad. Nauk. Ser. Geogr. 2, 66–71 (in Russian).
Vronsky, V.A., 1987. Stratigraphy and paleogeography of the caspian Sea during the Holocene//bulletin of the USRR Academy of Sciences. Geology 2, 73–82 (in Russian). (Translated in: International Geology Review, 1987, 14–24.).
Weninger, B., Jöris, O., Danzeglocke, U., 2007. CalPal-2007: Cologne Radiocarbon Calibration & Palaeoclimate Research Package. http://www.calpal.de/.
Yanko, V.V., 1990. Stratigraphy and Paleogeography of Marine Pleistocene and Holocene Deposits of the Southern Seas of the USSR: Memorie Della Societa Geologica Italiana, pp. 167–187, v. 44. .
Yanko-Hombach, V., 2007. Controversy over Noah's flood in the Black Sea: geological and foraminiferal evidence from the shelf. In: Yanko- Hombach, V., Gilbert, A.S., Panin, N., Dolukhanov, P. (Eds.), The Black Sea Flood Question: Changes in Coastline, Climate, and Human Settlement. Springer, Dordrecht, The Netherlands, pp. 149–203.