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First evidence of agro-pastoral farming and anthropogenic impact in the Taman Peninsula, Russia

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ABSTRACT

Debate on the complex coevolution that has shaped interactions between forested ecosystems and humans through constantly evolving land-use practices over the past millennia has long been centered on the Mediterranean because this area is seen as the cradle for the birth and growth of agricultural activities. Here, we argue that the transition from hunting–gathering by Mesolithic foragers to the food-producing economy of Neolithic farmers was a main trigger of biological changes not only in the Mediterranean but also in the Black Sea and Azov Sea coasts through woodcutting, herding, fire and agriculture. Although the ecological erosion was clearly focused on forested ecosystems, this process seems to have fostered an increased biodiversity. We show, by focusing on the fertile coast of the Azov Sea, that (i) the first evidence of cereal cultivation and human-induced fire occurred in southern Russia 7000 years ago; (ii) the early development of agriculture was a major but discontinuous process; (iii) the coastal ecosystems were rapidly disturbed by anthropogenic activities; and (iv) the Neolithic was a critical threshold for the forested ecosystems of the coastal area. The impact of early anthropogenic pressures seems to have been largely neglected or underestimated for the period encompassing the Neolithic cultural phase.

1. Introduction

Although the onset of agriculture about 10,000 years ago in the Pre-Pottery Neolithic Near East is considered as a crucial event in human history (Lev-Yadun et al., 2000), the impact of expanding anthropogenic activities on the biosphere has largely been neglected. There is clearly a paucity of data concerning the environmental stresses caused by these new forms of anthropogenic impacts. The Neolithic, also dubbed the “Agricultural Revolution” (Kislev et al., 2004), emerged in the Levantine Corridor, a narrow geographic region located between the northeast Mediterranean

Sea and the desert to the southeast (Blockley and Pinhasi, 2011). Because estimating the timing of plant domestication has been, and still is, fundamental to understanding and reconstructing the cultural processes underlying the Neolithic, several authors have long debated the chronology of this process (e.g. Pringle, 1998; Salami et al., 2002; Hartmann et al., 2006; Kislev et al., 2006; Tanno and Willcox, 2006; Weiss et al., 2006; Lev-Yadun et al., 2006a, 2006b), leaving aside the secondary markers of the ongoing changes. The increased pressures on the local environment through the adoption of a sedentary lifestyle, the early development of urbanization, and demographic growth, must have left deep imprints in the ecosystems, but this factor is rarely considered in Neolithisation models (e.g. Banffy, 2006; Linstädter et al., 2012). However, some recent studies are trying to address this by focusing on how growing conditions, farming practices and crop domestication have evolved since the onset of agriculture. Understanding

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these processes is crucial in revealing the complexity and dynamics of ancient societies in order to comprehend current Mediterranean landscapes (e.g. Arous et al., 2006).

Di Castri (1981) has suggested that a complex coevolution has shaped the interactions between ecosystem components and human societies, but without clarifying when this process began. Blondel (2006) has summarized the two contrasting concepts that consider these interactions in the Mediterranean: (i) the “Lost Eden theory” suggests that deforestation and overgrazing resulted in the degradation and desertification of Mediterranean landscapes (e.g. Naveh and Dan, 1973; Thirgood, 1981; Attenborough, 1987; McNeil, 1992); (ii) by contrast, the opposite school of thought argues that human societies have contributed to the maintenance, diversity, and even the embellishment of Mediterranean landscapes (Grove and Rackham, 2001). Although the reality almost certainly lies between these two extremes (Blondel, 2006), outcomes from neighboring regions such as the Black Sea and the Azov Sea (Bolikhovskaya et al., 2014) may shed new light on this key debate.

Here we present a numerical-derived environmental proxy based on a detailed pollen record retrieved from the alluvial deposits of the Kuban Delta, Taman Peninsula, and covering the period 7800–4600 cal yr BP. This record provides the first reconstruction of the landscape evolution in southernmost coastal Russia, at the edge between the Black Sea and the Azov Sea, and provides insights into the ecosystem dynamics following the introduction and development of agricultural practices in this fertile area. Around 4500 years before the Greek colonization of the peninsula and the foundation of Phanagoria (Kuznetsov, 2003), the growing impact of agricultural practices has drawn a parallel between the ecological erosion recorded in the Black Sea/Azov Sea coastal areas and the Mediterranean regions.

2. Site description

Taman is a 75 by 35 km peninsula located in southern Russia (Fig. 1), to the east of the Kerch Strait, separating the Black Sea from the Azov Sea. The regional climate is temperate continental. At the nearby city of Krasnodar, present mean monthly temperatures

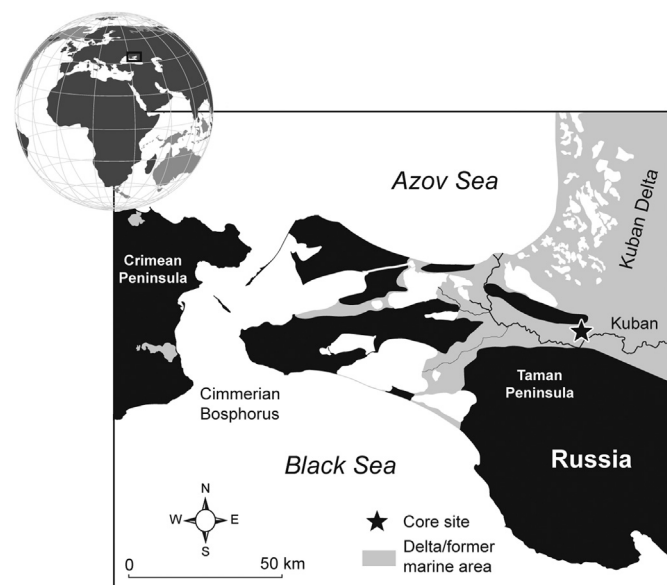


Fig. 1. Map of the Taman Peninsula with the location of the core site and the position of the former marine area. Core ORI 09 was drilled in September 2012. The core site presently lies 1.5 m above MSL, 25 km from the Azov Sea and 37 km from the Black Sea.

range from $-4\text{ }^{\circ}\text{C}$ to $32\text{ }^{\circ}\text{C}$ and mean annual precipitation varied between 361 and 543 mm during the period 2008–2010. Today, the Taman Peninsula belongs to the northern Pontic steppe belt, which has been largely transformed by agricultural processes. Dominant species include *Stipa lessingiana*, *S. ucrainica*, *S. rubens*, and *Festuca sulcata* s.l. (Walter, 1974). Southward, the forest-steppe zone covers the lower slopes of the North Caucasus Mountains. The broad-leaved forests begin above 200–300 m above mean sea level (MSL) and are dominated by *Quercus* (*Quercus petraea*, *Q. hartwissiana*), *Carpinus*, *Fraxinus*, *Ulmus* (*U. scabra*) and *Acer* (Tseplyaev, 1965). During the mid-Holocene, following the marine transgression of the peninsula, the Taman comprised an archipelago of four islands that have since been landlocked by fluvio-deltaic sediments deposited by the Kuban River, whose vast 4300 km² delta straddles both the Black Sea and the Azov Sea (Kelterbaum et al., 2011). This palaeo-geographic context made the peninsula particularly attractive to early human activities and the peninsula became a centre of Greek and Roman culture, articulated around these palaeo-islands, from the 6th century BC onwards (Giame et al., 2014). In a broadly stable sea-level context during the past 3000 years, sediment supply has been the key driver of geomorphological change on the Taman Peninsula, indirectly mediating the geography of human settlement on the peninsula.

3. Material and methods

Biological indicators, extracted from a 975-cm continuous core (ORI 09, $45^{\circ}9'59.80''\text{N}$, $37^{\circ}39'22.86''\text{E}$; +1.5 m MSL, about 25 km from the Azov Sea and 37 km from the Black Sea) drilled in September 2012 in the Taman Peninsula, were used to reconstruct the long-term ecosystem dynamics and plant distribution in the coastal area of southern Russia. No gaps or unconformities were observed in the core logs and laboratory data.

3.1. Chronology

The chronology of core ORI 09 (Fig. 3) is based on five accelerator mass spectrometry (AMS) radiocarbon (¹⁴C) dates on short-lived samples (seeds and small leaves) and charcoal remains (Table 1) at 860 cm ($6340 \pm 30\text{ }^{14}\text{C yr BP}$), 830 cm ($6160 \pm 30\text{ }^{14}\text{C yr BP}$), 790 cm ($6050 \pm 30\text{ }^{14}\text{C yr BP}$), 590 cm ($4720 \pm 30\text{ }^{14}\text{C yr BP}$), and 568 cm ($4130 \pm 30\text{ }^{14}\text{C yr BP}$). Although no single value, neither the intercept nor any other calculation, adequately describes the complex shape of a radiocarbon probability density function (Telford et al., 2004), a single value has to be used to calculate the time-scale for numerical analyses. Compaction corrected deposition rates have been computed between the intercepts of adjacent ¹⁴C ages. Because samples have been taken at regular distances on the 975 cm sediment column, the time resolution is directly dependent on the sedimentation rate. Plant remains are scarce in the lower part of the core ORI 09, limiting an extended chronology. No plant remains were found in the upper part of the sedimentary deposits (Fig. 2).

3.2. Biological data

A total of 98 samples were prepared for pollen analysis using the standard palynological procedure for clay samples. Only the chronologically well-constrained samples were preserved (from 975 to 568 cm depth; Fig. 2). Pollen grains and dinoflagellate cysts were counted under $\times 400$ and $\times 1000$ magnification. Pollen frequencies (%) are based on the terrestrial pollen sum excluding local hygrophytes and spores of non-vascular cryptogams. Aquatic taxa frequencies are calculated by adding the local hygrophytes-hydrophytes to the terrestrial pollen sum. The aquatic taxa scores

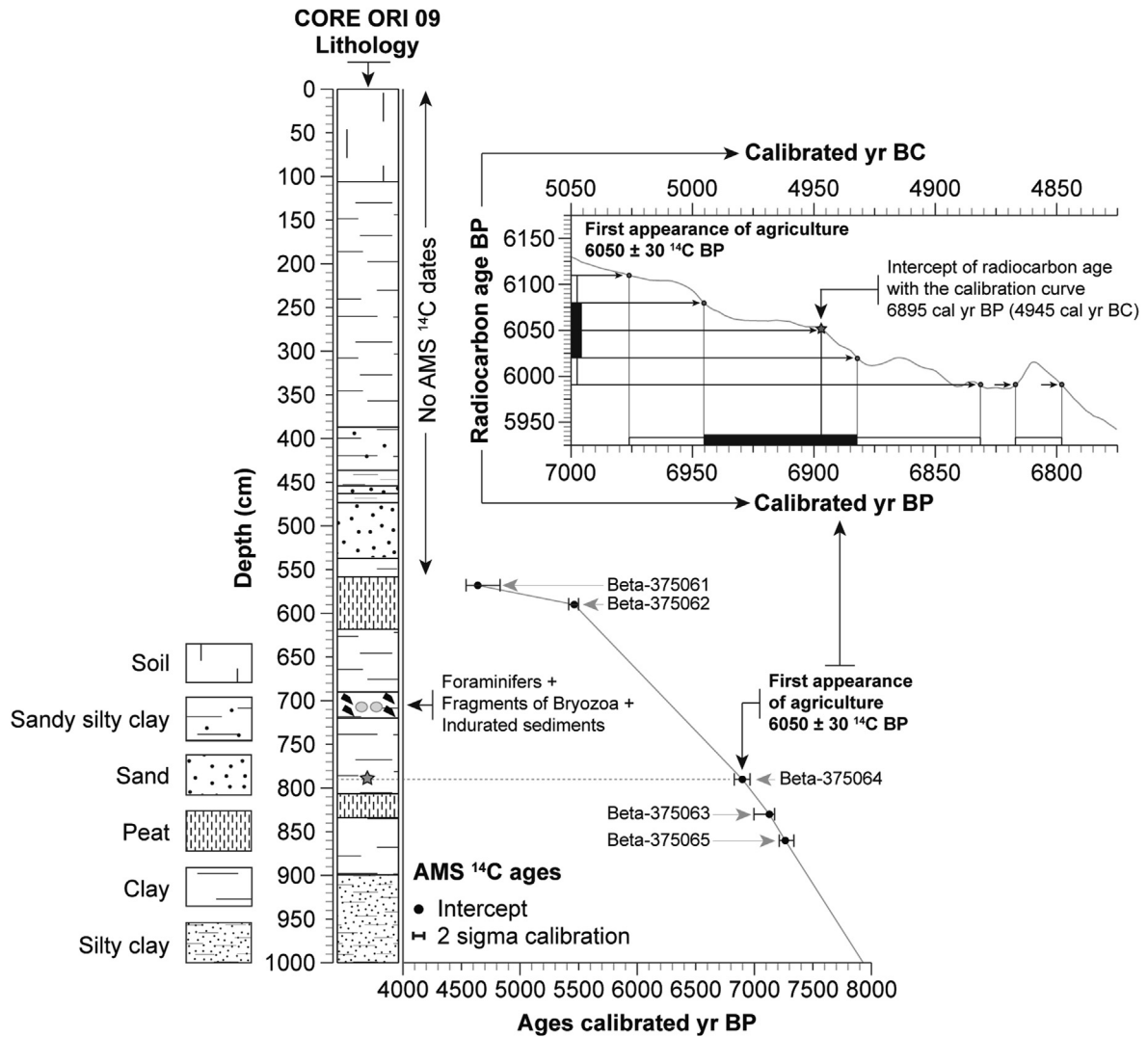


Fig. 2. AMS ^{14}C calibrated ages and age-depth curve. The 975-cm core presents a classic transgressive-regressive sequence of marginal marine and fluvio-deltaic sediments consistent with the drowning and subsequent progradation of the Kuban Delta. The ^{14}C date for introduction of agro-farming practices is denoted in the upper part of the graph.

were calculated by summing the local hygrophytes-hydrophytes. Dinoflagellate cysts were counted on pollen-slides and are displayed as concentrations (cysts per cm^3). All pollen data were transformed into pollen-derived biomes (PdBiomes) (Tarasov et al., 1998), with Desert (DESE), Steppe (STEP), Xerophytic woods/scrubs (XERO), Warm mixed forest (WAMX), Cool mixed forest (CMF), Temperate deciduous forest (TDF), Cool conifer forest (CCF) and Cold mixed forest (CdMF). A Margalef's richness index (M^{RI}) was also computed on the data set to estimate variations in the alpha diversity through time.

3.3. Fire history

The fire history of the coastal plain was reconstructed by counting charcoal particles (50–200 μm) from the 98 slides prepared for pollen analysis as well as from larger charcoal remains (>200 μm) (Gavin et al., 2006; Higuera et al., 2007). The 50 μm size criterion was chosen to avoid confusion of microscopic charcoal fragments with opaque minerals, which are typically <50 μm (Parshall and Foster, 2002; Pederson et al., 2005). Macroscopic charcoals, extracted with Na_2HPO_4 , were sorted and counted under a binocular microscope (at $\times 36$).

3.4. Numerical analyses

Pollen data were analysed using neighbour joining (NJ) analysis (Fig. 3). The NJ method is an alternative process for hierarchical cluster analysis, finding hierarchical groupings in multivariate data sets. Here, it is based on pollen-type time-series (presence/absence and abundance). NJ analysis was used to compute the lengths of branches of a tree, using branches as ecological distances between groups of taxa (descending type). NJ was computed using *correlation* as the similarity measure and *outgroup* as root. The primary anthropogenic indicators from the cluster “cultivated species” were summed to create a pollen-derived vegetation pattern (Fig. 4).

Principal components analysis (PCA) was performed to test the ordination of samples by assessing major changes in the PdBiome -scores. Cultivated species and weeds are excluded from the matrix. The main variance is loaded by the PCA-Axis1. The PCA-Axis1 has been plotted on a linear age-scale with the M^{RI} , cultivated species and fire activity (Fig. 4).

To establish if the ecosystem dynamics were modulated by anthropogenic activities, and if the increase in weeds was influenced by agricultural disturbances, linear detrended cross-correlations (LDCC , $P = 0.05$) were computed (Fig. 5). The LDCC assesses the time alignment of two time series by means of the

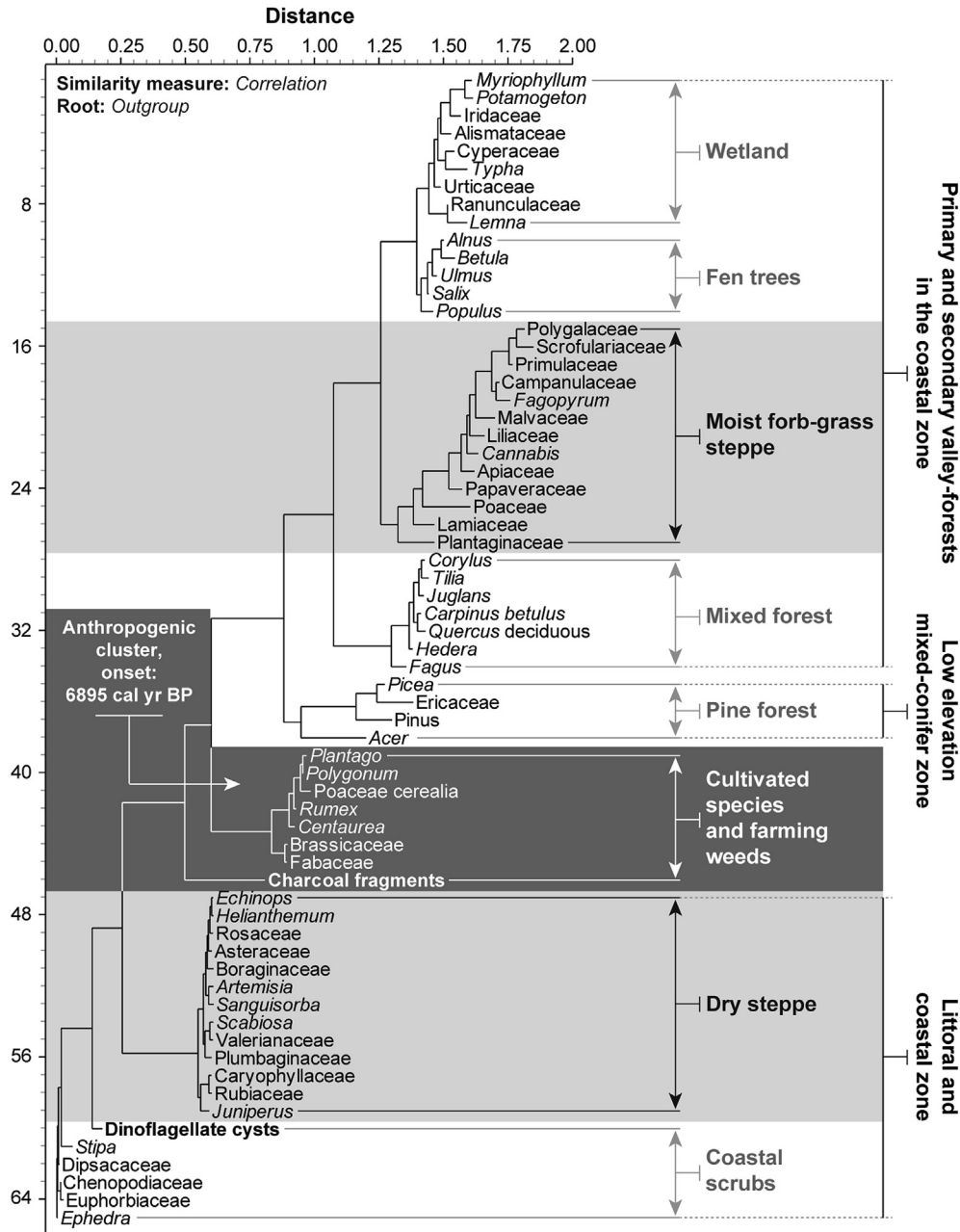


Fig. 3. Neighbour Joining analysis of the main taxa from the core ORI 09 computed with *correlation* as similarity measure and *outgroup* as root. The two stepic clusters (dry steppe and moist forb-grass steppe) are underlined in pale grey. The cluster that includes the indicators of anthropogenic activities is underlined in dark grey.

correlation coefficient (CC). The time-series have been cross-correlated to ascertain the best temporal match and the potential delay between the two time-series. The CC is then plotted as a function of alignment position. This numerical approach is well-

adapted to detect and quantify potential links between environmental data and anthropogenic activities. Positive correlation coefficients are considered, focusing on the Lag_0 value (with $+0.50$ as the significant threshold). Negative correlations are also assessed to

Table 1

Details of the radiocarbon age determinations for the core ORI 09. The radiocarbon ages are expressed in calibrated years BP and BC at 68–95% of probability.

Taman Peninsula – core ORI 09 – Russia								
Code	Depth (cm)	¹⁴ C yr BP	Calibrated dates BP		Calibrated dates BC		Intercepts	
			1σ – 68%	2σ – 95%	1σ – 68%	2σ – 95%	BP	BC
Beta-375061	568	4130 ± 30	4655–4575	4825–4530	2705–2625	2875–2580	4625	2675
Beta-375062	590	4720 ± 30	5475–5450	5485–5445	3525–3500	3535–3495	5470	3520
Beta-375064	790	6050 ± 30	6945–6880	6975–6830	4995–4930	5025–4880	6895	4945
Beta-375063	830	6160 ± 30	7160–7000	7165–6955	5210–5050	5215–5005	7125	5175
Beta-375065	860	6340 ± 30	7275–7255	7320–7245	5325–5305	5370–5295	7265	5315

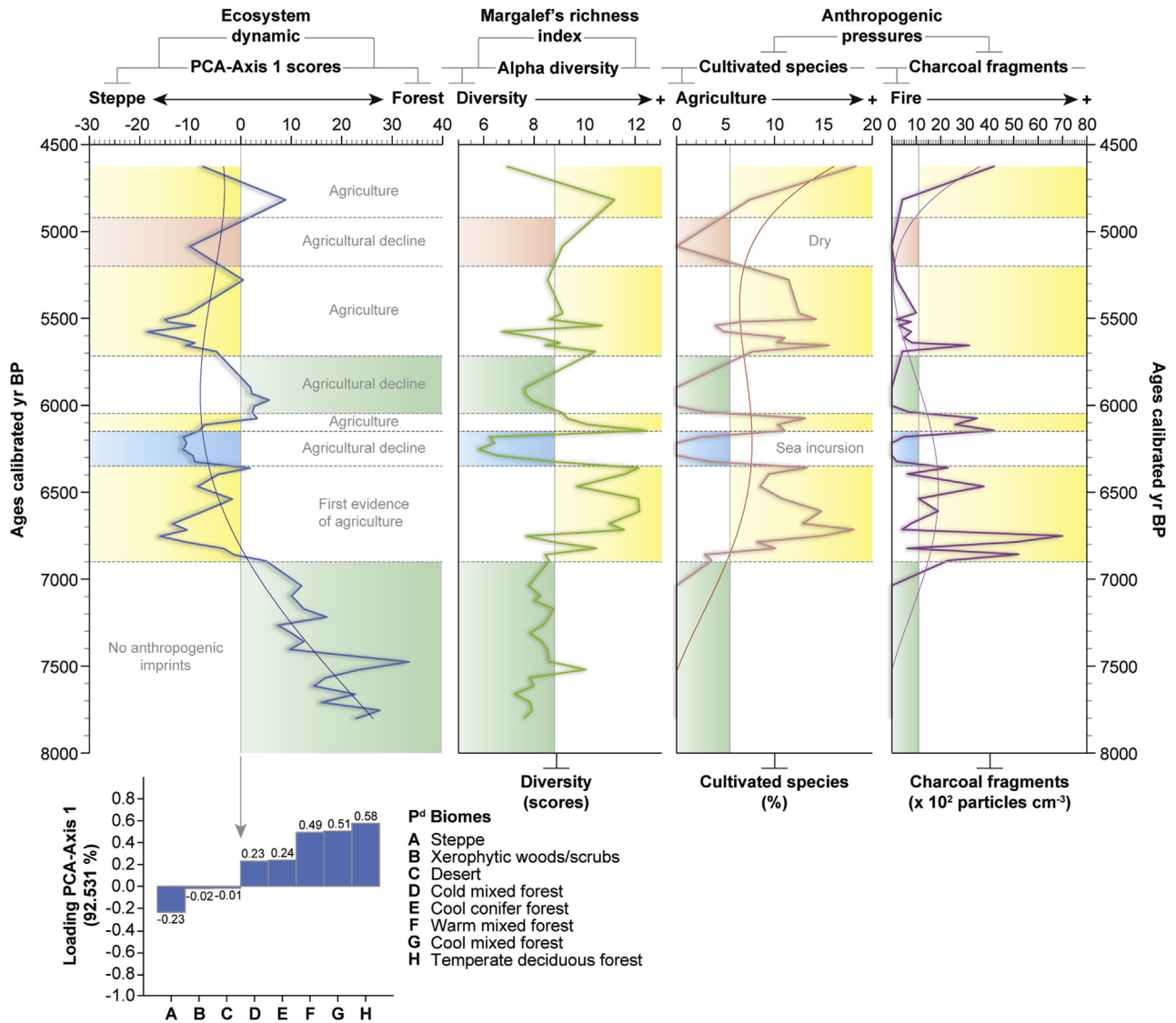


Fig. 4. A 3200-year environmental reconstruction of the coastal Azov Sea (7800–4600 cal yr BP). PCA-Axis1, Margalef's richness index, agriculture and fire are displayed as scores, percentages and concentrations plotted on a linear timescale. A polynomial curve was established for three components (PCA-Axis1, agriculture and fire activities) and plotted on a linear timescale. The anthropogenic periods are underlined in yellow, the marine incursion in blue and the climate shift in red.

test the inverse- or non-correlation between the two time-series (with -0.50 as the significant threshold). Non-significant values indicate a complete lack of correlation.

The ecosystem dynamics were also analysed using CABFAC analysis (Fig. 5) to test the impact of anthropogenic factors. The CABFAC factor analysis (Q-mode factor analysis) implements the classical method of factor analysis and environmental regression (CABFAC and REGRESS). Anthropogenic data are regressed on the CABFAC factors using the second-order (parabolic) method, with cross terms. The regression model (RMA) reports the observed values against the values reconstructed from the factors. The selected data for this study are the cultivated species. The consistency of the reconstructed model is indicated by the R^2 .

4. Results

Potential influence of anthropogenic activities on the ecosystem dynamics and biodiversity for the period 7800–4600 cal yr BP was investigated by applying different numerical analyses on the

palynological data. Cultivated species, weeds and fire activity, which are respectively direct and indirect indicators of agricultural practices in the area, are considered as biological and physical stresses on Holocene coastal ecosystems.

4.1. Onset of agricultural practices

The AMS ^{14}C date determined for the introduction of agricultural practices in the Taman Peninsula is 6050 ± 30 ^{14}C BP (Fig. 2), calibrated to 6975–6830 yr BP [2 sigma (σ) - 95% probability]. The intercept with the ^{14}C calibration curve gives an age of 6895 calibrated (cal) yr BP, indicating that since this date, anthropogenic activities, with a clear imprint in the environment, are recorded. The NJ analysis (Fig. 3) shows that the cultivated species were mostly cereals with some Brassicaceae and Fabaceae. The weeds, also termed secondary anthropogenic indicators (*Centaurea*, *Plantago*, *Polygonum*, *Rumex*), are included in the cultivated cluster, also with the fire activity, suggesting close relationships through time.

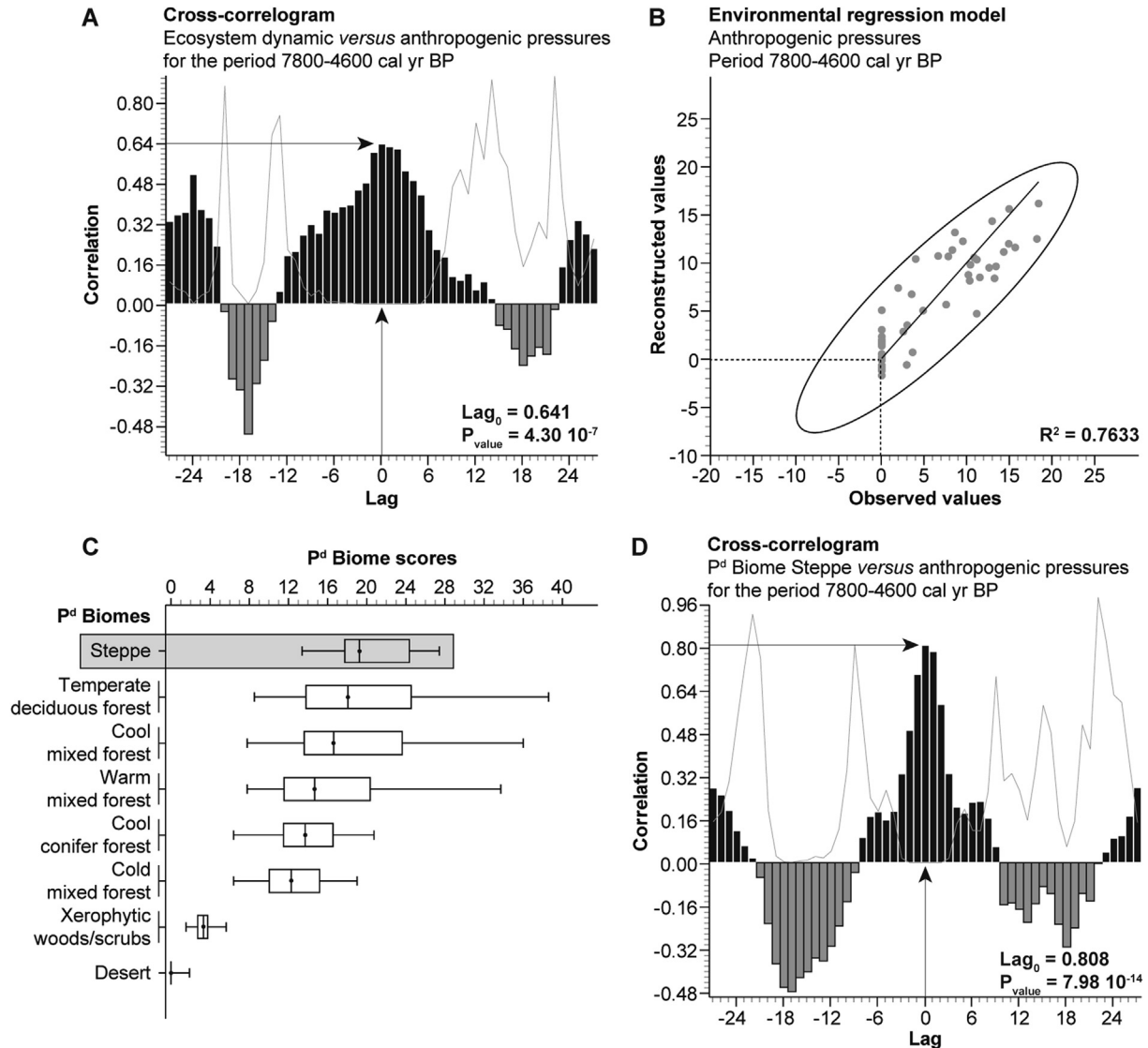


Fig. 5. Linear detrended cross-correlations ($P = 0.05$), regression model from the CABFAC analysis and the Boxplot are displayed as four items (A to D). A and D: the Lag_0 score and the associated P_{value} are indicated on each graph. B: the R^2 value of the regression model is also depicted on the graph. C: the P^d Biome Steppe is underlined in grey.

4.2. Ecosystem dynamics

PCA ordination was applied to the ORI 09 core samples (Fig. 4). PCA-Axis1 explains 92.53% of total inertia. PCA-Axes 2 and 3 respectively account for 5.58% and 0.98% of the total inertia. The PCA-Axis1 positive scores are loaded by forested components whereas negative scores correspond to steppe vegetation-types (Fig. 4). The PCA-Axis1 scores shows that, for the 7800–4600 cal yr BP period, the coastal vegetation has evolved from a forest (P^d Biomes WAMX, CMF, TDF, CCF and CdMF) to an open steppe (P^d Biomes STEP, DESE and XERO). The NJ analysis indicates that the steppic elements can be divided into two clusters, a wet (moist forb-grass steppe) and a dry steppe (Fig. 3). From 7800 to 6895 cal yr BP, the area was covered by a dominant forest comprising *Carpinus betulus*, *Quercus deciduous* and *Fagus*. The introduction of agriculture at 6895 cal yr BP induced an important decrease in the forested cover but a rise in biodiversity (Fig. 4). Five periods of open steppe development have been identified in the area at 6860–6400, 6350–6150, 5700–5300, 5200–4950 and 4625 cal yr BP. Only three of them, however, can be unequivocally attributed to human pressures (strong increase of anthropogenic

indicators), suggesting other stresses on the ecosystems. The three anthropogenic phases, underlined by the lowest values on the PCA-Axis 1, are well correlated with increased M^{RI} scores.

4.3. Agricultural decline

Three phases of decline were recorded for the period 7800–4600 cal yr BP. The first phase is linked with an increase in dinoflagellate cysts (Fig. 4). The sea invasion, that reached the coring site at 6350 cal yr BP, acted like an erosive agent, leading to an accentuated alteration of terrestrial ecosystems. Locally, the M^{RI} curve indicates an important loss of diversity. The agricultural decline is linked to a ca 200-year marine inundation at 6350 cal yr BP. This marine transgression, expressed by dinoflagellate cysts, foraminiferas and fragments of Bryozoa (Fig. 2), can be attributed to the maximum marine ingression during the mid-Holocene and is consistent with the formation of deltaic systems in both the Black Sea and the Mediterranean (Stanley and Warne, 1994). The transgressive contact, between –615 and –585 MSL, fits tightly with RSL data from the Taman Peninsula (Porotov, 2007; Brückner et al., 2010; Fouache et al., 2012), attesting to a rapid sea-

level rise between 7000 and 4500 cal BP. The progradation of the Kuban Delta in this area is recorded after around 6000 years ago. The pollen record demonstrates that these coastal dynamics facilitated the recolonization of the area by human societies. The rich deltaic resources would have provided a multiplicity of opportunities for human activities and agriculture. The relatively rapid shift (around 200 years) is consistent with high sediment supply from the Kuban River and the relatively limited accommodation space of the ria system. The subsequent coastal progradation that ended at ca 6150 cal yr BP upon the coring site is correlated with a new phase of agriculture (mainly comprising cereals). The second phase of agricultural decline, ca 6000–5700 cal yr BP, seems to be independent of physical pressures on anthropogenic activities and can be solely attributed to human factors (e.g. lower density of population, migrations, or a reduced society mainly focused on local pastoral activities). The third phase seems to be linked with the stresses resulting from the 5.2 ka BP event (Andreev et al., 2004; Kotova and Makhortykh, 2010; Zakh et al., 2010).

4.4. Link between ecosystem dynamics and agricultural practices

The cross-correlogram (Fig. 5A), resulting from the LDCC ($P = 0.05$), shows a positive and significant correlation between the ecosystem dynamic and the anthropogenic activities (+.641) for the period 7800–4600 cal yr BP, suggesting that human pressures were a structuring factor behind the observed changes. This implies that, in the Taman Peninsula, three main parameters may have influenced the ecosystem dynamics: important geomorphological processes, climate shifts and anthropogenic activities. This result is strengthened by the RMA that highlights the role of anthropogenic activities as a decisive factor, with an R^2 of +.7633 (Fig. 5B). The boxplot (Fig. 5C) further indicates that the main P^d Biome for the considered period is STEP. The second cross-correlogram (Fig. 5D) shows that the P^d Biome STEP is positively and significantly correlated with the anthropogenic activities (+.808; e.g. deforestation, agriculture, pastoralism), suggesting strong coupling through time.

5. Discussion

Full understanding of the ecological consequences resulting from the introduction and development of agriculture practices in the coastal area of the Taman Peninsula is challenging (Adger et al., 2005; Kaniewski et al., 2014), where complex biological mechanisms need to be considered. Since the mid-Holocene, human populations are concentrated along coasts and, accordingly, coastal ecosystems are amongst the most heavily modified environments worldwide (Adger et al., 2005). The capacity of ecological systems to absorb recurrent disturbances, such as anthropogenic pressures, so as to retain essential structures and processes, is hard to quantify for the past. Several abiotic stresses (e.g. RSL changes, floods, and drought) have also played a role in the observed changes, adding pressures to the coastal ecosystem dynamics (Fig. 4).

5.1. Onset of agricultural practices

The spread of agro-pastoral farming from the Fertile Crescent (Colledge et al., 2005; Weninger et al., 2006), and especially the diffusion (and local inventions) of agricultural practices (Dolukhanov et al., 2005; Velichko et al., 2009), may have been one of the primary drivers behind environmental shifts recorded since the Neolithic in the eastern Mediterranean, Black Sea and Azov Sea. The spread of the Neolithic and the adoption of farming in Western Asia and Europe largely coincided with the Climatic Optimum of the Holocene (Dolukhanov and Shilik, 2007).

There are no radiocarbon dates available for the emergence of agro-pastoral farming in the Taman Peninsula. Our results may have filled this knowledge gap by providing the first evidence of agriculture practices at 6050 ± 30 ^{14}C yr BP (2σ calibration: 6975–6830 cal yr BP), at the end of the Neolithic period. This radiocarbon-dated evidence seems to be coherent with an agricultural dispersal that followed the Caucaso–Caspian corridor and the Eurasian steppe (Motuzaitė-Matuzeviciute, 2012).

The emergence of agriculture dates back to the Pre-Pottery Neolithic A culture in the Near East (11,700/11,400–10,300 calendar yr BP; Blockley and Pinhasi, 2011), whereas the first domesticated grains seem to have appeared during the period from 11,000–10,500 to 9300–9000 uncalibrated yr BP (Lev-Yadun et al., 2000; Salamini et al., 2002; Weiss et al., 2006). Studies focused on wheat in northern Syria and southern Turkey have mainly shown an increase in the cultivated form during the Pre-Pottery Neolithic B culture, since 9250 uncalibrated yr BP (Tanno and Willcox, 2006). The oldest charred botanical remains from Aratashen and Aknashen, the earliest known agricultural settlements in the Republic of Armenia, were radiocarbon-dated to 6821 ± 46 ^{14}C BP (2σ calibration: 7740–7580 cal yr BP) and 7035 ± 69 ^{14}C BP (2σ calibration: 7975–7705 cal yr BP), giving an accurate time-window for the introduction of cultivated plants (Hovsepian and Willcox, 2008) near the Caucasus corridor.

Archaeobotanical and archaeological evidence from Eastern Ukraine and southwestern Russia have suggested that cereal cultivation began later, during the Chalcolithic period, with a maximum recorded for the Sredny-Stog culture (Motuzaitė-Matuzeviciute, 2012) at 4400–3500 cal yr BC (6350–5450 cal yr BP; Telegin et al., 2003). A statistical analysis, based on Early Neolithic sites distributed from the Eastern European Plain to Central Europe, shows a concentration of radiocarbon dates in the 5300–4900 cal yr BC (7250–6850 cal yr BP) time-window, but with a high heterogeneity and a maximum at 6910 cal BC (8860 cal yr BP) for the Yelshanian Culture (Dolukhanov et al., 2005). The earliest evidence of domesticated wheat in the Crimea (site Ardych-Burun) dates back to the Chalcolithic (Motuzaitė-Matuzeviciute et al., 2013), at 4772 ± 51 ^{14}C yr BP (2σ calibration: 5600–5445 cal yr BP). In the northern Pontic area, it has been suggested that the gradual transition to pottery-making occurred at 8950 cal yr BP and that early farming cultures appeared around 7150 cal yr BP (Dolukhanov and Shilik, 2007).

The first evidence of agricultural practices in the Taman Peninsula (i) appears chronologically after domestication and early cultivation in Armenia (Hovsepian and Willcox, 2008), (ii) is quite similar to the emergence of agro-pastoral farming in the Eastern European Plain, and (iii) precedes cereal cultivation in Crimea (Motuzaitė-Matuzeviciute et al., 2013).

5.2. Impact of agricultural practices

Although it is widely believed that regions which experienced an early transition to Neolithic agriculture also became institutionally and economically more advanced (Olsson and Paik, 2012), the impact linked to these changing socio-economic models may have hastened environmental shifts. The impact of Neolithic economies on the biotic communities of the Mediterranean Basin has long been demonstrated (Zeder, 2008), but pressures resulting from the Neolithization process in the northern Black Sea, especially the Taman Peninsula, are unclear. Previous palynological studies from the peninsula have looked at the Palaeolithic cultural phases (Shchelinsky et al., 2010) or the last 3000 years (Matishov et al., 2013), leaving a gap for the Early-to-Middle Holocene period that is filled by our data. The introduction of agro-pastoral

farming in the Taman Peninsula seems to have been one of the primary drivers behind vegetation changes with a loss of forested areas resulting in an expansion of a steppe-landscape between the Azov and Black Seas since 6895 cal yr BP (Fig. 4). Recent pollen studies from Zarishat fen (Armenia; Joannin et al., 2013) and Lake Paravani (South Caucasus; Messenger et al., 2013) have suggested that climate variations were the main factors controlling the vegetation dynamics until 3000 cal yr BP (Messenger et al., 2013) in the southern Caucasus Corridor, probably due to areas not intensively used for woodcutting, herding, fire and agriculture. A similar process was recorded at Lake Van (Eastern Turkey), suggesting that proximal areas were also not used for grazing and agricultural practices before 600 cal yr BP (Wick et al., 2003). Other studies from the Caucasus Corridor, in Georgia, are much contrasted (e.g. Cordova et al., 2009; Connor, 2011), showing that humans have also played a major role in shaping the composition of Holocene vegetation, but at a local scale. Our data from Taman fit with this conclusion as anthropogenic activities probably acted at a local scale, disturbing coastal deltaic areas where fertile soils are located. The accumulation of local pressures on ecosystems at different locations gives a regional event but with different characteristics, depending on the intensity, duration and frequency of pressures, and the technologies employed and the local innovations.

Studies from lands facing the Taman Peninsula in southwestern Crimea suggest that human disturbance may also have created conditions appropriate for the expansion of Mediterranean plants on the Black Sea coast (Cordova, 2007). This could be the case in the local expansion of a phrygana between 7000 and 5000 cal yr BP. The rise of phrygana scrubs in Crimea and the Mediterranean region is often associated with grazing and general agricultural pressure (Cordova, 2007).

Our data demonstrate that stresses resulting from agro-pastoral farming in the Taman Peninsula were not continuous, providing insights into the recovery process, especially during the period ca 6000–5700 cal yr BP (Fig. 4). The local vegetation seems to have lost the ability to fully recover during this phase of agricultural decline, suggesting that coastal ecosystems lost their “resilience”. The cumulative impact of anthropogenic pressures and marine transgression (ca 6350–6150 cal yr BP) damaged the forested ecosystems of the coast, favouring the development of a steppe marked by an increased biodiversity.

5.3. The 5.2 ka BP event

A negative deviation of the PCA-Axis1 from ca 5200 to 4950 cal yr BP (Fig. 4) seems to correspond to the 5.2 ka BP event. This climate event is recorded at several sites. The stalagmite $\delta^{13}\text{C}$ record from the Sofular Cave, on the southern Black Sea coast, indicates a downward trend of the effective moisture from 6000 to 5200 cal yr BP (Göktürk et al., 2011). The reconstructed Dead Sea level curve shows a dry episode between 5400 and 5100 cal yr BP (Migowski et al., 2006). $\delta^{18}\text{O}$ speleothem record at Soreq Cave, a proxy for regional precipitation in the southern Levant, indicates a drop in rainfall at 5200 cal yr BP (Bar-Matthews et al., 2003). The aridity index reconstructed from sediment cores from the northern Red Sea (Arz et al., 2006) clearly increase around 5000 cal yr BP, as well as aeolian mineral concentration in the Gulf of Oman (Cullen et al., 2000) and dust flux around 5500 cal yr BP in the Arabian Sea (Sirocko et al., 1993). This event is well-expressed in the coastal area of the Taman Peninsula due to ca 1500 years of human-induced pressures and shoreline changes, which cumulatively eroded the ecology of coastal ecosystems before the onset of this climate event. Outside the Mediterranean areas, dry peaks at 5200 cal yr BP are also mentioned in the northern Pontic steppe (Kotova and Makhortykh, 2010) and in the forest-steppe region of

West Siberia (Zakh et al., 2010). A rise in summer temperatures around 5000 cal yr BP was also recorded in the Nikolay Lake (Lena Delta, Russia; Andreev et al., 2004). Our data show that the 5.2 ka BP climate shift clearly corresponds to a new expansion of a steppe-landscape (Fig. 4).

6. Conclusions

Our results show that agricultural practices began ca 7000 years ago in the coastal wetlands of the Taman Peninsula, an area vulnerable to coastal change but of high fertility. The anthropogenic pressures were mainly focused on the forested coastal ecosystems, leaving open spaces that were colonized by a steppe vegetation. Two independent processes have also contributed to shifts in local ecosystems, a marine transgression (6350–6150 cal yr BP) and a climate shift at ca 5200 cal yr BP. The coastal area of the Taman Peninsula mainly suggests that agro-pastoral farming has significantly altered the ecosystems, leading to a loss of resilience, but that it has also generated an increased biodiversity.

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