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Kurgans as indicators of co-existence between *Anopheles atroparvus* van Thiel, 1927 (Diptera: Culicidae) and ancient human populations in the Hungarian Great Plain

Kurgany ako znak spolubytje *Anopheles atroparvus* van Thiel, 1927 (Diptera: Culicidae) a davnych ljudi vo Velike madjarske nizine

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ABSTRACT

While the potential malaria vector *Anopheles atroparvus* occurs in Hungary to the present day, malaria was endemic to the country only until the mid-20th century when it was eradicated. Estimating the historical distribution of malaria-infected populations in the Great Plain is difficult, since it requires spatial data about mosquito breeding habitats and the former settlements in wetland areas. Since river regulation dramatically changed the water supply of the Great Plain, the present distribution of malaria-transmitting mosquitoes is smaller than it was in the ancient times. It was hypothesized that the distribution of kurgans can indicate areas of *Anopheles*-human encounters in the Copper Age and Bronze Age. It has been shown that kurgans can be found especially in the water system of the river Tisza, mainly near existing or ancient channels. Today, *An. atroparvus* breeds mainly in the remaining wetlands of the Great Plain, even where channel systems have been dramatically reduced. *An. atroparvus* are rare in Transdanubia and absent from the mountainous areas of Hungary. About two thirds of the known occurrence sites of *An. atroparvus* lie within a 15-km radius of known kurgans. It was found that the presence of kurgans indicates former habitable areas for human populations in wetland areas of the Great Plain. It is concluded that the kurgans indicated areas can be targeted by future anthropological investigations to identify the historical distribution of malaria.

ABSTRAKCIJNY

Hot' perenosčik malarije *Anopheles atroparvus* jest v Madjariji do dnes, malarije byla izničena vo Madjariji vo sredine 20. stoletje. Ocenit istorijnou distribuciji naseljenji s malarijuo vo Velike madjarske nizine jest težke, ibo by bylo treba znati prostorova data o vyskitu komaru a staryh ljudskih sel. Ibo regulace rek drsatičně izmenila vodstvo Velike niziny, dnešna distribucija komarov prenosujici malariju jest o mnoho menši než vo starověku. V tutov članoku jest uvedena hipoteza že distribucija kurganu može indikovat oblast'i s vyskitem komarov *Anopheles* a ljudi vo med'enem a bronzovem věku. Jest pokazano že kurgany se znahodiji glavno vo vodstvu reky Tisza pri tutodennyh a davnyh kanalu. Dnes sa *An. atroparvus* razmnažuje glavno vo ostalyh mokriščih Velike niziny hot' byli reky drastičně redukovany. *An. atroparvus* jest redki vo Transdanubiji a nežije vo gorskih oblastech Madjarije. Okolo dvou tritin vseh znanyh mist vyskitu leži do petnadset'i kilometru od znanyh kurganov. Bylo ukazano že prisučnost kurganu označuje byvši obyvatel'ne oblast'i pro ljudi vo Velike nizine. Jest zaključiteno že kurgany se možu stati prědmetem budučiho antropologčneho raziskani s cel'em identifikovani historičnou distribucije malarije.

Keywords: *Anopheles*, ecology, tomb, wetland, malaria

Introduction

Prior to the 1950s, malaria was endemic to Hungary. In the 1920s, about 6 to 8 thousand new cases were registered each year. Given the former population of Hungary, this represents an incidence of 75-100 cases per 100,000 inhabitants.[1,2] The members of the *Anopheles maculipennis* complex were the main vectors of non-falciparum malaria. In Hungary, *Anopheles algeriensis* Theobald, 1903, *Anopheles atroparvus* van Thiel, 1927, *Anopheles maculipennis* Meigen, 1818 and *Anopheles messeae* Falleroni, 1926 were plausibly the main potential malaria vectors.[2] The last epidemic localizations of malaria were eradicated in the Upper Tisza and the Lower Drava valleys in the 1950s and since 1956 no further autochthonous cases were reported from Hungary. *Anopheles atroparvus* was one of the vectors of malaria.

This species prefers warm waters of sunny marshes, swamps, puddles and the soda water of the shallow lakes of the Hungarian Great Plain.[3] It was shown that the former seasonality of malaria coincided with meteorological patterns and the seasonal activity of *Anopheles* species.[4] Determining the co-existence areas of former human and mosquito populations would have important implications for archaeology and anthropology. It is probable that malaria influenced the population dynamics and even the genetics of the human populations of the Tisza valley, although the lack of the subfossil remains of the vector mosquitoes (in contrast to the common subfossilized remains of Chironomids in lake sediments[5]) does not allow the direct investigation of the taxonomic composition and distribution of the ancient malaria mosquito fauna. Although many archaeological sites are known in the Great

Plain, the distribution of the excavated remains of ancient settlements does not indicate in general which settlements were directly exposed to mosquitos.

Kurgans ('kunhalom' in Hungarian, meaning kurgans, barrows, burial mounds) are characteristic elements of the landscape of the Great Plain. Although their popular name refers to the suspected kurgan builders, these prehistoric hills were built mainly in the Copper and Bronze Ages. In terms of their function and size, kurgans form a very heterogeneous group of man-made structures. Some kurgans were used as burial mounds. In later times, these hills were used for several other purposes as well. For example, the Csolt clan built a monastery at the foot of the Mágor hill kurgan, sometime before 1222. It is plausible that some of the smaller kurgans were originally burial tombs which erected from the surrounding ground. Many of them could be the artifact of the people of the kurgan cultures. Kurgan cultures migrated into Central Europe around the 3rd millennium BC. Barczi and Joó (2000) hypothesized that the burial mounds were built in a relatively short time period[6]. It is also probable that uses of the manmade hills changed over time. For example, some kurgans were used as the location of windmills or geodetic points in later times. Some of the artificial hills in the Tisza River Basin are tells and not kurgans, in the narrower sense. For example, the Lapos-(Kucorgó) mound (Tószeg, Jász-Nagykun-Szolnok county) was a mound settlement during the Bronze Age. The houses were made of clay and reed. The damaged houses were repeatedly rebuilt, but some of the accumulated refuse accumulated and remained within the settlement. These 'cake-like' settlements were built in two phases: in 4000-3500 BC and 2600-1500 BC[6]. Sherds preserve evidence of the formerly wet environment (Fig.1).

Fig. 1: Bronze Age sherd with wavy ornamentation from the Lapos-mound, Tószeg. The ceramics were made from local alluvial clay.

Obr. 1: Črep iz bronzoveho věku s valnitou ornamentaci iz kurganu Lapos, Tószeg. Kermaika byla iztvorena iz alluvialne gliny.

Kurgans also fall into the scope of interest of botany and archeology. In many cases they preserve the remains of the former loess steppes[7]. The geographical distribution of kurgans is mainly concentrated around the river basin of Tisza and its tributaries; very few kurgans have been found in Transdanubia or the river basin of Danube. Kurgans follow the ancient river channels and can be found mainly in the former holms of larger rivers and creeks[8]. Since the topography of the Great Plain is expressly flat (for example, the slope rate between Szolnok and Szeged is only 9.5cm/km within 105 kilometers), every slight hill could provide some protection against spring or summer floods. Kurgans were made mainly from the soils found in their close vicinity. After the river was regulated, the water supply and the channel structure of the Great Plain dramatically changed. Most of the channels dried out and the rivers were greatly shortened. Before the 19th century, the majority of the Great Plain was cyclically flooded[9]. As a result of the river regulation that began in 1840, the current extent of former wetlands, and consequently the extent of mosquito habitats, have declined significantly, probably contributing to the decline of *Anopheles* mosquito populations (Fig.2).

During the Ottoman occupation, both Christian and Turkish troops frequently suffered from malaria.[10] However, we have no direct data about the occurrence of this disease in the pre-industrial era which is expressly true for the ancient distribution of

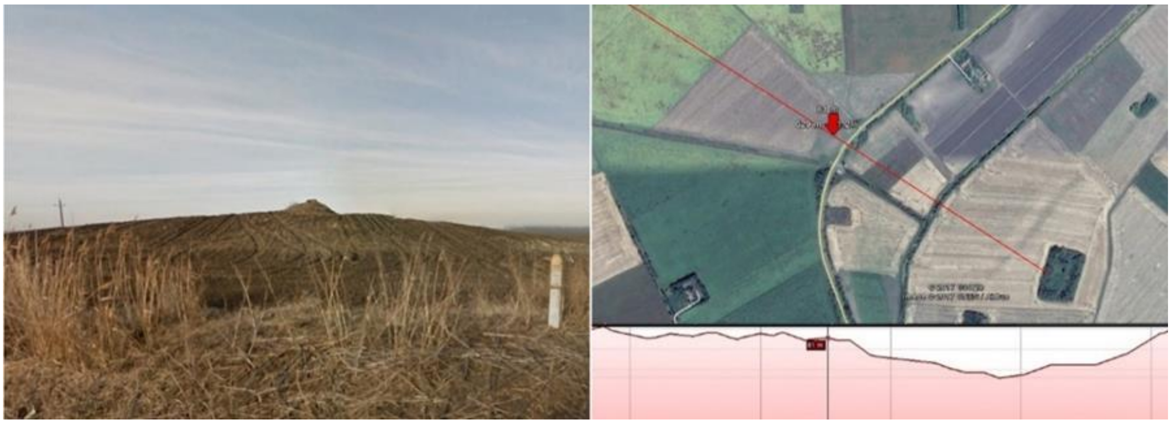

Fig. 2: Left: Kurgan between Öcsöd and Mezőhék, Békés county. Note the presence of the common reed (*Phragmites australis* L.) in the foreground of the hill. A notable upper part of the hill was eroded by deep ploughing. Right: The relief of the environment of the kurgan according to the red line. The dry bank of the former side arm of 'triple' Körös river can be seen in the left side of the model. The red arrow shows the position of the kurgan (source: Google Earth).

Obr. 2: Vlevo: Kurgan medzi sely Öcsöd a Mezőhék, oblast' Békés. Pred kurganom raste *Phragmites australis* L. Značna čast' vrhne gorače byla erodovana glubokou orbou. Vpravo: Relief okoli kurganu po črvene črkě. Suhe dno byvšiho pritoku reky Körös jest vidima vo leve čast'i modelu. Črvena strela znači poziciju kurganu (Google Earth).

potential mosquito vectors. The presence of malaria depends on the encounter probability between a susceptible human population and the potential vector *Anopheles*. The willingness of malaria-infected female mosquitoes to feed on humans and the infection rate of mosquitoes also determine the prevalence of malaria in the human population. It is important to note that in contrast to several other mosquito-borne diseases such as the West Nile disease, humans are the only host of (non-avian) *Plasmodium* parasites. Apart from the absolute prevalence-determining environmental and socio-economic factors, the distribution of malaria is primarily the function of the spatial occurrence patterns of potential *Plasmodium*-vector *Anopheles* species and the presence of settlements in or near to the mosquito breeding sites. In ancient times, humans were strongly bound to natural water sources, partly due to reliance on irrigation or livestock watering. In the Bronze Age, people also collected mussels from river Tisza for eating and naturally fishing provided a very important protein source throughout the year. Estimating the historical distribution of former malaria-infected areas should be an important research goal since it may have had a notable impact on the history of the Great Plain.

It was hypothesized that the distribution of kurgans can indicate both i) the distribution of the human population of the Great Plain predominantly in the Copper Age and Bronze Age in the river basin of Tisza and its tributaries and ii) the presence of ancient wetlands where malaria mosquitoes could breed.

The encounter probability of the *Plasmodium*-infected *Anopheles* mosquito populations and the susceptible organisms, in case of humans can be estimated according the following equation:

$$P_m \sim A_{im} \times PD_h \qquad \text{(Eq.1)}$$

where:

P_m: prevalence of malaria

A_{im}: abundance of the infected *Anopheles* mosquitoes

PD_h: human population density

Based on the above described circumstances these hypotheses were made: i) the distribution of kurgans indicates the human-habitable places in former wetland areas and ii) the distribution of the potential malaria vector *An. atroparvus* correlates with the occurrence of kurgans, noting that the extent of wetlands today is much smaller from what it has been in the ancient times.

Materials

Anopheles atroparvus was selected to characterize the distribution of potential malaria-vector mosquitoes because this species was plausibly the most notable potential vector of *Plasmodium* in Europe[11, 12] and was recorded from the Great Plain at several sites[3]. It should be noted that the distribution of *An. maculipennis* and *An. messeae* in the Hungarian Great Plain is similar to the occurrence patterns of *An. atroparvus*. Mosquito occurrence data were based on the revised checklist of Tóth and Kenyeres (2012)[3]. Data on the distribution of kurgans was obtained from the Nature Conservation Information System of Ministry of Rural Development of Hungary.[13] The geological map of Hungary was obtained from the MBFSZ map server of the Geological and Geophysical Institute of Hungary.[14]

Results

Geological setting and the distribution of kurgans

From comparing the geological map and the distribution of kurgans in east Hungary it is apparent that kurgans are generally absent from the mountainous areas and the sand and loess ridges of the Great Plain. In the Duna-Tisza Interfluve, kurgans can be found mainly near ancient salt (soda) or freshwater lakes. It is also apparent that in many areas kurgans form necklace-like distribution patterns. These occurs in places where currently only dry channels can be found, but active streams existed before river regulation (see for example the relief picture of Fig.2). This pattern is especially striking in the Körös and Maros river valleys. Kurgans follow the course of major rivers (Tisza, Berettyó, Maros, Körös rivers) but only few kurgans were built directly at the river banks. Where this was the case, kurgans were built on the high loess embankments. The border area of the sand ridge of Nyírség and the plain of Hajdúság in Northeast Hungary is characterized by the absence of kurgans. In the south foothills of the North Middle Mountains, the distribution pattern is similar. In case of the sand ridge of the Tisza-Danube interfluve, the distribution limit of kurgans is less clearly defined; but it can be stated that kurgans were mainly built on the wetlands of the Great Plain (Fig.3).

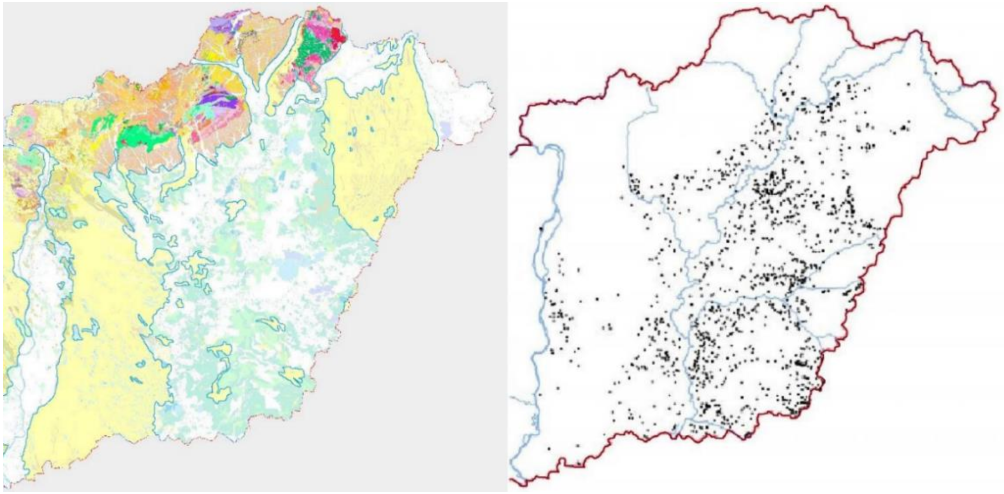

Fig. 3: Left: The geological setting of the Great Plain. White color indicates the occurrence of fluvial clay, blue and pale green colors show the occurrence of fluvial aleurite, sand and infusion loess, pale yellow color marks sand ridges, other colors show the presence of loess, proluvial-deluvial sediments of mountain slopes and the rocks of the mountains. Right: black points show the localization of kurgans in the Great Plain.

Obr. 3: Vlevo: Geologične uslovje Velike niziny. Běla barva iznačuje vyskit fluvialne gliny, modara a bledežolta zelena pokazuje vyskit fluvialneho aleuritu, pěsku a infusneho loessu, blede žlota iznačuje pěskove hrebety, inake barvy iznačuji loess, proluvialny a deluvialny sediment gorskyh spadu a gorske skal. Vpravo: Črne točky pokazuji uměščenje kurganu vo Velike nizine.

Based on the above described findings, the following correspondence can be described between long-term human population density - which can coincide with the distribution of habitable areas in wetland areas - and the density of kurgans in an area:

$$PD_h \sim D_k \qquad \text{(Eq.2)}$$

where:

PD_h: long-term human population density

D_k: density of kurgans

The presence of Anopheles atroparvus *compared to the occurrence of kurgans*

About 2/3 of the known occurrence sites of *An. atroparvus* can be found within a 15-km radius of known kurgans. Except for the Balaton area and the Little Hungarian Plain, most breeding sites of *An. atroparvus* are confined to the Great Plain and only few of them can be found in Transdanubia. *Anopheles atroparvus* habitat sites can also be found at the Duna-Tisza interfluve's soda lakes where several kurgans occur. *Anopheles atroparvus* was collected only in at a few sites in North Hungary. Many mosquito occurrence sites follow the swamps of the Great Plain not depicted on the map. The habitats of *An. atroparvus* follow the river bank of Tisza (Fig.4).

wetlands which plausibly were the breeding habitats of mosquitoes, it can be hypothesized that the distribution and density of kurgans in the Great Plain approximate the long-time mean or cumulative population density of the susceptible human populations. Accepting the observation that kurgans were built in or in the immediate neighborhood of channels the differences between the former, long-term malaria prevalence patterns can be approximated with the following equation:

$$\Delta\, P_m \sim \Delta D_k \qquad \text{(Eq.3)}$$

where:

ΔP_m: long-term differences in the prevalence values of malaria

ΔD_k: density of kurgans according to the mean value

Discussion

This is the first study to raise the hypothesis that kurgans can be used as potential indicators of the former co-existence areas of malaria mosquitoes and ancient human populations in the Copper and Bronze Ages. Indirectly, kurgans could indicate the potential occurrence of malaria in this period. Further studies are needed to determine whether the results of this study can be extended to the other areas of Eurasia.

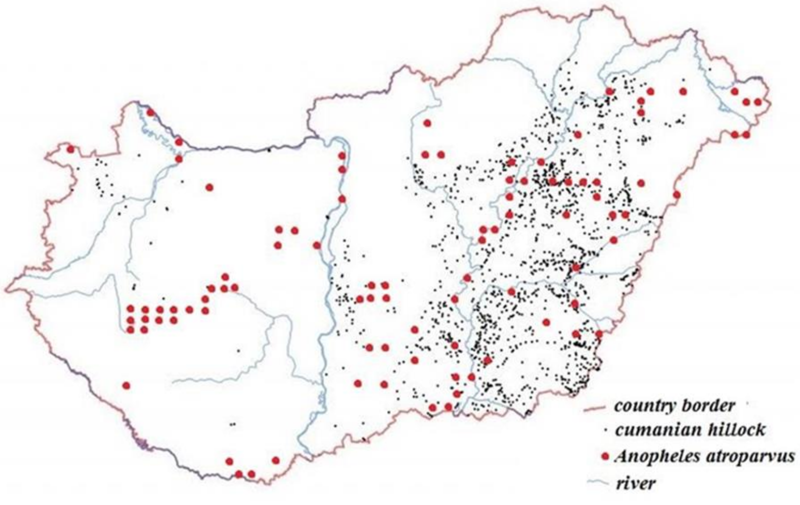

Fig. 4: *An. atroparvus* occurrences compared to the localizations of kurgans in Hungary.
Obr. 4: Vyskit *An. atroparvus* sravnany s vyskitem kurganov vo Madjariji.

patterns of alluvial basins and plausibly with the ancient streams (channels) and wetlands in the Great Plain. It is clear, that the current distribution range of the mosquito is smaller than the distribution area of kurgans since these artificial mounds were made before the river regulation which exterminated most of the wetlands of the Great Plain including most of the former breeding habitats of *An. atroparvus*. Since many kurgans were originally tombs, human remnants were sometimes found in the excavations of the mounds. The anthropological material of the already unearthed kurgans could be the subject of osteological and genetic investigations to explore the former presence of malaria. On the other hand, it is important to note that all the kurgans are 'ex lege' protected objects in Hungary, which means that the targeted further exploration and archeological or anthropological investigation legally cannot be performed. In an anthropological sense, porotic hyperostosis (*e.g*. the deviation of the bony structure of cribriform plate) can provide indirect evidence of malaria infection of the deceased.[15] The detection of the genetic traces of *Plasmodium* parasites can provide direct evidence if the stage of the bones allows the examination.[16]

It should be added that land uses of the Great Plain and its population distribution have changed over time. For example, the flood basins of the Körös and Berettyó rivers in the central part of the Great Plain were a major focus of settlement in Neolithic times. This has changed with the emergence of tumuli-building, steppe-inhabiting people.[17] However, the majority of both the tumuli and the Neolithic settlements were built in wetland areas. Although, several kurgans are not the remnant of settlements, the number of funeral sites can also indicate the inhabitancy and population density of wetland areas during the Copper and Bronze Ages. Naturally, in areas outside of the flood basins, human populations also existed in the past, but it seems that in these sites artificial hills were generally not erected. It can be concluded that the presence of kurgans can be used as an indicator of the presence of ancient human populations in wetland areas.

Fig. 5: The crystallized sodium covered floor of a small desiccated soda lake in Tiszakécske (Tiszabög), Hungary in August 2016.

Fig. 5: Kristalizovany natrij na dnu drobneho izsušeneho slaneho jezera vo Tiszakécske (Tiszabög), Madjarija v avgustu 2016.

For example, the skeletal remains of juveniles in tumuli at Lofkend and Apollonia, Albania, show the possible effect of malaria infections.[18]

Based on the ecological character of protected wetland habitats in the Great Plain today, it can be approximated that the restricted environment of kurgans could have been the ideal habitats for malaria vector mosquitoes in the past. It is plausible that in the past thousand years, the human populations of the Great Plain inhabited mainly the dryer parts of the wetland areas, near to the breeding habitats of malaria mosquitoes. In case of the Csípő-mound kurgan, paleosoil investigations showed that this kurgan was once surrounded by a mosaic of warm, dry steppe, half-shaded tall grass steppe environment, wetlands, and sodic areas[19]. Similarly, marshes, alkaline marshes, and wet alkaline meadows dominated at regional and local level the environment of the Ecse-halom kurgan.[20] In summer, wet grasslands and swamps existed in the vicinity of kurgans. Wet grasslands provided good conditions for livestock grazing and plausibly also *An. atroparvus*, which occurs mainly in swamps, litoprofundal shallow lakes, and rainy puddles in Hungary.[21] *Anopheles atroparvus* larvae prefer the warm water of soda lakes. Out of the entire Carpathian Basin, the Great Plain has the warmest summers. This can explain the presence of *An. atroparvus* in the area, which is otherwise predominantly a Mediterranean faunal element. According to palynological data, thermophilus steppe species (including Ponto-Mediterranean and Sub-Mediterranean floral elements) reached the Great plain during the late glacial interstadial and Holocene.[22]

It seems likely that the predominantly Mediterranean, soda-lake breeder *An. atroparvus* reached the Carpathian Basin at the time when the southern Eurasian flora elements arrived to the Great Plain. Unfortunately, river regulations were started before the Hungarian mosquito fauna was comprehensively studied. The regulation of river Tisza started in the mid-1800's. Pál Vásárhelyi (25 March 1795 – 8 April 1846) presented the draft of the 'General regulation of the river Tisza' in March 1846. Vásárhelyi had two goals in his plan: limiting floods and ensuring navigability. He believed that the success of the regulation should increase the fall of the river, and thereby increase its slow running speed in the flat countryside. To increase the fall, he aimed to shorten the river length by 452 km. The works started on 27 August 1846 based on plans by Pietro Paleocapa (11 November 1788 - 13 February 1869) and Pál Vásárhelyi. By 1879, a total of 112 cuts were made on river Tisza, reducing the total length of the river from 1419 km to 962 km (38% decrease). River regulation caused devastating floods and salinization in dry areas. The contiguous shallow water surface essential to the fish reproduction was also drastically reduced. The inland waters could not run out to the river due to the dams. The process culminated in an almost complete devastation of the wetland habitats. Although soda lakes already existed before the river regulation in the Great Plain, it is likely that salinization of waters has changed the mosquito fauna (Fig.5).

It is widely suspected that malaria could be linked with the decline of city-state populations in ancient Greece and may have contributed to the fall of the Roman Empire during the 5th century AD.[23,24] While it is plausible that malaria was occasionally a notable determinant of demography in the Mediterranean, there is little data about the effect of malaria on the demography of other Eurasian civilizations including the ancient Kurgan Culture. It is also open to question when and how malaria was introduced to Europe. Kuhn (2006) hypothesized that the transmission of malaria was most likely established in the Neolithic period in Europe[25] which implicates that malaria was endemic in the Hungarian Great Plain when Kurgan Culture's people arrive to the Carpathian Basin. Further development and testing of the presented hypothesis may contribute to a better understanding of the distribution of malaria and its possible impact on human populations in the Tisza River Basin in the Copper and Bronze Ages.

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