Journal of Anthropological Archaeology 53 (2019) 92–101

Contents lists available at ScienceDirect

Journal of Anthropological Archaeology

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

Ecological dimensions of population dynamics and subsistence in Neo-Eneolithic Eastern Europe

Thomas K. Harper[a,*], Aleksandr Diachenko[b], Yuri Ya Rassamakin[b], Douglas J. Kennett[a]

[a] Department of Anthropology, The Pennsylvania State University, USA
[b] Institute of Archaeology, National Academy of Sciences of Ukraine, Ukraine

ARTICLE INFO

Keywords:
Holocene
Paleoecology
Eastern Europe
Eneolithic
Early Bronze Age
Soil quality
Ideal Free Distribution
Cucuteni-Tripolye culture

ABSTRACT

During the fourth millennium BCE socioeconomic change from a regime of Neo-Eneolithic village-based sedentary agriculture to more itinerant pastoralism dramatically changed European society. Continental-scale archaeological and genetic studies generally attribute this change to the movement of Early Bronze Age (EBA) populations into Eastern Europe ca. 3000 BCE. However, archaeological assemblages in Ukraine, Moldova, and Romania suggest that migrations and changes in subsistence regime started earlier, coinciding with climatic change during the 5.9 ka event (Bond Event 4) and continuing into the Atlantic/Subboreal transition. We apply the Ideal Free Distribution (IFD) to a settlement record spanning over 3000 years (ca. 6100–3000 BCE) in 14 subregions of Eastern Europe to establish a quantitative indicator of changing subsistence strategies throughout the fourth millennium BCE. This provides corroboration for arguments made on the basis of careful study of material culture, which suggest that economic changes were gradual, regionally diverse in their manifestation and predate the arrival of EBA populations in Eastern Europe. Our implementation of the IFD shows it to be a useful tool for highlighting changes in regional subsistence regimes, but further analysis is required to address issues of habitat ranking, migratory vectors, and settlement dating on smaller scales.

1. Introduction

1.1. Background

The Neo-Eneolithic, lasting from ca. 6100–3000 BCE in Eastern Europe, can be broadly categorized as a period of sedentary village-based agriculture. A diagnostic trait of this throughout Europe during this time is serial migration and colonization of resource-rich areas. This is most famously apparent in the settlement systems of the Linear Pottery culture of the Middle Neolithic, which show a systematic preference for productive loess soils (Bickle and Whittle, 2013; Milisauskas and Kruk, 1989). Similar site selection behavior, displaying short- to medium-range serial migration and preference for river valleys with rich soils, can also be observed in archaeological cultures throughout Neo-Eneolithic Eastern Europe.

There is substantial disagreement among archaeologists regarding the nature of acculturation into the succeeding cultural system of the Early Bronze Age (EBA), contrasted with Neo-Eneolithic "Old Europe" by a prevailing preference for more mobile, pastoralist means of subsistence. One prevailing hypothesis, sharing some level of common descent from the "Kurgan hypothesis" of Marija Gimbutas, posited that Terminal Eneolithic and EBA groups overlapped substantially, coming into conflict with one another (Dergachev, 2007). David Anthony imagined the EBA transition as an overtly political process, whereby Indo-European groups originating from the Eurasian steppe imposed a new cultural hierarchy on the existing Terminal Eneolithic substrate over the course of centuries (Anthony, 2007). It is now apparent that members of the EBA Yamnaya, Corded Ware, and Globular Amphora cultures—cultures identified with the Bronze Age invaders of the Kurgan hypothesis—were in fact bearers of Indo-European genetic markers (Goldberg et al., 2017; Haak et al., 2015). However, existing radiocarbon data and pottery seriation in Ukraine suggest only a brief period of synchronicity between Terminal Eneolithic and EBA groups (Diachenko and Harper, 2016) and, therefore, a rapid transition between fairly discontinuous cultural horizons.

In this paper we present the hypothesis that the Eneolithic societies of Ukraine, Moldova and Romania gradually transitioned to a pastoral economy over the course of the fourth millennium BCE, and that this occurred independently of the later establishment of EBA cultural groups in the region. While addressing some aspects of cultural development spanning the entire Neo-Eneolithic, we focus primarily on the Cucuteni-Tripolye cultural complex (ca. 5050–2950 BCE), which

* Corresponding author at: 403A Carpenter Building, University Park, PA 16802, USA.
E-mail address: tkh130@psu.edu (T.K. Harper).

https://doi.org/10.1016/j.jaa.2018.11.006
Received 8 February 2018; Received in revised form 9 July 2018

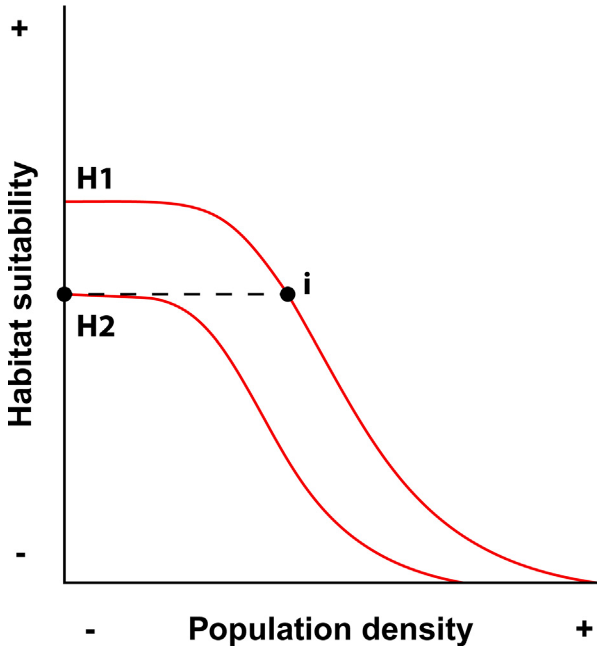

Fig. 1. The Ideal Free Distribution, illustrating the basic negative density dependence between population density and suitability in two habitats with differing carrying capacity (H1 and H2). Vector i illustrates a theoretical migratory threshold, where the suitability of H1 and H2 become equivalent.

encompasses most Eneolithic settlement within our study area. We will examine the interplay between developments in subsistence economy and population trends of this period via the ecological and geomorphological characteristics of settlement sites, examined within the framework of a model from population ecology known as the Ideal Free Distribution.

1.2. The Ideal Free Distribution

The Ideal Free Distribution (IFD) is a model adapted from population ecology (Fretwell and Lucas, 1970) first applied archaeologically to examine island colonization in the Pacific (Kennett, 2005; Kennett et al., 2006). The key assumption of IFD is that the suitability of a given habitat for colonization is a function of negative density-dependent resource availability, with suitability decreasing as population density increases. Fig. 1 illustrates the basic expectations of IFD, where two habitats of unequal quality may reach parity (vector i) due to the density-dependent effect of increasing population. The IFD predicts that the most ideal habitats within a given region are occupied first (Codding and Bird, 2015) and further habitats are occupied in order of suitability.

IFD and its variants have become a major component in studies of human behavioral ecology in anthropology and archaeology (Codding and Bird, 2015). Provided that representative quantitative indicators of habitat suitability can be reliably generated, habitat ranking and density-dependent effects can help to explain several archaeological phenomena. Applications include the use of IFD to understand the settlement ecology of the Northern Channel Islands of California (Kennett et al., 2009; Winterhalder et al., 2010), Early Neolithic eastern Spain (McClure et al., 2009), Bronze Age Messenia (Jazwa and Jazwa, 2017), and the population density and distribution of language groups in coastal California (Codding and Jones, 2013).

1.3. Study area

Over the course of two millennia, the territory of the Cucuteni-Tripolye complex expanded from a small area around the Prut, Siret and Dniester river valleys to become the largest cultural unit in Eastern Europe, occupying territory from the Carpathian mountains to the eastern bank of the Dnieper, and from the forest zone of modern Ukraine to the northwestern coast of the Black Sea. Over 5000 Cucuteni-Tripolye sites form a suitable and representative database used to study the demographic development, spatial organization and subsistence strategies at the northeastern frontier of “Old Europe.” Starting from approximately 4400 BCE, during the middle period of the cultural complex (Cucuteni A/Tripolye B), regional differences in settlement structure and material typology became notable. Taxonomically they are represented by the Ariuşd, Cucuteni, Eastern Tripolye (ETC) and Western Tripolye (WTC) cultures, constituent local groups and types of sites at different spatial scales. Relative differences in pottery assemblages increase along this hierarchy.

The Cucuteni-Tripolye cultural complex is widely known for its giant-settlements (recently also known as mega-sites), belonging to the Vladimirovskaya, Nebelevskaya, Tomashovskaya and Kosenovskaya local groups of the WTC (ca. 4100–3300 BCE). These settlements are the largest population agglomerations in Eneolithic Europe (150–320/340 ha), located in the Southern Bug-Dnieper interfluve in modern Ukraine (Chapman et al., 2014; Rassmann et al., 2014, 2016). The formation, chronology, socio-political organization and decline of these remarkable sites are actively debated in European archaeology (see Diachenko and Menotti, 2017; Gaydarska, 2016 for the most recent overviews). Large WTC sites in this region did not function contemporaneously, but replaced each other over time in successive population movements. The long-term economic viability of such sites is questionable, especially given the probable effects of deforestation and agricultural inefficiency (Kruts, 1989; Harper, 2012). The WTC chronological sequence in the Southern Bug-Dnieper region, which includes 10 chronological periods of 50-year duration, is based upon ceramic seriation and spatial analysis of sites (Diachenko and Menotti, 2012; Ryzhov, 2012). Many sites existed for only a single 50-year period (or less), though in some cases the existence of a giant-settlement exceeded the duration of a chronological period, with its beginning overlapping the preceding chronological period and its decline overlapping the subsequent period (Diachenko, 2012).

The rise of the WTC giant-settlements is one among several population anomalies coinciding with the onset of the 5.9 ka event (Bond Event 4; Weninger and Harper, 2015). These include the collapse of settlements belonging to the neighboring Gumelniţa culture in the Danube Valley, the end of the Tisza-Tiszapolgár-Bodrogkeresztúr cultural sequence in Transylvania, and a sudden increase in the number of settlements in the Upper Siret-Prut and Upper Dniester regions (Harper, 2016). Analysis of Holocene pollen core data using the modern analog approach indicates that an appreciable drop in growing-degree days, possibly accompanied by increased flood vulnerability in the Danube valley caused by Alpine deglaciation, would have had a negative influence on agricultural systems in Romania at this time (Harper, 2017). Resumption of more continuously favorable conditions did not occur until ca. 3300 BCE, providing a basis for viewing almost the entire span of the fourth millennium as a period of instability that necessitated adaptations in subsistence and settlement strategies.

The decline of the Cucuteni-Tripolye cultural complex occurred over a span of 300–400 years and is represented by the Horodiştea-Folteşti sites in modern Romania and Tripolye C2 sites in modern Ukraine and Moldova. This period is characterized by significant influences of other neighboring Terminal Eneolithic cultures, finally resulting in the incorporation of Cucuteni-Tripolye populations in the steppe with peoples of the Early Bronze Age (EBA) Yamnaya culture and the incorporation of Cucuteni-Tripolye populations in the forest zone into the peoples of Globular Amphora culture (Kruts, 2012). This process may be explained within a framework of deep economic, socio-political and cultural transformations embodied in the increase of the importance of stock-breeding, the transformation of centralized chiefdoms into dispersed chiefdoms and the adoption of cultural features from more developed political economies of the late fourth to early third millennia BCE (Diachenko, 2016).

2. Methods

In our application of IFD to Neo-Eneolithic Eastern Europe, we seek to test whether the key economic components of this transformation, the transition away from sedentary village-based agricultural systems over the course of the fourth millennium, can be discerned quantitatively. To this end, we perform a space-time analysis of settlement conditions. The key variables of regional population density and habitat suitability are generated by estimates based on the archaeological settlement record and soil quality, respectively. Further variables useful in describing the economic functioning of sites include site relief, fortification frequency, and the incidence of certain artifact classes.

2.1. Settlement data

This paper uses the Eastern European Neo-Eneolithic Sites Repository (EENSR) version 1.0, published here for the first time in its entirety (Linked Research Data, Table S1). This database was constructed over several years from dozens of sources, but chiefly from national-level registries such as the *Repertoriul Arheologic Național* (RAN; Sandric et al., 2017), *Reyestr pamjatok tripolskoyi kultury* (RPTK; Videiko et al., 2004), and *Registrul Monumentelor Republicii Moldova* (Ciocanu, 2014). EENSR is intended to be an expandable database for Neo-Eneolithic chronological and settlement analysis but also contains some information regarding cemeteries and isolated artifacts. Of 8164 sites and habitational layers, 6756 (83%) have spatial coordinates. 4038 entries (49%) have a habitational component, some form of chronological assignment and associated spatial coordinates, and it is this subset that is used for the presented site suitability and location analysis (Fig. 2).

Demographic trends were reconstructed from EENSR using a derivative of the SARP model (Ammerman et al., 1976; Harper, in press) using a 48-phase chronology assembled for this purpose (Harper, 2016; Linked Research Data, Table S2). In order to examine regional trends, the study area is divided into 14 analytical regions delineated according to ecoregional extents, river catchments, and interfluvial zones commonly referenced in regional archaeological literature. While EENSR extends to Northeastern Ukraine, Crimea, and parts of Belarus, these regions are comparatively data-deficient and were excluded from the analysis presented here.

2.2. Potential productivity and subsistence strategies

Productivity indices are tools used in agricultural science that provide a relative measure of productivity across geographic contexts. On the site-specific level these determinations can be made with reference to a host of factors, including soil permeability, texture and nutrient composition, pH, water availability, and meteorological factors. Regionally, more generalized estimates can be attempted on the basis of soil typology and average characteristics. Potential productivity of field crops was of great importance to sedentary farming societies but presumably became less of a factor in habitat selection during and after the EBA transition.

Here, we assign suitability scores based on the Muencheberg Soil Quality Rating (SQR; Mueller et al., 2007) applied to the European Soil Database (ESDB; Panagos et al., 2012) using QGIS software. SQR can be distinguished from soil typology-based approaches in that it is interoperable between different typological schemes (WRB, FAO, USDA, etc.) and scores soils on the basis of eight main factors: soil substrate, A horizon depth, topsoil structure, soil compaction, rooting depth, available water, drainage, and slope. We first extract the SQR of individual settlement locations and, from this, calculate regional averages for each temporal period (Linked Research Data, Table S3).

Our chief assumption in the context of the IFD is that, within each analytical region, the average SQR of settlement sites will decrease as population increases, illustrating density-dependent competition over limited subsistence resources. SQR data are plotted against population values for a given time reference, with bivariate regressions calculated according to the ordinary least squares method. The resulting r^2 statistic

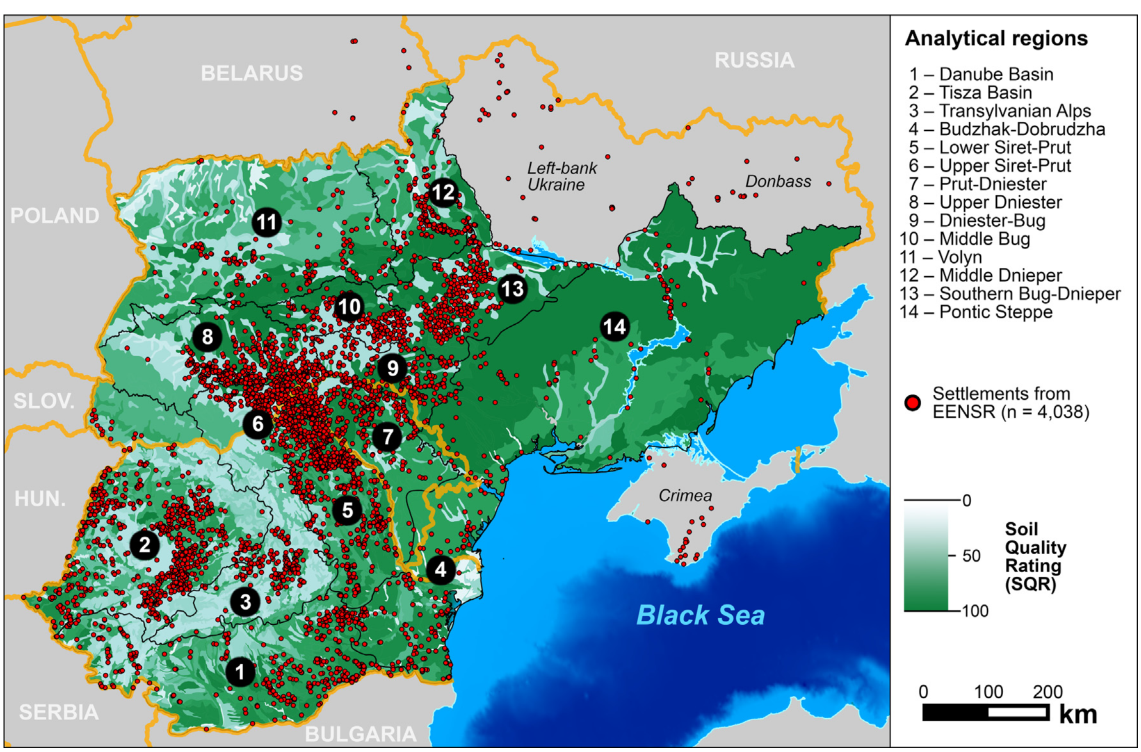

Fig. 2. The study area, showing the 14 analytical regions, the distribution of settlement sites with known spatial coordinates from EENSR, and SQR values estimated from ESDB (Panagos et al., 2012).

is indicative of the how well population correlates with SQR over one or more time spans within each region.

2.3. Conflict

A further variable we examine is the average relief of settlements during each phase, obtained in QGIS by comparing the elevation of each site with an average of observations from a 1-km buffer surrounding it. This is denoted as meters above mean elevation (MAME). The intent here is to give an indication of whether or not the immediate approaches to a location are situated either downslope or upslope, and to what degree. In rare cases of exceptionally large settlements this calculation likely does not reveal much due to the fact that a 1-km radius often does not extend beyond the site perimeter, but these constitute an insignificant portion of the sample (less than half of one percent). The operating assumption is that site relief is a function of economic necessity, settlement defensibility, or both.

Finally, we examine the temporal distribution of fortified sites, defined as the number of synchronous observations per chronological phase, as a proxy for resource competition. These observations, included as a component of EENSR, are derived mainly from the RAN for Neo-Eneolithic sites throughout Romania and from an extensive data set compiled by Valentin Dergachev for the Cucuteni-Tripolye complex (Dergachev, 2007). Additionally, Dergachev provides two additional proxies for conflict and economy: the incidence of arrowhead caches; and the percentage of wild species versus domesticates found in faunal assemblages. In the latter case, we have expanded on his analysis with the inclusion of further data from Zhuravlov (2008).

These variables, along with other larger-scale proxy records presented in Fig. 3, are also included in the Linked Research Data (Table S4).

3. Results and discussion

3.1. General and long-term trends

On the level of the entire study area, the Middle to Late Eneolithic represents a complex nexus of climatic, cultural, and ecological change (Fig. 3). The importance of Balkan cultural connections in western Romania reached a peak during the Vinča C shock, a sudden influx of settlement belonging Vinča culture in Transylvania and the Danube valley (Lazarovici, 1987). Most of the Neo-Eneolithic period subsequent to this event is focused to the east, dominated by the population development of the Cucuteni-Tripolye complex and its rapid expansion into the forest-steppe zone beginning ca. 4500 BCE. The increasing population of the study area shares a moderate linear correlation with trends in several variables, including a reduction in wild species exploitation ($r = -0.469$; $p = 0.003$), an increase in settlement relief ($r = 0.415$; $p = 0.004$), and an increase in the incidence of fortified settlements ($r = 0.419$; $p = 0.008$).

Our inferences regarding the role of conflict during the Eastern European Eneolithic are hampered by a scarcity of primary evidence for traumatic injury or violent destruction, the former due to a rarity of inhumation burials and the latter possibly masked by the prevailing practice of ritualized house burning. However, there is no reason to assume that these societies were either exceptionally peaceful or hostile. While the sample is limited, there is a high correlation between the incidence of settlement fortification and arrowhead caches ($r = 0.767$; $p < 0.001$), proxies suggested by Dergachev as being indicative of violence (Dergachev, 2007). While the presence of arrowhead caches could also show the relative importance of hunting as a subsistence strategy, the proportion of wild species encountered in Ukrainian faunal assemblages was lowest during this time and the two variables are uncorrelated overall ($r = 0.015$; $p < 0.930$). These data suggest that violent competition peaked during the interval of ca. 4600–3900 BCE, which encompasses a period of rapidly accelerating population growth and territorial expansion during the Cucuteni A/Tripolye B1 (and early Tripolye B2) period (ca. 4500–4000 BCE). This fits with our expectations of density-dependent competition, according to the IFD.

From 4500 BCE onwards, there is a substantial inverse relationship between the relative elevation of sites and fortification incidence ($r = -0.561$; $p = 0.001$), suggesting that in some cases geographic relief may preclude the necessity for formal defenses. However, relative elevation is uncorrelated with fortification incidence during the earlier part of the Neo-Eneolithic ($r = -0.104$; $p = 0.711$). A lack of significant correlation between relative elevation and soil quality ($r = -0.207, p = 0.164$) would seem to indicate little direct productive impetus behind the relief of settlement sites, at least on the scope analyzed here (limited to 1-km buffers). Throughout the entire Neo-Eneolithic period settlement relief is negative on average, the result of an overriding preference for settlement sites in relatively low-lying areas adjacent to watercourses. It is highly probable that the record of site fortification is biased, as those sites with presently known fortifications are likely to be extensively, if not fully, excavated, including a large number of type-sites for regional material assemblages.

Diachronic variation in SQR on the broad scale can be broken into four main periods: the Early to Middle Neolithic (up to ca. 5100 BCE), when settlements are sited in consistently productive zones; the Early Eneolithic (ca. 5100–4600 BCE), where there is a prominent trough; the Middle to Late Eneolithic (ca. 4600–3500 BCE), where average SQR returns to higher values; and the Terminal Eneolithic to EBA transition (ca. 3500–3000), when values drop off substantially. This could be explained as the manifestation of subsistence strategies generally based on sedentary agriculture, broken by a substantial interval of highly volatile population dynamics (including the Vinča C shock) and colonization of peripheral regions, followed by a decline in the importance of soil fertility during the transition to a more pastoral economy during the Terminal Eneolithic.

Assessment of the IFD requires examining each analytical region in more specific detail. The results of this study present an interesting case of regional variability that in some cases may be indicative of differentiated economic regimes or the confounding role of climate change and large-scale population movements. For each analytical region, regressions were calculated according to the ordinary least squares method. Overall, six of the 14 regions adhered to the base expectations of the IFD; that is, they conform to a generally decreasing trend of average productivity as population increases (Fig. 4). A further four regions adhere to our expectations for part of the study period but otherwise exhibit random or inverse behavior, two regions show inverse trends (with SQR values actually *increasing* with greater population), and the last two have quite stable values with little significant upward or downward trend (Fig. 5).

3.2. Regional SQR and subsistence

In those regions consistently adhering to IFD expectations (Budzhak-Dobrudzha, Transylvanian Alps, the Tisza Basin, Pontic Steppe, Southern Bug-Dnieper, and Upper Dniester), trends during the Neo-Eneolithic are co-linear with those observed for the Terminal Eneolithic and Bronze Age transition. Vladimir Kruts proposed that the colonization of Central Ukraine and giant-settlement development could be partially explained by the fact that the forest-steppe region was an "ideal environment" for both agronomic production and stockbreeding (Kruts, 2008). This appears to be the case for the Southern Bug-Dnieper region, where site selection preferences are constant across time and changing economic regimes. While the Tisza Basin can be considered a "core" area for much of the Neo-Eneolithic period, these regions otherwise are notable as peripheral areas with mixed modes of subsistence, which seem to be more or less durable across the entire study period.

Six regions (Danube Basin, Prut-Dniester, Dniester-Bug, Lower Siret-Prut, Upper Siret-Prut, and Volyn) show marked difference in density-

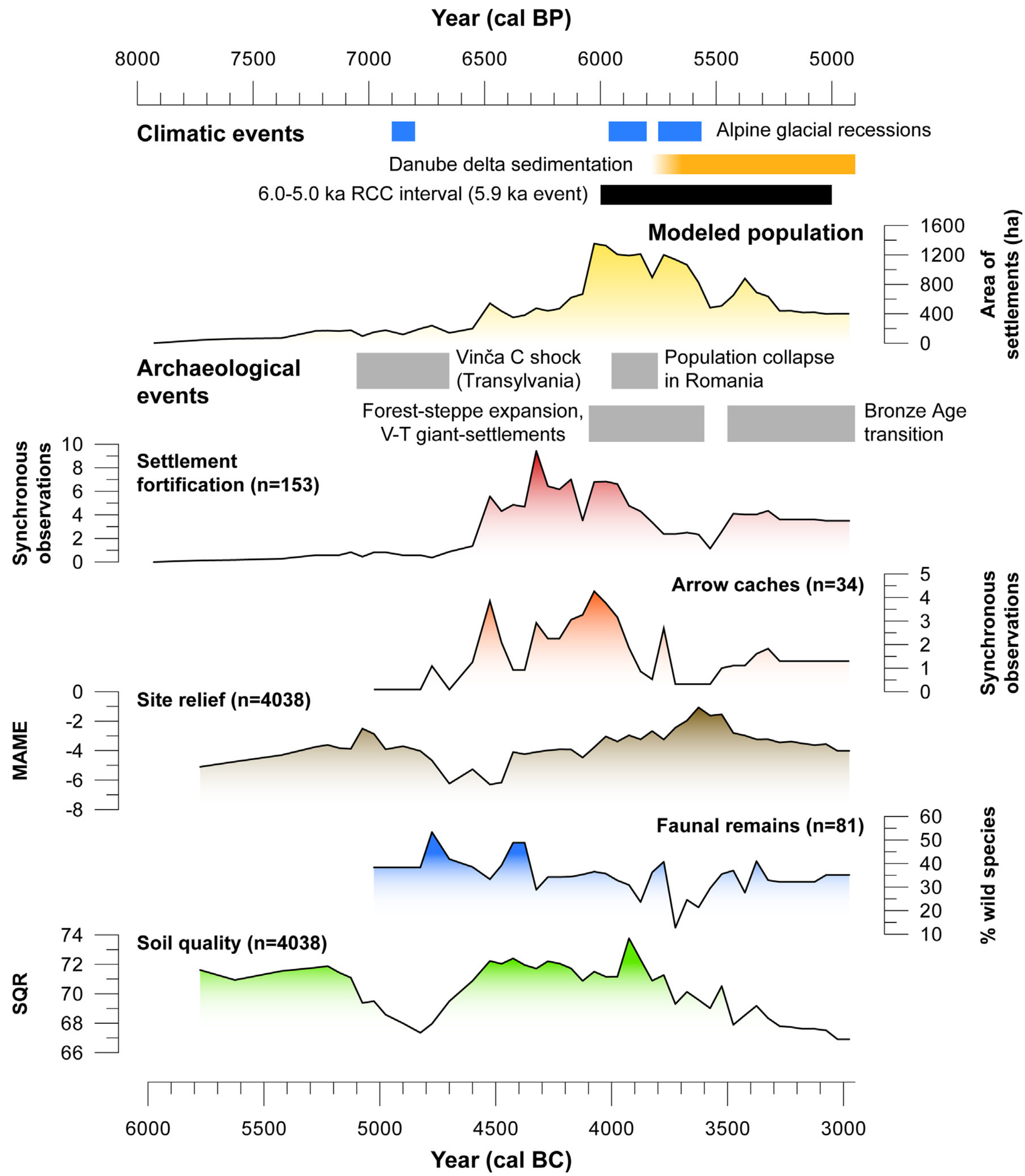

Fig. 3. Temporal comparison of climatic events, population dynamics, and socioeconomic and ecological variables in Neo-Eneolithic Eastern Europe. Data from Dergachev, 2007; Harper, 2016, 2017).

dependent trends, often in the form of a completely independent trend line during the Terminal Eneolithic and EBA transition. Four of these—the Danube Basin, Prut-Dniester, Lower Siret-Prut and Upper Siret Prut—have a particular pattern that may be interpreted based on their roles as "core" regions. These regions exhibit little change in settlement location despite growth in population, suggesting a consistent socio-economic focus on maximizing agricultural output throughout the entire Neo-Eneolithic period. However, during the Terminal Eneolithic and EBA transition (ca. 3500–3000 BCE) settlement location shifts dramatically, relating to SQR along a separate trend line or becoming entirely indifferent to SQR. This discontinuity is put forth as a quantitative indicator of the shift to pastoralism in these regions.

Some outliers are indicative of extreme environmental conditions wrought by major climate events. In the Danube Basin and Budzhak-Dobrudzha, the time references shown as outliers are entirely associated with a population collapse following the demise of settlements belonging to the Gumelnița culture, during the interval of ca. 3900–3500 BCE. During this period, the settlements of the Cernavodă I culture (periods 1c/2a) hosted far less population and were sited in more marginal locations, indicating a retreat from alluvial floodplains following the 5.9 ka event. We hypothesize that concurrent Alpine glacial recession and the beginning of sedimentation in the Danube Delta mark a change in the flood regime of the Danube, adversely affecting the habitability of regions that were otherwise fairly insulated from changes in temperature and precipitation during the fourth millennium (Harper, 2017; also proposed by Anthony, 2007). An analogous scenario of cultural change based on flood vulnerability is put forth for the Iron Gates region around the time of the 8.2 ka event, when all Mesolithic sites in the region were abandoned with the exception of Lepenski Vir (Bonsall et al., 2002).

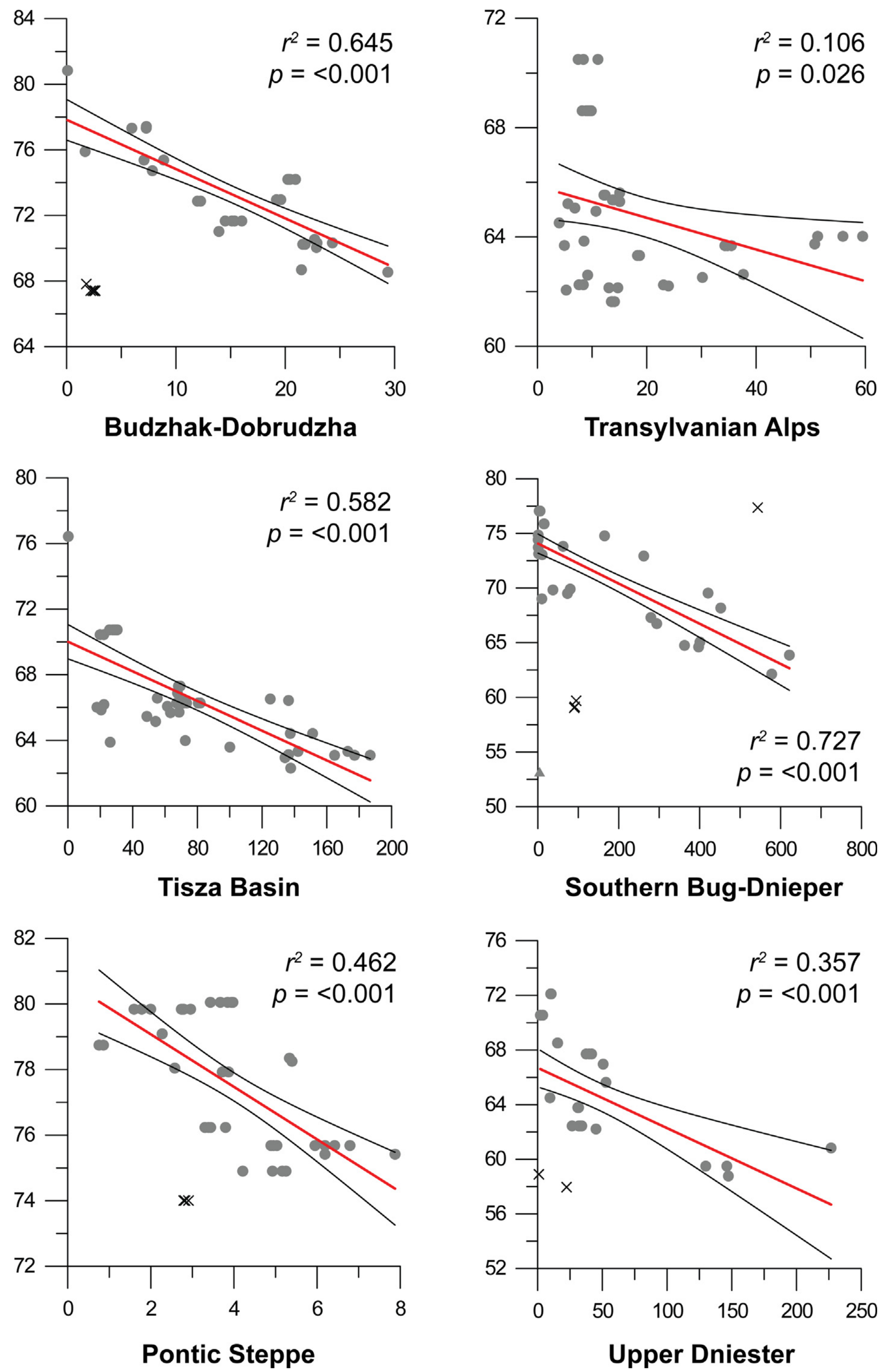

Fig. 4. Linear regressions of population (x-axis) vs. SQR (y-axis) in regions adhering to IFD expectations. Points – observed values, X – omitted outliers.

In other regions, however, outliers cannot as yet be explained but may be a result of local socio-political strife or competition over subsistence resources. In the Upper Siret-Prut region, for example, very poor SQR values are observed for the periods of 5300–5100 and 4800–4600 BCE, corresponding to phase 4 of the Starčevo-Criș culture and phase 2 of the Precucuteni culture, respectively. While population values for these periods are elevated in relation to other time references during the Late Neolithic/Early Eneolithic, it should be noted that much greater population growth during the later periods of Precucuteni 3 and Cucuteni A/B is accompanied by preference for sites with high SQR values.

In peripheral regions with generally low population levels, the arrival of distinct cultural units can produce highly divergent patterns in site selection criteria due to the overlap or displacement of different subsistence regimes. In some situations we can tie these outliers to a signal of certain economic activity. This seems to particularly be the case for certain periods in the development of the Middle Dnieper region. The initial Neolithic settlement record for this region consists of isolated sites belonging to the easternmost group of the Linear Pottery culture (Gaskevych, 2006), which are then joined by settlements of the Dnieper-Donets culture ca. 5200 BCE. This population of hunter-gatherers was likely indifferent to the soil quality of settlement sites. Later,

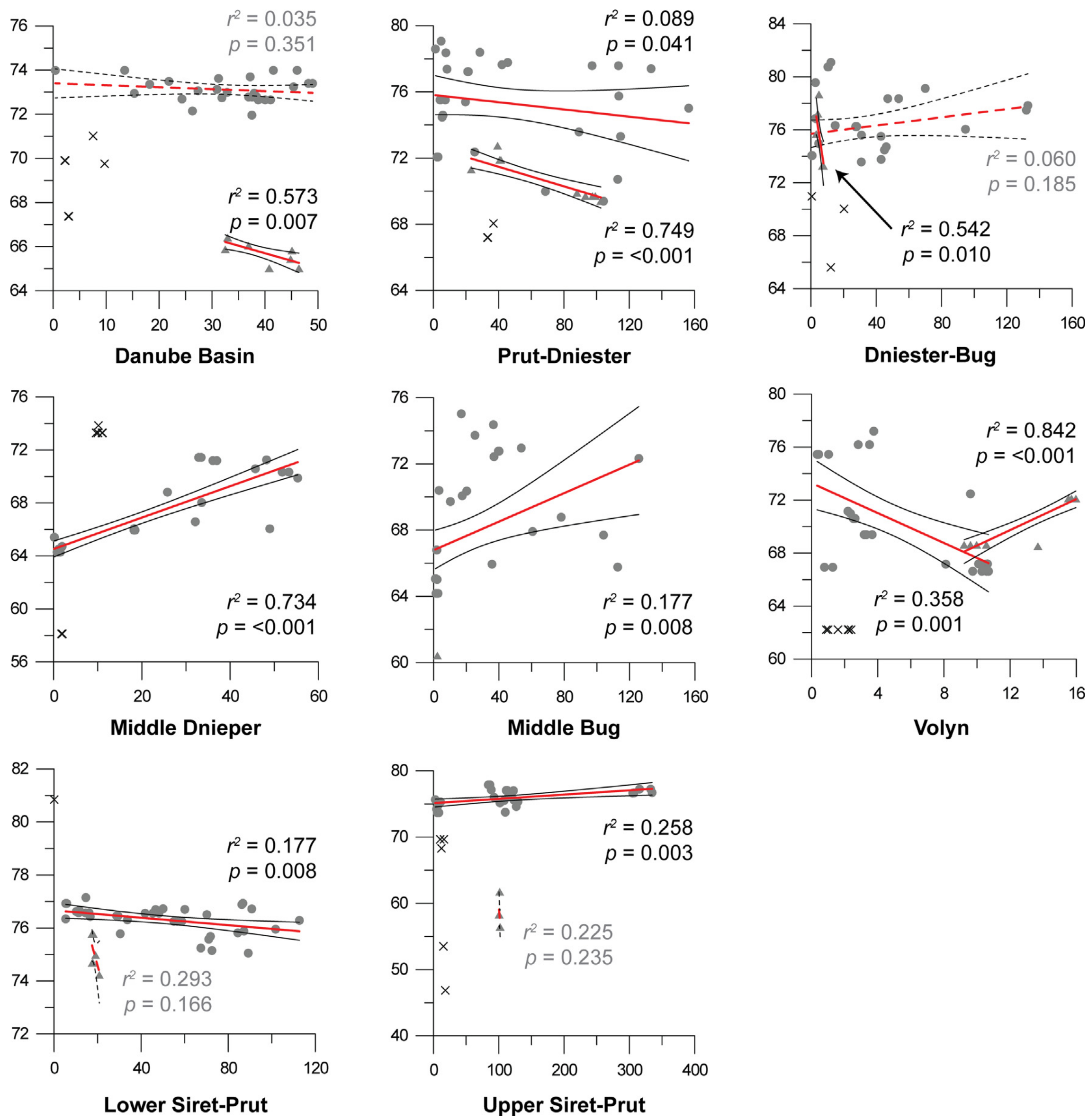

Fig. 5. Linear regressions of population (x-axis) vs. SQR (y-axis) in regions only partially adhering to or deviating from IFD expectations. Points – observed values (Neo-Eneolithic); triangles – observed values (Bronze Age transition); X – omitted outliers.

the arrival of ETC colonists belonging to the Bug-Dnieper and Kolomijshchinskaya local groups (Tripolye B1-2 and B2) produces an abnormally high average SQR during the interval of 4200–3950 BCE.

Such trends appear to be diagnostic of the agricultural colonization of a peripheral region predominately engaged in hunting and gathering or pastoralism. This is also apparent in the Middle Bug region, a region which, despite belonging to the forest-steppe "corridor" and hosting a brief period of intensive settlement during the Middle-Late Eneolithic, seems to have largely been a more marginal region. Here, while the Neolithic economy included cereal cultivation along with other aspects of the Neolithic "package," settlement was initially limited to sparse sites of the Bug-Dniester culture (ca. 5700–4800 BCE) and Tripolye A (4800–4400 BCE), precluding the need for intensive agriculture until Tripolye B1.

Perhaps the most enigmatic results are from Volyn, where habitat suitability predictably decreases as population increases during the Neo-Eneolithic, but then increases with population during the Terminal Eneolithic and EBA transition. This may be reflective of changes in subsistence strategy accompanying the colonization of the region by populations belonging to the Bynzenskaya local group (Diachenko and Kyrylenko, 2016; Kruts and Ryzhov, 2000), an early Tripolye C2 group that initially developed in northern Moldova. Lower-lying areas of Volyn tend to have marshy, hydric soils that are poor for agriculture, so the influence of topography here may be elevated in relation to other regions.

3.3. Material indicators of resource competition

The spatio-temporal specificity of settlement fortification is substantial, with settlements in Ukraine generally not exhibiting defensive features until Tripolye C2. Fortification incidence in Romania is temporally diverse, but in Moldavia it can mostly be attributed to settlements during the interval of Cucuteni A and A-B (ca. 4550–3850 BCE). Fortified settlements at this time generally follow the template of sites such as Hăbășești-Holm, where a small settlement is situated on a natural promontory and the least defensible approach is bisected by a ditch (Dumitrescu et al., 1954). In comparison to the Cucuteni B period (ca. 4000–3500 BCE), which exhibits a broader spatial distribution of sites, the earlier fortified settlements are more densely clustered in the Siret-Prut interfluve, "homeland" of the complex. The presence of

Cucuteni B fortified settlements as far flung as Northern Muntenia (in the isolated case of Sărata Monteoru-Cetățuia) reflects the general dispersion of the Cucuteni culture around this time, immediately prior to its replacement by the Tripolye C2/Horodiștea-Foltești horizon.

In Ukraine and Moldova, only 21 and 22 Cucuteni-Tripolye sites, respectively, are indicated as having explicitly defensive characteristics. Most of these belong to the later phases of the Tripolye culture, particularly Tripolye C2. This is likely a biased sample, given that every major late local group type-site (incidentally, sites which have been extensively or fully excavated) is fortified, including the sites of Brînzeni 3, Gorodsk-Krasnaya Gora, Gordineshty 2, Horodiștea 2, and Foltești-La Ruptura. Northern Moldova, an area of intensive settlement during the Late Tripolye period, shows the highest density of fortified sites. In the case of Brînzeni 3, type-site of the Brynzenskaya local group, the settlement is situated on a high promontory and its approach is defended by a ditch (Markevich, 1981), similar to the earlier model of Romanian sites. However, in their farthest peripheral extent fortifications are also found at flat sites such as at the Sofievskaya local group settlement of Kazarovichi in the Middle Dnieper region (Kruts, 1977).

As indicated by the data of Dergachev (2007), supplemented by other sources within EENSR, the temporal frequency of settlement fortification and arrowhead caches is highly correlated and supports the notion that the periods of Cucuteni A to A-B/Tripolye B1 to B2 constituted the peak of violent competition. Large-scale migration to the Southern Bug-Dnieper region and other forest-steppe areas briefly drove overall SQR to its highest levels during the first half of the fourth millennium, while simultaneously relieving competitive stress on core regions to the west. The unfortified nature of these communities, perhaps a result of unassailable strength in numbers (Harper, 2016; Kruts, 2012), and the reduced population density in the Cucuteni-Tripolye core led to an overall drop in the incidence of fortification that did not rebound until Tripolye C2.

The resumption of settlement fortification during the Terminal Eneolithic (3500–3000 BCE) has been framed either in response to "external" or "internal" threats, with Dergachev (2007) taking the position that this was in response to a new wave of population from the steppe. We take the opposite position, that such developments were spurred on by significant socio-economic transformation of the Late Tripolye population. The clearly identified shift from agriculture to stock-breeding and increase in exchange between related communities caused the formation of competitive, dispersed chiefdoms (after Earle and Kristiansen, 2010).

4. Conclusions

4.1. The Bronze Age Transition and changes in subsistence

Macro-scale trends in diminishing SQR illustrate the gradual transition to a pastoral form of subsistence economy during the Terminal Eneolithic. Aside from a brief spike in population, associated with a final phase of settlement nucleation during Tripolye C1-2, population attains a plateau at approximately 3600 BCE that continues until the EBA transition. Terminal Eneolithic groups, largely represented by the Late Tripolye, Baden, Cernavodă 3, and Coțofeni cultural units, showcase a shift from intensive agronomy-focused subsistence patterns to an emphasis on pastoralism and less intensive cultivation. Additionally, the exploitation of wild game returns to earlier levels, prior to the intense episodes of population agglomeration during the early fourth millennium.

The gradual economic transition shown by our analysis is not in itself wholly at odds with narratives dependent on on Late Eneolithic-EBA interaction, which in some cases is described as a gradual process of acculturation (e.g. Anthony, 2007). However, in terms of site stratigraphy and typochronology, archaeological synchronicity between Eneolithic and EBA groups has yet to be demonstrated beyond a possible, very brief, interval at the beginning of the third millennium at sites such as Usatovo. In our assessment, the Terminal Eneolithic marks a large shift in economy and material culture of local origin that prefigured the EBA transition, represented by syncretic assemblages such as the "common Late Tripolye horizon" (Dergachev, 1980) and Cernavodă 3-Baden-Boleráz complex. These units developed gradually, possibly as an adaptive response to climatic conditions over the course of the fourth millennium, and adopted a way of life that was not too dissimilar to their EBA successors. Current radiocarbon data suggest a sudden end to Terminal Eneolithic assemblages in the region occurring ca. 2950 BCE. The swift acculturation of these groups into a new cultural order may be partially explained by their convergent trajectories of socioeconomic development.

It is important to note that we do not neglect the importance of steppe interactions in Central Ukraine, which was a longstanding zone of cultural contact for millennia. Influences from earlier steppe groups such as the Dnieper-Donets culture were common among the peripheral components of the Tripolye culture, manifested through exchanges of both diagnostic materials (Telegin, 1987) and cultural practices. These include inhumation burials found near Tripolye sites on the steppe frontier, as well as Tripolye pottery found in Middle and Late Eneolithic steppe burials of various steppe local groups. These issues were investigated previously by several Ukrainian scholars, especially Tamara Movsha (Movsha, 1993, 1998, 2000). It is important to note that the steppe contact zone, while persistent, was porous and does not exhibit much evidence for violent or coercive interactions consistent with the EBA versus "Old Europe" dichotomy. The development of steppe populations was influenced by the developmental dynamics of the Eneolithic agricultural world (including the Tripolye culture; Rassamakin, 2004), and the decline of this system was one of the causes of cultural transformation in the steppe and formation of the common Yamnaya horizon (Rassamakin, 1999, 2006, 2013).

4.2. Analytical limitations and further research

Our basic application of IFD has proven to be a useful tool for identifying changes in regional subsistence regimes. However, certain limitations exist owing to the treatment of data as averaged regional groupings. While this was deemed a necessity for ensuring a practical and systematic workflow when compiling and analyzing large amounts of time series data within subsets of EENSR, the results do not reflect the true diversity and variability of habitats within regions. As a result, this is not conducive to assessing habitat ranking (in the sense of Codding and Bird, 2015) and we cannot as yet identify migratory vectors. At present, assessment of whether population growth within our analytical regions is endogenous or the result of migration is mainly dependent on case-specific analysis of material culture. Meanwhile, the present relative chronology (Harper, 2016), while fairly well synchronized between regions and honed through analysis of those reliable absolute dates that exist, does not always have the temporal resolution needed for distinguishing specific population events.

Sergei Ryzhov's observation that pottery types of the Tomashovskaya local group (ca. 3850–3600 BCE) of the Southern Bug-Dnieper region influenced assemblages in Moldova and northeastern Romania during the latter part of Tripolye C1 (Ryzhov, 1999) lends some credence to the idea that the forest-steppe migratory stream was well-traveled in both directions, with some portion of the population returning to the west in "back migrations" during and after the period of giant-settlement development. This kind of back-and-forth behavior is suggestive of negative migrant selection, wherein individuals are "pushed" from their homes but later return when conditions normalize (Lee, 1966). While this corresponds well with generally poor growing conditions observed in the pollen record around the time of the 5.9 ka event in Ukraine and Romania (Harper, 2017), the environmental impact within specific regions is poorly understood.

In order to improve upon the analysis presented here, as well as other concerns such as the regionally variegated development of material typologies (Diachenko and Harper, 2016; Diachenko and Menotti, 2015) and timing of interactions between the steppe and Middle-Late Tripolye groups (Rassamakin, 2013), we are conducting an extensive campaign of AMS ^{14}C dating. While a sizable corpus of radiocarbon data have been generated to address the more sensational aspects of the Cucuteni-Tripolye complex, namely the giant-settlements and their intra-site development, it is only through consideration of the overall chronology and dating of local group phenomena that we may be able to better explain the socioeconomic dynamics of Late Eneolithic society.

5. Declarations of interest

None.

6. Contributions

T.K.H. designed research and performed the analysis; T.K.H., A.D., Yu.Ya.R. and D.J.K. wrote the paper.

Acknowledgments

Collaborations crucial to this research were facilitated by an agreement between the Department of Anthropology, Pennsylvania State University, and the Institute of Archaeology, Ukrainian National Academy of Sciences. Funding was provided by the National Science Foundation, grant BCS-1725067: "Long Term Population Response to Environmental Fluctuation" (D.J. Kennett and T.K. Harper).

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jaa.2018.11.006.

References

Ammerman, A.J., Cavalli-Sforza, L.L., Wagener, D.K., 1976. Toward the estimation of population growth in old world prehistory. In: Zubrow, E.B.W. (Ed.), Demographic Anthropology: Quantitative Approaches. University of New Mexico Press, Albuquerque, pp. 27–62.
Anthony, D.W., 2007. The Horse, The Wheel, and Language: How Bronze-Age Riders from the Eurasian Steppes Shaped the Modern World. Princeton University Press, Princeton.
Bickle, P.B., Whittle, A. (Eds.), 2013. The First Farmers of Central Europe: Diversity in LBK Lifeways. Oxbow Books, Oxford.
Bonsall, C., Macklin, M.G., Payton, R.W., Boroneanţ, A., 2002. Climate, floods, and river gods: environmental change and the Mes-Neolithic transition in southeast Europe. Before Farm.: Archaeol. Old World Hunter-Gatherers 3–4 (2), 1–15.
Chapman, J.C., Videiko, M.Yu., Gaydarska, B., Burdo, N., Hale, D., 2014. Architectural differentiation on a Trypillia mega-site: preliminary report on the excavation of a mega-structure at Nebelivka, Ukraine. J. Neolithic Archaeol. 16, 135–157. https://doi.org/10.12766/jna.2014.4.
Ciocanu, S., 2014. Registrul Monumentelor Republicii Moldova. Ministerul Culturii al Republicii Moldova. Available at: < http://date.gov.md/ckan/dataset/5180-registrul-monumentelor-republicii-moldova > (accessed 16 August 2017).
Codding, B.F., Bird, D.W., 2015. Behavioral ecology and the future of archaeological science. J. Archaeol. Sci. 56, 9–20. https://doi.org/10.1016/j.jas.2015.02.027.
Codding, B.F., Jones, T.L., 2013. Environmental productivity predicts migration, demographic, and linguistic patterns in prehistoric California. Proc. Natl. Acad. Sci. USA 110 (36), 14569–14573. https://doi.org/10.1073/pnas.1302008110.
Dergachev, V.A., 1980. Памятники позднего Триполья (опыт систематизации). Shtiintsa, Kishinev.
Dergachev, V.A., 2007. О скипетрах, о лошадях, о войне: Этюды в защиту миграционной концепции М. Гимбутас. Nestor-Istoriya, Saint Petersburg.
Diachenko, A., 2012. Settlement system of west Tripolye culture in the southern bug and Dnieper interfluve: formation problems. In: Menotti, F., Korvin-Piotrovskiy, A.G. (Eds.), The Tripolye Culture Giant-Settlements in Ukraine: Formation, Development, and Decline. Oxbow Books, Oxford, pp. 116–138.
Diachenko, A., 2016. Small is beautiful: a democratic perspective? In: Müller, J., Rassmann, K., Videiko, M. (Eds.), Trypillia Mega-Sites and European Prehistory, 4100–3400 BCE. Routledge, London, pp. 269–280.
Diachenko, A., Harper, T.K., 2016. The absolute chronology of Late Tripolye sites: a regional approach. Sprawozdania Archeologiczne 68, 81–105.
Diachenko, A., Kyrylenko, A., 2016. Позднее Триполье Западной Волыни: состояние источников и краткий обзор хронологических схем. In: Diachenko, A., Krol, D., Kyrylenko, A., Rybicka, M., Werteletski, D. (Eds.), Nowomalin-Podobanka i Kurgany-Dubowa - Osiedla kultury trypolskiej na zachodnim Wolyniu. Instytut Archeologii UR, Rzeszow, pp. 125–132.
Diachenko, A., Menotti, F., 2012. The gravity model: monitoring the formation and development of the Tripolye culture giant-settlements in Ukraine. J. Archaeol. Sci. 39, 2810–2817. https://doi.org/10.1016/j.jas.2012.04.025.
Diachenko, A., Menotti, F., 2015. Cucuteni-Tripolye contact networks: cultural transmission and chronology. In: Diachenko, A., Menotti, F., Ryzhov, S., Bunyatyan, K., Kadrow, S. (Eds.), The Cucuteni-Trypillia Cultural Complex and its Neighbours: Essays in Memory of Volodymyr Kruts. Institute of Archaeology of the University of Rzeszów, Rzeszów, pp. 131–152.
Diachenko, A., Menotti, F., 2017. Proto-cities or non-proto-cities? On the nature of Cucuteni-Trypillia mega-sites. J. World Prehist. 30 (3), 207–219. https://doi.org/10.1007/s10963-017-9105-8.
Dumitrescu, V., Dumitrescu, H., Petrescu-Dîmboviţa, M., Gostar, N., 1954. Hăbăşeşti, monografie arheologică. Editura Academiei R.P.R, Bucharest.
Earle, T., Kristiansen, K., 2010. Organizing bronze age societies: concluding thoughts. In: Earle, T., Kristiansen, K. (Eds.), Organizing the Bronze Age Societies: The Mediterranean, Central Europe and Scandinavia Compared. Cambridge University Press, Cambridge, pp. 218–256.
Fretwell, S.D., Lucas Jr., H.L., 1970. On territorial behavior and other factors influencing habitat distribution in birds. I. Theoretical development. Acta Biotheor. 19, 16–36.
Gaskevych, D., 2006. Stanowisko 2 w miejscowości Vita-Poshtova na Ukrainie — nowe, najbardziej na wschód wysunięte stanowisko kultury ceramiki wstęgowej rytej. Sprawozdania Archeologiczne 58, 216–221.
Gaydarska, B., 2016. The city is dead! Long live the city!. Norw. Archaeol. Rev. 49 (1), 40–57. https://doi.org/10.1080/00293652.2016.1164749.
Goldberg, A., Günther, T., Rosenberg, N.A., Jakobsson, M., 2017. Ancient X chromosomes reveal contrasting sex bias in Neolithic and Bronze Age Eurasian migrations. Proc. Natl. Acad. Sci. USA 114 (10), 2657–2662.
Haak, W., Lazaridis, I., Patterson, N., Rohland, N., Mallick, S., Llamas, B., Brandt, G., Nordenfelt, S., Harney, E., Stewardson, K., Fu, Q., Mittnik, A., Bánffy, E., Economou, C., Francken, M., Friederich, S., Garrido Rena, R., Hallgren, F., Khartanovich, V., Khokhlov, A., Kunst, M., Kuznetsov, P., Meller, H., Mochalov, O., Moiseyev, V., Nicklisch, N., Pichler, S.L., Risch, R., Rojo Guerra, M.A., Roth, C., Szécsényi-Nagy, A., Wahl, J., Meyer, M., Krause, J., Brown, D., Anthony, D., Cooper, A., Werner Alt, K., Reich, D., 2015. Massive migration from the steppe is a source for Indo-European languages in Europe. Nature 522, 207–211.
Harper, T.K., 2012. Sustaining Talianki: a model of eneolithic subsistence economics at a Giant-settlement of the Western Tripolye Culture, Ukraine. Department of Anthropology, SUNY at Buffalo (M.A Thesis).
Harper, T.K., 2016. Climate, Migration, and False Cities on the Old European Periphery: A Spatial-demographic Approach to Understanding the Tripolye Giant-Settlements (Ph.D. dissertation). Department of Anthropology, SUNY at Buffalo, Proquest, Ann Arbor.
Harper, T.K., 2017. Demography and climate in Late Eneolithic Ukraine, Moldova, and Romania: multiproxy evidence and pollen-based regional corroboration. J. Archaeolog. Sci.: Rep. https://doi.org/10.1016/j.jasrep.2017.06.010.
Harper, T.K., 2018Harper, in press. SARP revisited: reconstructing population trends in Neo-Eneolithic Eastern Europe through large-scale analysis of archaeological settlement data. In: Pelisiak, A., Diachenko, A., Nakoinz, O. (Eds.), Recent Issues in Archaeological Demography. Springer (in press).
Jazwa, C.S., Jazwa, K.A., 2017. Settlement ecology in bronze age Messenia. J. Anthropol. Archaeol. 45, 157–169.
Kennett, D.J., 2005. The Island Chumash, Behavioral Ecology of a Maritime Society. University of California Press, Berkeley.
Kennett, D.J., Anderson, A., Winterhalder, B., 2006. The ideal free distribution, food production, and the colonization of oceania. In: Kennett, D.J., Winterhalder, B. (Eds.), Behavioral Ecology and the Transition to Agriculture. University of California Press, Berkeley, pp. 265–288.
Kennett, D.J., Winterhalder, B., Bartruff, J., Erlandson, J.M., 2009. An ecological model for the emergence of institutionalized social hierarchies on California's Northern Channel Islands. In: Shennan, S. (Ed.), Pattern and Process in Cultural Evolution. University of California Press, Berkeley, pp. 297–314.
Kruts, V.A., 1977. Позднетрипольские памятники Среднего Поднепровья. Naukova Dumka, Kiev.
Kruts, V.A., 1989. К истории населения трипольской культуры в междуречье Южного Буга и Днепра. In: Berezanskaya, S.S. (Ed.), Первобытная археология: Материалы и исследования. Naukova Dumka, Kiev, pp. 117–132.
Kruts, V.A., 2008. Giant-settlements of the Tripolian culture. In: Korvin-Piotrovskiy, A.G., Menotti, F. (Eds.), Tripolye Culture in Ukraine: the Giant-settlement of Talianki. IANANU, Kiev, pp. 42–48.
Kruts, V.A., 2012. Giant-settlements of Tripolye culture. In: Menotti, F., Korvin-Piotrovskiy, A.G. (Eds.), The Tripolye Culture Giant-settlements in Ukraine: Formation, Development and Decline. Oxbow Books, Oxford, pp. 70–78.
Kruts, V., Ryzhov, S., 2000. Tripolye culture in Volhynia (Gorodsk-Volhynian group). Baltic-Pontic Stud. 9, 86–110.
Lazarovici, G., 1987. „Şocul" Vinča C în Transilvania. Acta Musei Porolissensis 11, 37–38.
Lee, E.S., 1966. A theory of migration. Demography 3 (1), 47–57.
Markevich, V.I., 1981. Позднетрипольские племена северной Молдавии. Shtiintsa, Kishinev.
McClure, S.B., Barton, C.M., Jochim, M.A., 2009. Human behavioral ecology and climate change during the transition to agriculture in Valencia. Eastern Spain. J. Anthropol. Res. 65 (2), 253–269.
Milisauskas, S., Kruk, J., 1989. Neolithic economy in Central Europe. J. World Prehist. 3 (4), 403–446.

Movsha, T.G., 1993. Взаємовідносини степових і землеробських культур в епоху енеоліту – ранньобронзового віку. Археологія 1993 (3), 36–51.
Movsha, T.G., 1998. Зв'язки Трипілля-Кукутені зі степовими енеолітичними культурами (до проблеми індоєвропеїзації Європи). Праці Археологічної Комісії 235, 111–153.
Movsha, T.G., 2000. К проблеме взаимодействия древних земледельцев трипольско-кукутенской общности с носителями культур понтийских степей. In: Marina, Z.P. (Ed.), Labores Pariunt Honores. Dnipropetrovsk State University, Dnipropetrovsk, pp. 29–53.
Mueller, L., Schindler, U., Behrendt, A., Eulenstein, F., Dannowski, R., 2007. The Muencheberg Soil Quality Rating (SQR): Field Manual for Detecting and Assessing Properties and Limitations of Soils for Cropping and Grazing. MunchebergLeibniz-Centre for Agricultural Landscape Research (ZALF) e.V.
Panagos, P., Van Liedekerke, M., Jones, A., Montanarella, L., 2012. European soil data centre: response to European policy support and public data requirements. Land Use Policy 29 (2), 329–338.
Rassamakin, Yu., 1999. The eneolithic of the Black Sea steppe: dynamic of cultural and economic development 4500–2300 BC. In: Levine, M., Rassamakin, Yu., Kislenko, A., Tatarintseva, N. (Eds.), Late Prehistoric Exploitation of the Eurasian Steppe. McDonald Institute for Archaeological Research, Cambridge.
Rassamakin, Yu.Ya., 2004. Степи Причорномор'я в контексті розвитку перших землеробських суспільств. Археологія 2004 (2), 3–26.
Rassamakin, Yu., 2006. Cultural transformation in the Black Sea steppe between the eneolithic and bronze age: migrations or economic changes? In: Peterson, D.L., Popova, L.M., Smith, A.T. (Eds.), Beyond the Steppe and the Sown. Brill, Colloquia Pontica 13. Leiden, pp. 448–458.
Rassamakin, Yu.Ya., 2013. From the late Eneolithic period to the early bronze age in the black sea steppe: what is the pit grave culture (the Late 4th – middle 3rd Millennia BC). In: Heyd, V., Kulshár, G., Szeverényi, V. (Eds.), Transitions to the Bronze Age: Interregional Interaction and Socio-Cultural Change in the Third Millennium BC Carpathian Basin and Neighbouring Regions. Archaeolingua, Budapest, pp. 113–138.
Rassmann, K., Ohlrau, R., Hofmann, R., Mischka, C., Burdo, N., Videjko, M.Yu., Müller, J., 2014. High precision Tripolye settlement plans, demographic estimations and settlement organization. J. Neolithic Archaeol. 16, 96–134. https://doi.org/10.12766/jna.2014.3.
Rassmann, K., Korvin-Piotrovskiy, A., Videiko, M., Müller, J., 2016. The new challenge for site plans and geophysics: revealing the settlement structure of giant settlements by means of geomagnetic survey. In: Müller, J., Rassmann, K., Videiko, M. (Eds.), Trypillia Mega-Sites and European Prehistory, 4100–3400 BCE. Routledge, London, pp. 29–54.
Ryzhov, S.M., 1999. Кераміка поселень трипільської культури Буго-Дніпровського межиріччя як історичне джерело. IANANU, Kiev.
Ryzhov, S.N., 2012. Relative chronology of the giant-settlement period BII–CI. In: Menotti, F., Korvin-Piotrovskiy, A. (Eds.), The Giant-settlements of the Tripolye Culture: Formation, Development and Decline. Oxbow Books, Oxford, pp. 79–115.
Șandric, B., Borlean, O., Steinu, M., Buruiana, M., Miu, C., 2017. Repertoriul Arheologic Național. Institutul Național al Patrimoniului. Available at: < http://ran.cimec.ro/ > (accessed 25 October 2017).
Telegin, D.Ya., 1987. Neolithic cultures of the ukraine and adjacent areas and their chronology. J. World Prehist. 1 (3), 307–331.
Videiko, M.Yu., Kvitnytskij, M.V., Ovchynnykov, E.V., Kochnin, I.T., Polishchuk, L.Yu., Pichkur, E.V., 2004. Археологічні пам'ятки трипільської культури на території України. In: Burdo, N.B., Videiko, M.Yu. (Eds.), Енциклопедія трипільської цивілізації. Ukrpoligrafmedia, Kiev, pp. 563–700.
Weninger, B., Harper, T., 2015. The geographic corridor for rapid climate change in Southeast Europe and Ukraine. In: Hansen, S., Raczky, P., Anders, A., Reingruber, A. (Eds.), Neolithic and Copper Age between the Carpathians and the Aegean Sea: Chronologies and Technologies from the 6th to the 4th Millennium BCE. Deutsches Archäologisches Institut, Berlin, pp. 475–505.
Winterhalder, B., Kennett, D.J., Grote, M.N., Bartruff, J., 2010. Ideal free settlement of California's Northern Channel Islands. J. Anthropol. Archaeol. 29 (4), 469–490. https://doi.org/10.1016/j.jaa.2010.07.001.
Zhuravlov, O.P., 2008. Тваринництво та мисливство у трипільських племен на території України. IANANU, Kiev.