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Journal of Neolithic Archaeology

www.j-n-a.org

July 09th, 2015
doi 10.12766/jna.2015.1

Stabilization Points in Carrying Capacity: Population Growth and Migrations

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Article history:
Received March 25th, 2015
reviewed April 20th, 2015
published July 9th, 2015

Keywords: Carrying capacity • Cucuteni-Tripolye cultural complex • Migrations • Population growth • Site catchment analysis • Stabilization points

Cite as: *A. Diachenko/E.B.W. Zubrow 2015: Stabilization Points in Carrying Capacity: Population Growth and Migrations. JNA 17, 2015, 1–15 [doi 10.12766/jna.2015.1].*

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Acknowledgements
We are grateful to Karin Winter for the graphical adaption of figure 1.

Abstract

This study focuses on stabilization points in carrying capacity. Using simulations based upon well-known mathematical approaches in theoretical ecology, one calculates carrying capacity out of the trends in a demographic development. It is an alternative to most approaches in archaeology and anthropology concerning potential resources and the cost of labor. Finally, this approach is also useful for the analysis of migrations and site catchments.

Introduction

The Carrying Capacity is one of the key concepts in theoretical ecology, population biology, demography, economics, as well as other fields. It is defined as the maximum size of a population which can be maintained indefinitely within an area (Zubrow 1975; Sinclair 1997). Linking resources, economic development and population, this concept became an important tool in archaeology and anthropology. However, most calculations are based on simulations of potential resources and the cost of labor within a region. The verification of obtained results is complicated, if not impossible. This paper presents a research procedure, integrated from a set of well-known equations, that make calculations of carrying capacity out of trends in demographic development possible. The application of this method to settlements of the Cucuteni-Tripolye cultural complex provides an identification of migrations.

Carrying capacity: a brief theoretical and mathematical overview

The concept of carrying capacity and its applications to different fields, including archaeology and anthropology, has been heavily reviewed (May 1974; Zubrow 1975; Glassow 1978; Hassan 1981; Murray 1993; Hastings 1997; Seidl/Tisdell 1999; Allen et al. 2001; May/McLean 2007; Lane et al. 2014 et al.)

The issue of the complex interrelation between population growth and economic development goes back to the works of T. Malthus. He argued that sustenance increases arithmetically, while population grows geometrically. Population grows only to the stabilization point that is limited by resources (Malthus 1798). Since the time of Marx (1867), critics of the carrying capacity mainly focused on the accumulation of capital and technological progress to alleviate the

Malthusian dilemma. Each separately or together increases the potential for population growth and the quality of life. Although frequently modified, Malthus's fundamental idea has persevered to the present. It is illustrated with frightening reports by the Club of Rome regarding the medium-term perspectives of the global socio-economic development (Meadows et al. 2004; but also see: Cole et al. 1973).

The concept of the carrying capacity is highly applicable to pre-industrial societies. Considered by J. Steward (1949) and L. White (1959), it spread to processual archaeology. Birdsell (1953) correlated rainfall and Australian aboriginal population density and Childe's two revolutions were explained with demographic pressure (Fried 1960; Carneiro 1960; 1970; Binford 1968; Flannery 1969; Harner 1970 et al.).

Further analyses showed that even from a relatively short-term perspective, carrying capacity is a variable rather than a constant when it is influenced by climate change, non-renewable resources and other factors. The impact of changes in population growth, demographic transitions, migrations, economic innovations and population densities has been discussed in a large body of research literature (Boserup 1965; 1976; 1981; Zubrow 1975; Glassow 1978; Hassan 1981; Kremer 1993; Bintliff 1997; Wood 1998; Seidl/ Tisdell 1999; Shennan 2000; Klasen/Nestmann 2006; Bocquet-Appel/Bar-Yosef 2008; Nehlich et al. 2009; Richerson et al. 2009; Lycett/Norton 2010; Müller 2013 et al.). This was not limited to the West. Malthusian ideas were also developed by Soviet archaeologists since S. Bibikov (1965). Although originally applied to Cucuteni-Tripolye settlements in the Middle Dnieper region, the theoretical section was censored on ideological grounds.

The actual ratio of population growth to increases in sustenance in Malthus's original formulation was mistaken. The correction came when the Belgian mathematician P. Verhulst introduced the logistic equation in the first half of the nineteenth century. It is:

$$\frac{dP}{dt} = rP\left(1 - \frac{P}{C}\right) \text{ or} \qquad (1)$$

$$P_{x+1} = rP_x(1 - P_x) \qquad (2)$$

where C is the carrying capacity, and r is the rate of population growth. In equation (2) P_x is the initial population, and P_{x+1} is the population after time $x+1$. Both variables are the relative values with $C = 1$ (Verhulst 1838; 1845).

The logistic function models the "S-shaped" behavior of growth. Population slowly grows, but at an increasing rate, until it is growing rapidly. Then, growth slows as the rate of increase decreases – growing ever more slowly until it stabilizes in the final stage. It is a first order differential equation and a special case of the sigmoid function. In the classic case, the "rate of change of the growth rate" is a constant. By this is meant that the size (absolute value) of the rate of change of the rate of growth is a constant. However, this need not always be the case and one finds many empirical cases where it is not exactly equal over the time domain. It frequently has been applied to empirical data and used as the basis of simulations (Ammerman et al. 1973; Eighmy 1979; Haggett 1979; Porčic 2010; 2011 et al.). For a recent review of its applications and derivatives see J. Steele (2009). However, S. Milisauskas and J. Kruk (1989) argued that populations do not adapt to "average" conditions, but to bad years when food resources are limited. For them, population grows in a series of spurts and declines determined by a wide variety of idiosyncratic conditions.

Three questions arise from this discussion. 1) Are there generalities for demographic growth? 2) If so, is carrying capacity the limit to growth? 3) And finally, when there is a stabilization of growth, represented by the S-shaped curve, does it correspond to the carrying capacity?

The difference equation (1) may be solved graphically or algebraically. The former led some scholars to conclude that population tends to stabilize its growth when it reaches about half of the carrying capacity (Strogatz 1994, 18–24; Hastings 1997, 90–92). Once stabilized, additional growth results in either part of the population migrating to other habitats or corrections in the ratio of fertility and mortality (see more in: Zubrow 1975; Murray 1993; Hastings 1997; May/McLean 2007 et al.). Of course, both may occur simultaneously. Based on a series of case studies, S. Shennan explains the stabilization in growth as a balance between reproductive activity and successive subsistence (Shennan 2009).

Early work on the logistic curve was usually theoretical and growth needed to be described in continuous time. However, more recent work has relied on simulations in which time needed to be represented as having discrete units. Some of these studies showed that complex behavior arises even from the simple first-order difference equation (Gleick 1987). R. May (1976) in theoretical ecology and M. Feigenbaum (1978; 1979) in theoretical physics independently demonstrated that there were potential aperiodic regimes of growth. May's simulations were based on iterating equation (2) while gradually increasing growth r (May 1976). Feigenbaum (1978; 1979) worked with formula 3. It has equivalent properties:

$$P_{x+1} = 1 - \lambda P_x^2 \qquad (3)$$

The iterations lead to the transition from simple periodic behavior to a regime with complex aperiodic growth with period-doublings. Stabilization points are dependent on r. If r exceeds 1 but it is less than 2, population stabilizes near the following value.

$$P_s = \frac{r-1}{r} \qquad (4)$$

If r belongs to the range between 2 and 3, population oscillates around the same value (formula 4), and then stabilizes near it. If r is greater than 3 and less than 3.45, population oscillates between two values; if r exceeds 3.45 but it is less than 3.54, population oscillates between four values etc. (May 1976; Feigenbaum 1978; 1979; 1980).

Remembering that growth could increase by changes in fertility, mortality or migration, one turns to a research procedure where carrying capacity is a constant.

Research procedure

Long-term population growth is a fractal-like graph, consisting of S-shaped curves. Each graph starts from a stabilization point of a previous S-shaped curve (Batty 2007). Stabilization in logistic curves reflects either carrying capacities or stabilization points below these upper limits (Diachenko 2013). The following procedure is used for the demographic trends:

- First, analyze the empirical data to indicate one or more S-shaped curves within long-term population growth.
- Second, calculate the value of r as a ratio of population at the stabilization point and the initial population. At this stage of the research we simplify by using linear growth between two stabilization points (Kapitsa 2010).

- Third, calculate the carrying capacity from the relative size of the population at the stabilization point.
- Fourth, simulate the population growth in discontinuous time, introducing the obtained value of the carrying capacity from the analytical solution of the logistic equation. The latter is written as follows:

$$P_t = \frac{CP_0 e^{gt}}{C + P_0(e^{gt} - 1)} \qquad (5)$$

$$\left(\lim_{t\to\infty} P_t = C\right)$$

where P_0 is an initial population, P_t is a population after time t, g is an annual rate of population growth, and e is a base of natural logarithm (≈ 2.7183).

- Fifth, compare the model and the empirical data.

This research procedure was tested using settlements of the Western Tripolye culture in the Southern Bug and Dnieper interfluve (Ukraine).

Case study

Data input

The Western Tripolye culture (hereinafter, WTC) is one of the components of the Cucuteni-Tripolye cultural complex dating circa 4800 – 2950/2900 BC (hereinafter, CTCC). The term “Western Tripolye culture” was introduced by S. Ryzhov (2007; 2012) to characterize Tripolye sites where painted ceramics dominate incised ceramics. The WTC was formed on a base of the settlements that belonged to the Zaleshchitskaya local group in the Middle Dniester region. They may be dated no earlier than 4250 – 4200 BC. The latest WTC sites belong to the Usatovo and Kasperovskaya local groups. They correspond temporally with the final Tripolye – Horodiştea-Folteşti type. The latest absolute dates are actively debated (see Rassamakin 2012; Kadrow 2013). But, a reasonable upper limit is 2950 – 2900 BC.

Sites of the WTC in the Southern Bug and Dnieper interfluve (c. 4100 – 3600 BC) contain settlements with only one Tripolye layer (Fig. 1). They belong to the Vladimirovskaya, Nebelevskaya, and Tomashovskaya local groups that form a single “genetic” line of development (Ryzhov 2012). The phases and stages of the development of the Vladimirovsko-Tomashovskaya line are combined into analytical periods that are labeled from 1 to 8, computing a single S-shaped curve (Fig. 2). The settlements of stage 2 of phase 3 and phase 4 of the Tomashovskaya group are not considered because for both cases population values would be driven from the equilibrium. Stage 2 of phase 3 is associated with the migration wave from the Middle Southern Bug region, as shown by Diachenko (2012) and Tarapata (in press). This wave corresponds to the number of dwellings recently calculated for the settlement of Maidanetske (Rassmann et al. 2014). Therefore, the size of the population exceeds the stabilization point. Populations of the Vladimirovsko-Tomashovskaya line started to migrate out of the Southern Bug and Dnieper interfluve in phase 4 of the Tomashovskaya group. Thus, we deal with a time period of about 350 years. After a chronological gap of ca. 50 years, this region was populated by the peoples of the Kosenivska group as the result of a migration wave from the Dniester region (Diachenko 2012; Kruts

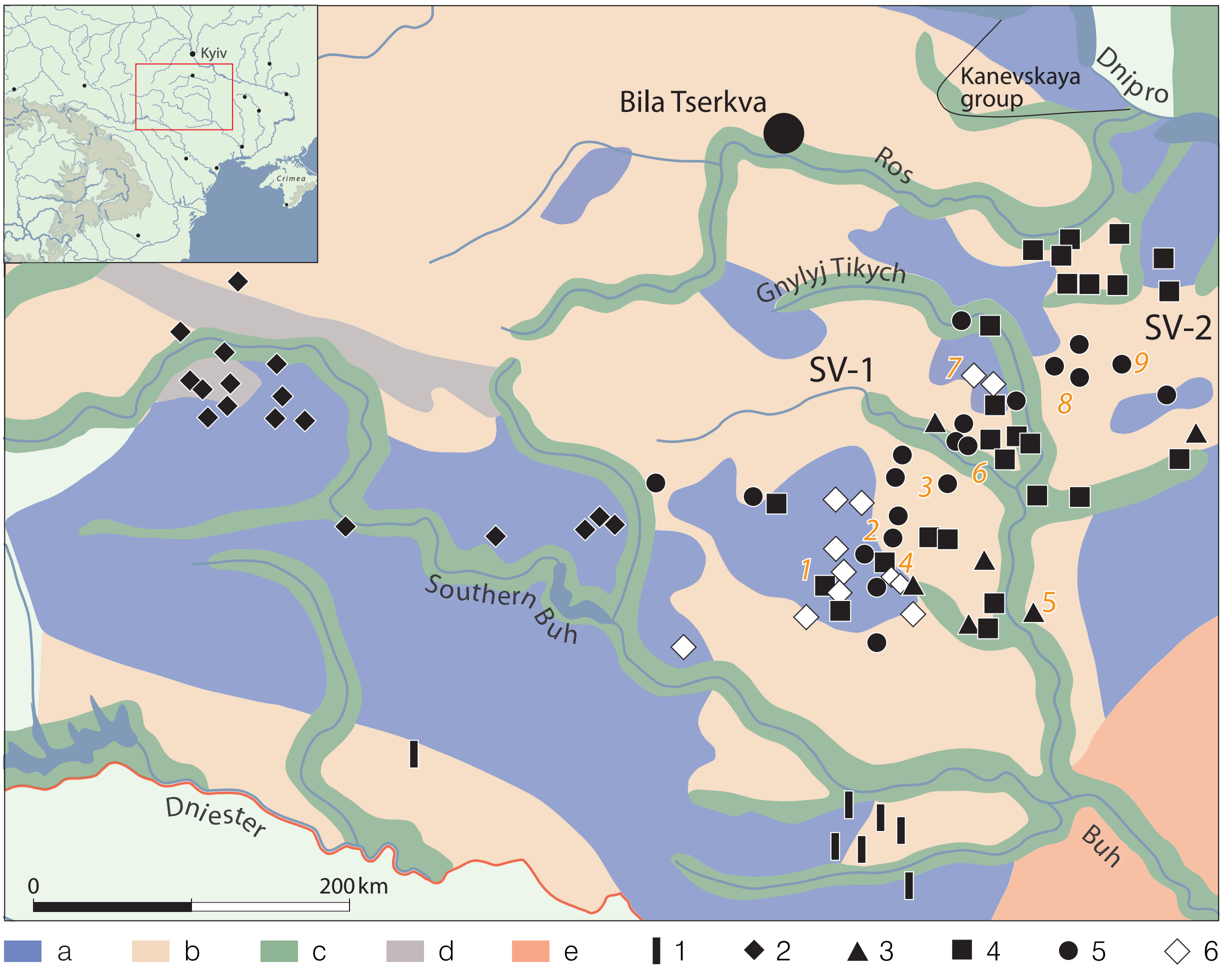

Fig. 1. Settlements of the Western Tripolye culture between the Dniester and the Dnieper. **Landscapes**: a – forest-steppe upland dissected landscapes; b – loess upland terrace landscapes; c – floodplain landscapes; d – pine forest terraces; e – northern steppe upland and slope landscapes.
Settlements (local groups): 1 – Chechelnitskaya local group; 2 – Srednebugskaya local group; 3 – Vladimirovskaya local group; 4 – Nebelevskaya local group; 5 – Tomashovskaya local group; 6 – Kosenovskaya group and Kocherzhintsy-Shulgovka type.
Settlement names: 1 – Tomashovka, 2 – Dobrovody, 3 – Maidanetske, 4 – Nebelevka, 5 – Fedorovka, 6 – Glubochek, 7 – Olkhovets 1, 8 – Chichirkozovka, 9 – Vasilkov (graphical adaptation K. Winter).

1989; Ryzhov 1999). One should note that the duration of this period was calculated from the end of analytical period 1 to the end of analytical period 8.

In this particular area of the CTCC, cemeteries and separate graves are not known. Sites of the Vladimirovsko-Tomashovskaya "genetic" line include the largest settlements in Europe (Fig. 1.3–5). All the "giant-settlements" exceed 100 ha in size, while some of them reach a size of 210 – 340 ha. Surprisingly, given the frequency and size of sites, the few radiocarbon dates make it difficult to construct radiocarbon chronological sequences (Rassamakin/Menotti 2011; Rassamakin 2012). The latest relative chronology is based on correlating ceramic seriation with the probabilistic data obtained from the gravity model. Ten phases and stages make up the Vladimirovsko-Tomashovskaya line (Diachenko/Menotti 2012). This scheme corrects and complements Ryzhov's original chronology (1993; 1999; 2000; 2011; 2012).

The average developmental stage covers a period of about 50 years (Markevich 1981; Kruts 1989). Settlements are highly clustered in space. There are groups of sites that not only are clustered in space but replace each other in time. These are labeled as two spatial variations of sites (hereinafter, SV). Each of them consisted of spatial groups (small clusters). The Gniloj Tikich river is a virtual border between two SV (Diachenko 2012). The carrying capacity of SV-1 was calculated.

Since there are no data to reconstruct the sex-age structure of the regional population, and since the estimated average population of a house is dependent upon the calculation methods, the demographic trends are analyzed using the number of synchronous dwell-

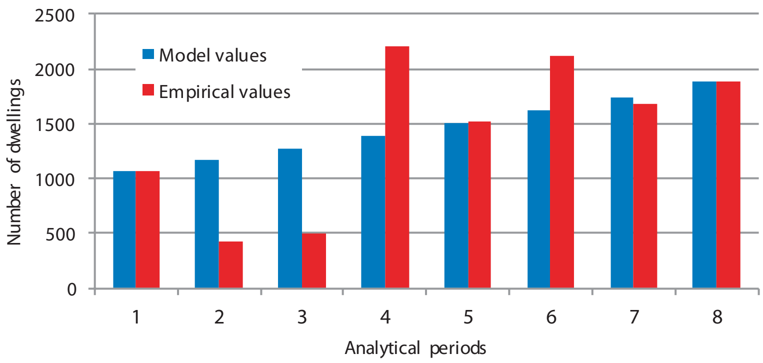

Fig. 2. Growth of population of the SV-1 of the Vladimirovsko-Tomashovskaya line in the Southern Bug and Dnieper interfluve. **Analytical periods**: 1 – Vladimirovskaya group (Vg), stage 1; 2 – Vg, stage 2; 3 – Vg, stage 3; 4 – Vg, stage 3 and Nebelevskaya group (Ng), phase 1; 5 – Ng, phase 2, stage 1; 6 – Ng, phase 2, stage 2 and Tomashovskaya group (Tg), phase 1; 7 – Ng, phase 2, stage 3 and Tg, phase 2; 8 – Tg, phase 3, stage 1.

ings within the settlements as a proxy. The initial data may be found in: Diachenko and Menotti 2012. These data are confirmed by new geomagnetic studies (Kruts et al. 2013; Chapman et al. 2014a; 2014b; Rassmann et al. 2014). Deviation between the calculations for the Nebelevskaya group and Tomashovskaya group does not exceed 3 %. The exception is the deviation between estimates for Nebelevka (phase 1 of the Nebelevskaya group) and Dobrovody (phase 2 of the Tomashovskaya group). Nebelevka includes 1357 houses (Chapman, pers. comment on 05.12.14). Dobrovody has been partly destroyed by modern construction. Thus, it is impossible to precisely estimate the number of dwellings for it (Rassmann et al. 2014).

Calculations

In general, the demographic trends of the population of SV-1 of the Vladimirovsko-Tomashovskaya line follow logistic growth (Fig. 2, empirical values). The population stabilized at the second phase – the first stage of the third phase of the Tomashovskaya group (Diachenko 2012). Therefore, the number of synchronous houses in the cluster of settlements with centers in Talianki and Kocherzhintsy-Pankovka, 1884 dwellings, is taken for the stabilization point in growth (Fig. 2, empirical values: analytical period 8). Subsequently, one calculates the rate of growth in discrete time, the relative value of the population at the stabilization point, and the carrying capacity of the regional population (formulas 1 and 4). The value of 1068 synchronic dwellings in Fedorovka (analytical period 1) reflects the size of the population occurring in the studied area as a result of migration. Previously, there were no WTC settlements in this area. The number of dwellings (1068) is the initial value for the population growth in this region at the particular carrying capacity. Short-time changes in population are followed by compensatory growth (Kolesnikov 2003, 45–51).

The rate of growth in discrete time, the relative value of the population at the stabilization point, and the carrying capacity of the regional population are as follows:

$$r = \frac{1884}{1068} \approx 1,76 \qquad (6)$$

$$P_s = \frac{1.76 - 1}{1.76} \approx 0.43 \qquad (7)$$

$$C = \frac{1884}{0.43} \approx 4381 \qquad (8)$$

There are four knowns in equation (5). Taking into account the initial population and the population at the stabilization point, the annual rate of growth is 0.0024 or 0.24 percent. This closely follows the global trends (Hassan 1981, 140). One notes that in the middle of the 1960's R. Carneiro and D. Hilse (1966) argued that such "post agriculture growth rates" were not "exceedingly rapid" (but also see: Shennan/Edinborough 2007). This obtained value somewhat exceeds the average population growth in Europe during the Holocene (Gignoux et al. 2011, 3, Table 1). However, this demographic rate is still generally low.

All simulations are simplifications and one should note that the following were used:

- g and C were constants;
- no iteration;
- values of e^{gt} were rounded to two digits after the decimal point;
- the number of dwellings was rounded to integers;
- model growth follows a linear trend (Fig. 2, model values).

For more complex simulations one should see Richerson/Boyd 1998.

Discussion of the obtained results

The resulting model and empirical data are both provided in figure 2. Initial and final model and empirical values are approximately equal (Fig. 2: analytical periods 1 and 8). So are the values for the sites belonging to the first stage of the second phase of the Nebelevskaya group, for the sites belonging to the third stage of the second phase of the Nebelevskaya group and the sites belonging to the second phase of the Tomashovskaya group (Fig. 2: analytical periods 5 and 7).

Empirical values exceed model data in two cases (Fig. 2: analytical periods 4 and 6). This corresponds to two migration waves of the WTC populations from the Dniester region to the Southern Bug and the Dnieper interfluve. They occurred in the final third stage of the Vladimirovskaya group – the first phase of the Nebelevskaya group and the second stage of the second phase of the Nebelevskaya group – the first phase of the Tomashovskaya group (Diachenko 2012). Not surprisingly, abnormally high population growth was accompanied with dramatic changes in material culture (Popova 1989; 2003; Tkachuk 2005; Ryzhov 1993; 2000; 2011; 2012 et al.).

Model values exceed empirical data in two cases (Fig. 2: analytical periods 2 and 3). On the one hand, this may be the product of the simulation simplifications. On the other hand, empirical data shows that synchronous dwellings decreased in the second and the third stage of the Vladimirovskaya group. This may be explained with colonization of the neighboring micro-region in the east (sites of the SV-2). It was not populated by the WTC population during the first stage of the Vladimirovskaya group (Fig. 2: analytical periods 1 and 2). Emigration of the former inhabitants of settlements of the SV-1 to settlements of the SV-2 in the first stage of the second phase of the Nebelevskaya group (Fig. 2: analytical period 5) and in the second phase of the Tomashovskaya group (Fig. 2: analytical period 7) is also statistically probable (Diachenko/Menotti 2012).

The similarities between the values for the theoretical model and empirical data, as well as the ease of discovering independent explanations for when they diverge, confirm the utility of this research procedure when applied to archaeological materials. The productivity of this research procedure leads to a discussion of development issues for the WTC populations.

Discussion

Issues of development for the WTC

One compares the obtained carrying capacity with earlier calculations. Taking 4 – 5 persons for the average number of inhabitants per house, the carrying capacity of the populations of Vladimirovsko-Tomashovskaya line reaches 17,524 – 21,905 people (i.e. 4381 synchronous dwellings). This range exceeds most of the values that were proposed prior to 2005 (Nikolova 2002; Nikolova/Pashkevich 2003; Gaydarska 2003 et al.). K. Davison and co-authors calculated the carrying capacity of the population of Maidanetske at about 18,000 people (Davison et al. 2008; Videiko 2013). This paper's values generally correspond to the results that T. Harper found for the settlement of Talianki. However, he worked with a single settlement. He initially calculated a stabilization of the population growth at one half of the carrying capacity (Harper 2012). According to this paper's calculations, the population of Talianki reached 43 % of the carrying capacity. It shows the necessity for long-term demographic studies in order to obtain correct values (Zubrow 1975; Dias 1996).

There are some other disclaimers one needs to take into account. This paper's calculations do not consider climate changes that surely impacted the values of the carrying capacity (Zubrow 1975; Seidl/Tisdell 1999; Riede 2009 et al.). The transition from dry and, probably, cold conditions to a more wet climate around 3800 BC is known to have occurred during the analyzed time range (Gerasimenko 2004; Diachenko 2010; Harper 2013 et al.). Therefore, in reality, the carrying capacity variable was smoothly increasing rather than a constant. This increase began in the analytical period 6 or 7. This is partially substantiated by the trend of a decreasing size of the largest settlements that belonged to the "genetically" and "chronologically" linked members of the Vladimirovskaya and Nebelevskaya groups. In addition, the transition to a better climate is associated with stabilization in size of the largest settlements that belonged to the Tomashovskaya group (Diachenko 2010; 2012). Analogous trends also are indicated in the population growth of the Dniester and Bug interfluve and the Middle Southern Bug region (Fig. 1). The largest settlements of the Nemirov and Kurilovka types of the Srednebugskaya group of the WTC also decreased in size over time (Fig. 1.2). They are contemporary with settlements of the first phase of the Nebelevskaya group and the first phase of the Tomashovskaya group. According to D. Tarapata (in press), the largest settlements of the Chechelnitskaya local group stabilized in size, reaching 55 – 65 ha. They, in turn, are contemporary to settlements of the second phase of the Tomashovskaya group – the third stage of the second phase of the Nebelevskaya group (Fig. 1.1).

D. Tarapata (in press) notes a very similar rhythm in the development of the material culture and the formation of the large settlements in these three regions. She suggests that this similarity was caused by migrations from the Dniester region to all three areas' However, according to this research procedure, the difference in stabilization points of the three regions is obvious. The populations of the Southern Bug and Dnieper interfluve stabilize at three times the corresponding values for the Middle Southern Bug region as well as the Dniester and Southern Bug interfluve.

This problem is being debated among the experts in Cucuteni-Tripolye. V. Kruts (2008) does not believe that populations of the Southern Bug and Dnieper interfluve reached the highest level of socio-economic development within the CTCC. M. Videiko (1992) argues the opposite, claiming that the socio-spatial hierarchy is the most complex for this area.

This paper's research procedure does provide a resolution for this debate. One notes that the model values correspond to empirical data in this case study for both single settlements (Fig. 2: analytical period 7) and clusters of sites (Fig. 2: analytical period 5). If spatial hierarchy was causal, there would be vastly different stabilization points. Since there are not, it would suggest that one removes spatial hierarchy from the list of possible reasons impacting population growth.

Spatial analysis of settlements of the Vladimirovsko-Tomashovskaya line demonstrates a well-developed socio-spatial hierarchy accompanied by poorly developed administrative functions of centers and transport arteries. There is evidence of direct natural exchange in minimal volumes (Diachenko 2012). Given that different habitats are never of the same quality (Dias 1996), one expects differing settlement sizes and exchanges across habitats with resources moving from the resource-rich areas to the resource-poorer areas. The largest settlements of the Chechelnitskaya group and the Vladimirovsko-Tomashovskaya line are located in meadow-steppe upland dissected and terrace forest-steppe landscapes that, probably, had the highest potential for agricultural activities (Fig. 1). The largest settlements of the Srednebugskaya group, located in forest-steppe upland dissected landscapes, correspond to the settlements of medium size of the Vladimirovsko-Tomashovskaya line (40 – 60 ha). The analysis of the exact reasons for different carrying capacities in different regions of the CTCC is a task for future work. Meanwhile, it is clear that – given a potential resource exchange – one one does not necessarily need large "labor armies" or massive intensification of labor to obtain regular surpluses.

Issues in site catchment analysis

Methodological issues are probably the reason for differences between these and results proposed by earlier studies. One should note that none of the previous applied models was verified empirically. Instead, they were obtained via site catchment analysis. Thus, a few comments regarding site catchment analysis are appropriate.

Site catchment analysis has been actively applied to the reconstruction of the structural interrelations between economic development and population since the 1960's (Chisholm 1962; Vita-Finzi/Higgs 1970; Higgs/Vita-Finzi 1972; Jarman 1972; Jarman et al. 1972; Hillman 1973; Roper 1979; Zorn 1994 et al.). The model is based on the regression dependence among the size of the resource zone, the cost of labor and the resultant product (Hodder 1974). In the case of prehistoric societies, the cost of labor usually includes the number of people involved in production, the amount of time each person dedicates to production, the time that is required to get to the hunting area or the cultivated field, etc. Site catchment analysis is complicated and, in many cases, it is impossible to verify the results. In particular, K. Flannery noted that it is often complicated to define resource areas. Their boundaries are not only fuzzy but are also not always geographically contiguous. Different resources were brought to settlements from many different areas and distances (Flannery 2009).

The results from this paper's procedure imply that modifications should be made to the site catchment analysis. One needs to consider stabilization in population growth below the limit of the carrying capacity. Furthermore, when reconstructing the size of a catchment area, it is important to consider the reserved resources. A similar argument was proposed by M. Varien and co-authors, who noted that climate variation does not correlate with population density in the Mesa Verde region between approximately 800 and 1300 AD. The fact that the Anasazi population did not decline with increasing aridity is explained by the high productivity of maize-agriculture and the potential use of available land that had previously not been put into production (Varien et al. 2007).

There is a similarity to the logic regarding "governing the commons", proposed by E. Ostrom. People are intelligent. The stabilization of population growth below the carrying capacity is caused by the experience of generations in resource management (Ostrom 1990). Conversely, if one looks at socio-economic development of the CTCC populations to the East of the Dniester in a much broader spatial and temporal perspective, it is clear that subsistence agriculture is destructive to previous landscapes. It is important to remember that early farmers were "responsible" for the earliest global ecological crises (Lemmen 2009), and collective management was (and is) not always successful (Ostrom 1990).

Conclusions

The integration of a set of well-known equations that describe population growth in discrete and continuous time into a single research procedure is a simple and practical way of calculating the carrying capacity and simulations of population growth. This procedure also helps to identify migratory behavior. It also points out necessary modifications in site catchment analyses.

Finally, it is possible that the research procedure has far broader applications. Hamilton and co-authors (2007; 2009) show that the empirical regularities of hunter-gatherer population size exhibit a fundamental congruence to what are called the statistical power laws. Furthermore, stabilization points in growth for many populations appear to be generally similar worldwide. It seems that they are independent of ecological zones. If this is the case, then demographic development may be more complex and far more generalized than has previously been thought. In short, this proposed research procedure is a step towards understanding demographic development as a nonlinear dynamic system.

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Imprint

ISSN 2197-649X

Layout draft: Holger Dieterich, Ines Reese
Technical edition: Ines Reese
Language revision: Eileen Küçükkaraca

Published by the Institute of Prehistoric and Protohistoric Archaeology, Kiel University;
For further information consult www.jna.uni-kiel.de