PERSPECTIVE

When the World's Population Took Off: The Springboard of the Neolithic Demographic Transition

Jean-Pierre Bocquet-Appel

During the economic transition from foraging to farming, the signal of a major demographic shift can be observed in cemetery data of world archaeological sequences. This signal is characterized by an abrupt increase in the proportion of juvenile skeletons and is interpreted as the signature of a major demographic shift in human history, known as the Neolithic Demographic Transition (NDT). This expresses an increase in the input into the age pyramids of the corresponding living populations with an estimated increase in the total fertility rate of two births per woman. The unprecedented demographic masses that the NDT rapidly brought into play make this one of the fundamental structural processes of human history.

After the members of the genus *Homo* had been living as foragers for at least 2.4 million years, agriculture began to emerge in seven or eight regions across the world, almost simultaneously at the beginning of the Holocene: in the Levant, in North and South China, in New Guinea and Ethiopia, and in eastern North America, Mesoamerica, and South America, all during the chronological window from 11,500 to 3500 years ago (*1*). In world archaeological sequences, the emergence of agriculture coincides with a considerable increase in artefact remains, which was long interpreted as indicating a spurt in demographic growth. The world's population on the eve of the emergence of agriculture is estimated to have been around 6 million (*2*) individuals as against almost 7 billion today, multiplying by 1200 in just 11,000 years. The shift from forager to producer societies is known as The Neolithic Revolution (*3*). The major change that arose from this "revolution" was, in evolutionary time, the number of potential mouths it was possible to feed per km^2, i.e., the weight of the population, 0.05 people per km^2 with the foraging system as against 54 today and, perhaps, 70 to 80 by 2050. The archaeological data, such as the increasing density of settlement sites during the transition, are too imprecise to express the demographic shift. Cemetery data provide a more direct reflection of demographic processes, and it is from cemeteries that the signal of a major demographic shift can be observed in world archaeological sequences in the Northern Hemisphere (Fig. 1). This signal is characterized by a relatively abrupt increase in the proportion of 5- to 19-year-old juveniles in cemeteries during the economic transition from foraging to farming. This proportion (called $_{15}p_5$ in demographic notation) leveled off 1000 years after the advent of the farming system locally (d*t* = 1000 years). This expresses an increase in the input into the age pyramids of the corresponding living populations (*4*, *5*),with an estimated increase in total fertility rate of two births per woman.

What, in the agricultural economy, had an impact on human biology that ultimately determined the growth of the population? The increase in natural maternal fertility, through a reduction in the birth interval, is mainly determined by the energy balance and the relative metabolic load (*6*). It implies a positive return of the postpartum energy balance, which occurred earlier in farming than in foraging societies due to the energy gain from the high-calorie food of sedentary farmers (wheat, lentils, peas, maize, rice, and millet) compared to the low-calorie food of mobile foragers (mainly game), coupled with a decrease in the energy expenditure of carrying infants. This signal is interpreted as the signature of a major demo-

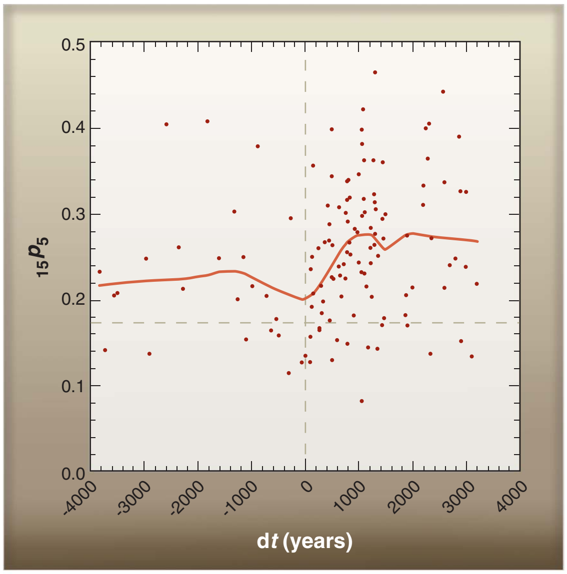

Fig. 1. The proportion of 5- to 19-year-old skeletons (to all skeletons 5 or more years old) (vertical axis: $_{15}p_5$) in 133 cemeteries across the Northern Hemisphere during the transition from foraging to farming (horizontal axis: d*t*). The horizontal axis d*t* represents the time that elapsed between the advent of farming at that particular location, aligned at d*t* = 0 [from (*25*)]. (**Below**) The population explosion of the Neolithic Demographic Transition, detectable in cemeteries, was unprecedented in the history of *Homo sapiens*. Neolithic gallery grave of La Chaussée Tirancourt, France (~4500 years before the present).

[PHOTO CL. MASSET]

CNRS (National Center for Scientific Research), UPR2147 and EPHE (Practical School of High Studies), 44, rue de l'Amical Mouchez, Paris 75014, France. E-mail: jean-pierre.bocquet-appel@evolhum.cnrs.fr

graphic shift in human history and is known as the Neolithic Demographic Transition (NDT) (*7*) or, synonymously, the Agricultural Demographic Transition. These demographic shifts can be seen in the west of southwestern Asia (*8*), mainland Southern Asia, Europe and North Africa, and the north and southwest of North America (*9*, *10*).

The NDT is detectable from a signal representing a shift toward higher fertility values, but the mortality part of the signal is missing and must be inferred. The universal density-dependent (also called Malthusian, or homeostatic) demographic model is used here. Unless we assume a demographic growth rate that would rapidly reach a cosmic number, the most likely scenario is that an increase in the birth rate was closely followed in time by an increase in mortality, producing the historical growth rate typical of pre-industrial farming populations (0.2 to 0.1% per year), with their high birth and mortality rates.

What might have been the causes of the increased mortality rate? Old and new pathogens would have contributed. With the appearance of sedentary village life and the corresponding growth in local population density, mortality rates inherited from the foragers rose rapidly, particularly in children under 5 years of age. Causes of increased infant mortality include a lack of clean drinking water, contamination by feces and the absence of latrines, and reduced breastfeeding as maternal fertility increased. Candidate infectious diseases, by epidemiological inference from current preindustrialized areas, include those associated with diarrhea (Rotavirus and Coronavirus) as the main killers of children under 5 years of age. Zoonoses could have had an impact on the population with the introduction of animal domestication, whether at the same time as plant domestication [pigs, water buffalo, and probably chickens in China; guinea pigs, llamas, and alpacas (*11*) in the Andean highlands] or later [goats, sheep, and subsequently cattle and pigs in the Levant (*12*)].

When compared with the Contemporary Demographic Transition (CDT) as described for Western industrialized societies, the NDT was its mirror image. In the CDT, the decline in mortality was followed by a decline in fertility, but in the NDT, increased fertility was followed by increased mortality. The CDT is slowing the growth of the world population, but the NDT was its springboard. In both cases, however, the time lag between the two stages produced an interval in which fertility exceeded mortality and resulted in a rapid increase in the population. As demographic density increased appreciably in the centers of these zones, the NDT triggered a major geographical redistribution of the population, with colonization or invasion by early farmers with their technologies, lifestyles, and languages that in some cases reached the continental scale, supporting what Renfrew and Bellwood have called "the farming/language dispersal hypothesis" (*13*). Simultaneously, the NDT was accompanied by increasing social stratification and complexity, the advent of market economies, and the ensuing emergence of states.

The demographic limit at which a hamlet becomes a village can be defined by the cognitive limit of integration by the human brain of numbers of interpersonal relationships, i.e., 150 people (*14*). Although villages were established by sedentary foragers, in geographically fixed zones with dense food resources (wild grasses, shellfish, freshwater fish, various nuts) in several points on the planet and in the same chronological window as the NDT, these forager villages were marginal exceptions. Their economic system was constrained by the limits of nature, which left little margin for demographic growth. World archaeological sequences show that the first sedentary villagers emerged in large numbers from the NDT. They were faced with entirely new social, economic, and ecological challenges. NDT villagers are discussed in the volume edited by Bandy and Fox (*15*). In comparison with nearly 2.5 million years of a forager culture, the NDT, in just a few hundred years, or two or three millennia at most, caused humans to domesticate themselves in villages. In these primitive village societies of farmers, say these two authors, life was improvised, provisional, and innovative. Do these early villages represent evolutionary responses from the first human farmers to a set of new, recurrent, and comparable socioecological conditions? If so, what were the major factors that shaped developments of these early villages? With the demographic concentration emerged political institutions, from village to proto-city, from big man to chiefdom. In world archaeological sequences, what are the similarities and dissimilarities with the tempo of demographic concentration (*16*)? At the peak of the NDT, there were children everywhere and the average age of the population was about 18 years old. What evidence or impacts of this exceptionally youthful population can be recognized in the patterns of cultural production of the first agricultural societies, from ceramics to statuary and images?

Theoretically, the NDT was accompanied by the first epidemiological transition (*17*). Coronavirus and Rotavirus are hypervariables, and their taxa are not specifically dated (*18*, *19*). Among extant taxa, do those endemic to prehistoric foragers and responsible for childhood diarrhea in the NDT still exist? The phylogenetic analyses of three important present-day infectious diseases either do not coincide with the timing of the NDT [measles: 1100 CE (*20*); severe form of smallpox: 350 to 1550 CE (*21*)] or suggest a zoonosis scenario, which is the reverse of what is intuitively expected: Tuberculosis (*Mycobacterium tuberculosis* complex) was transmitted by humans to bovines during their domestication in Mesopotamia 10,000 years ago (*22*). These epidemiological results are mixed and require closer investigation. The NDT implies Renfrew and Bellwood's farming/language dispersal hypothesis and Ammerman and Cavalli-Sforza's model of demic expansion (*23*). In molecular skeleton data, one must thus expect a phylogeny of pioneer farmers derived from populations of ancestral source regions of expansion, as shown, for example, by Haak *et al*. (*24*) on the expansion of pioneer Linearbandkeramik (LBK) farmers in central and northern Europe. But what emerges for other regions of agricultural invention? Because of the unprecedented demographic masses it rapidly brought into play, the NDT, which is now ending with the CDT and the collapse in fertility, is one of the fundamental structural processes of human history; its multidimensional consequences are just beginning to be explored in terms of sociopolitics and ideology, epidemiology, and population genetics.

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Acknowledgments: This work was supported by the French National Research Agency under reference number ANR-09-CEP-004-01/OBRESOC.

10.1126/science.1208880