Rethinking the Origins of Agriculture

What Do We Know about the Agricultural Demographic Transition?

by Timothy B. Gage and Sharon DeWitte

The Agricultural Revolution accompanied, either as a cause or as an effect, important changes in human demographic systems. The consensus model is that fertility and mortality increased and health declined with the adoption of agriculture, compared to those for hunter-gatherers. Analysis of the agricultural transition relies primarily on archaeological and paleodemographic data and is thus subject to the errors associated with such data. The assumptions needed to use these data can profoundly affect the inferences that are drawn. While it is clear that, in general, population growth accompanied the agricultural transition, it is not as clear exactly how fertility and mortality changed or whether the transition caused a decline in health. Although the model of the agricultural demographic transition as outlined here may be correct, researchers should remain aware of the underlying assumptions and be open to future empirical evidence.

Although often called a theory, the "demographic transition" (Thompson 1929) is an empirical model of the growth of human populations with industrialization. Population growth can be considered a cause of the Industrial Revolution, in the Bosrupian view, an effect of it, in the Malthusian view, or both. In any event, the proximate cause of human population growth over the industrial era was/is a decline in mortality, beginning in Western Europe in the late eighteenth and early nineteenth centuries, followed some years later by a decline in fertility. Populations grew, or at least the rate of growth accelerated, during the period between the decline in mortality and the decline in fertility. Of course, the demographic transition is a "model," that is, a simplification of reality. There is variation from population to population in terms of the time of onset, the speed of the decline in mortality and fertility, the length of time between the two, and so forth. Further, the industrial demographic transition is not complete. We do not know whether postindustrial populations will return to a stationary state with low mortality and fertility.

The demographic transition has been elaborated by the "epidemiological transition" (Omran 1977) and the "health transition" (Riley 1989). The epidemiological transition is an empirical model that describes consistent shifts in causes of death that accompany the demographic transition. In particular, this model argues that the frequency of the infectious causes of death declines while the frequency (not necessarily the risk; Gage 2005) of degenerative causes of death increases. The health transition adds a description of the secular trends in morbid states accompanying the demographic and epidemiologic transitions. This model summarizes the general finding that the prevalence (not necessarily the incidence) of morbidity increases as the demographic transition progresses (Riley 1989; Roos, Havens, and Black 1993). In particular, there appears to be a generally inverse relationship between mortality and morbidity. Perhaps the most convincing evidence concerning this relationship is not the general increase in morbidity observed with the decline in mortality but rather that morbidity has declined in instances where mortality has experienced secular increases since the advent of the Industrial Revolution (e.g., areas of Eastern Europe after the breakup of the Soviet Union; Riley 1992).

The demographic and health transitions illustrate the fact that mortality and health are not directly related (Gage 1989; Usher 2000; Crimmins, Hayward, and Saito 1994). This is because mortality is an "absorbing state": it removes people from the population. If people in poor health are more likely to die than people in good health, there will tend to be an inverse relationship between the level of health and mortality, as observed by Riley (1992). Again, this is a simplification, a model of reality. The relationship between health and mor-

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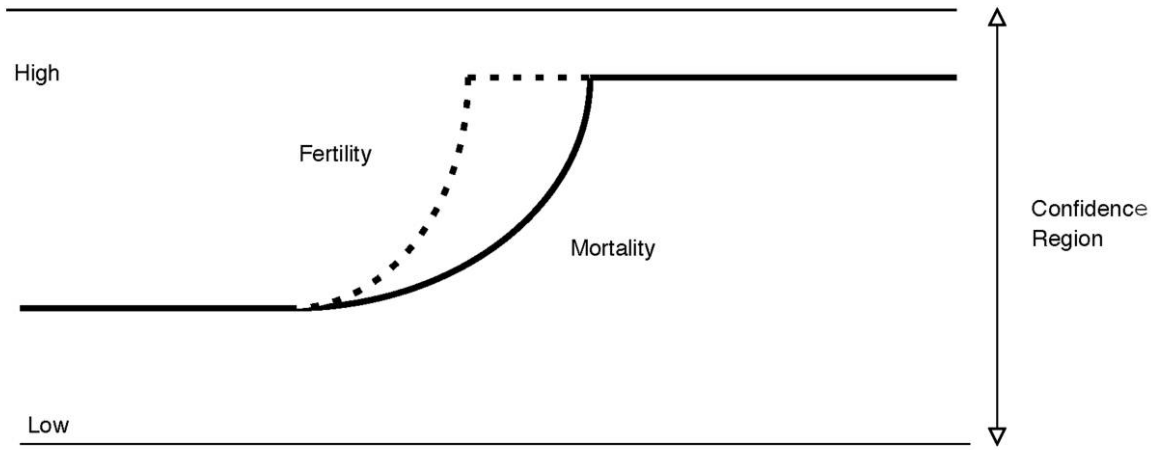

Figure 1. "Consensus" view of the demographic transition that accompanied the transition to agriculture under the Malthusian assumption that growth was zero before and after the transition. The thick solid line represents mortality and the dashed line fertility. The thin lines indicate the confidence region for both mortality and fertility. About the only reasonable certainty is that fertility exceeded mortality for some period of time during the transition, so that populations grew. The idea that mortality and fertility increased (the consensus view) is based on indirect evidence and assumptions.

tality is likely to be complex (Crimmins, Hayward, and Saito 1994; Crimmins and Saito 2001), and it depends critically on one's definition of "health." Death is fairly well defined, physiologically. Health, on the other hand, has many definitions and might best be considered a multifactorial condition. In medicine, health is traditionally defined as the absence of disease; the World Health Organization has expanded this definition to include "complete physical, mental, and social well-being" (WHO 1946). The definition typically used in descriptions of the health transition is the ability to perform "activities of daily life" (e.g., dressing and feeding oneself; Wiener et al. 1990). Increasingly, more "rigorous" physiological measures are being incorporated into large health surveys. On the other hand, the concept of "activities of daily life" as a general measure of health should be particularly appealing to anthropologists. It is an attempt to measure the frequency with which members of the population can carry out the tasks necessary for individual and group survival (Thomas, Gage, and Little 1989). Note that this is culturally relative. The activities of daily life for a hunter-gatherer, an agriculturalist, or an industrialist differ radically, and their relationship to individual physiological capabilities may differ as well.

It is clear that a reorganization of human demographic systems similar to the industrial demographic transition occurred prehistorically as either a cause or an effect of the Agricultural Revolution. The general (consensus) model suggests that among hunter-gatherers, mortality was moderate and fertility relatively low (perhaps because of lactational amenorrhea); fertility and mortality increased with the adoption of agriculture, while "health" declined. This model is based on the concept that fertility increased with agriculture (that is, the low-forager-fertility hypothesis) and that population growth was 0.0, or at least small, among hunter-gatherers and posttransition agriculturalists, a Malthusian assumption (fig. 1). If this was the case, then mortality must have increased, at least among posttransition agriculturalists. The exact dynamics of mortality and fertility during the transition is unknown. However, populations grew because fertility exceeded mortality at some point during the transition (Buikstra, Konigsberg, and Bullington 1986; Howell 1986; Bocquet-Appel 2002; Bocquet-Appel and Naji 2006). Health is considered to have declined because the proportion of skeletons with pathologies increased after the Agricultural Revolution (Cohen 1989; Cohen and Armelagos 1984*b*). Note that this view, when combined with the agricultural demographic transition, varies from the theoretically inverse association of mortality and health that is commonly observed during the industrial demographic transition.

The industrial and agricultural demographic transitions differ in two respects. First, when investigators consider the dynamics of the industrial demographic transition, they know that the transition is (or may be) ongoing. When investigators consider the agricultural transition, they often contrast pre- and posttransition demographic regimes instead of examining demographic trends during the transition itself. Second, demographic transitions are intended to be empirical (descriptive) models of the secular trends in mortality, fertility, population growth, and health; consequently, construction of such a model is relatively simple when the data are directly observable. However, demographic data for the prehistoric period are not directly observable and typically must be estimated on the basis of theoretical assumptions. These issues of formal paleodemography are not new and have been repeatedly discussed in the literature (Moore, Swedlund, and Armelagos 1975; Wood et al. 1992). Unfortunately, they are often ignored or first superficially acknowledged and then ignored. The aim of this paper is to review what we know about the agricultural demographic transition in light of these issues.

Population Growth

Perhaps the most reliable data concerning the agricultural transition are changes in population size during the transition to agriculture. In general, populations grew, although there are, no doubt, exceptions. The empirical evidence consists largely of archeological survey data (Hassen 1979). Whether population growth was 0.0 before and after the transition is not clear. The assumption that mortality increased during the agricultural transition depends on this Malthusian assumption. Von Foerster, Mora, and Amiot (1960) modeled human population growth from prehistoric times through the 1960s and showed it to be faster than exponential; that is, it has accelerated with time. This is at variance with the assumption of 0.0 population growth, although it is possible that local populations experienced Malthusian growth dynamics but that agriculture and later industrialization spread at ever-increasing rates, so that the total human population expanded at an ever-increasing rate. It is sobering to note that Von Foerster predicted human extinction in 2020, when his model predicts that the human population will reach infinity. While this seems patently ridiculous, United Nations estimates of world population levels fell below Von Foerster's modeled predictions only circa 1995 (T. B. Gage, unpublished calculations).

Mortality

Mortality is typically measured with a life table approach to estimate expectation of life. There are several issues associated with paleodemographic applications of the life table: taphonomy, age estimation, and the assumption of stationarity (0.0 population growth). Paleodemographic samples are potentially unrepresentative because of the variable taphonomic processes of burial, preservation, and recovery. This is not discussed further here except to note that if the biases are quantified (Walker, Johnson, and Lambert 1988), they can be included in demographic estimation.

The problems of age estimation using skeletal data have been widely discussed and may have been resolved. Briefly, the problem is that standard methods of estimating age using known-age reference collections bias the estimated ages toward the age structures of the reference collections. This phenomenon was first pointed out by Bocquet-Appel and Masset (1982). However, only recently has a potential cause of this bias been identified and Bayesian methods implemented to correct it (see Hoppa and Vaupel 2002 for a discussion of what is now known as the "Rostock Manifesto"). It is too early to tell whether these new age estimation methods will revolutionize paleodemographic life tables. For example, will they result in age-specific mortality curves that more closely resemble those of historic populations, including contemporary hunter-gatherers (Gage 1989)? Further, will they increase the range of expectations of life for paleodemographic life tables, which currently all fall within the rather restricted range of approximately 20–30 years at birth (Gage 2000)?

The assumption of stationarity has also been widely discussed (Moore, Swedlund, and Armelagos 1975; Wood et al. 1992). The assumption that a population is stationary (closed to migration and having constant age-specific fertility and mortality rates, a stable age distribution, and a growth rate of 0.0) is useful for paleodemography because it allows estimates of age-specific mortality rates and other life table parameters from skeletal age-at-death distributions. However, if a population is not stationary—if, for example, it has a nonzero growth rate—the estimated life table can be profoundly distorted. Researchers have shown, perhaps counterintuitively, that the age-at-death distributions of nonstationary populations are correlated more strongly with changes in fertility rates than with changes in mortality rates. For example, if a population experiences growth, which we expect to be the case during the transition to agriculture, there will be an increase in the proportion of young individuals in the population and expectation of life will be underestimated (regardless of the causes of growth). If, on the other hand, a population declines, expectation of life will be overestimated. In fact, under the stationary assumption, if populations grew during the transition to agriculture, the only unambiguous signal of a change in mortality would be an increase in expectation of life (mean age at death; Eshed et al. 2004), which would indicate that mortality had declined and fertility had not increased sufficiently to obscure the shift in mortality. On the other hand, evidence of a decrease in expectation of life could be due to a positive growth rate rather than a true decline in expectation of life. The situation is reversed if the growth rate of a population is negative. Consequently, under the stationary assumption, mean age at death is not a good method of estimating trends in mortality during the transition to agriculture.

A less stringent assumption is that the population under consideration was stable, that is, that all the assumptions for the stationary population held except zero population growth. Stability is potentially a serious problem in dealing with an age structure at a particular point in time, specifically for demographers observing living populations. However, archaeological age-at-death assemblages are deposited over an extended period, and all populations oscillate around their stable states. Consequently, paleodemographic assemblages, as averages across a number of years, may be close to stable conditions even though the population at a particular point in time is not. Very recently, a method of simultaneously estimating *r* (the intrinsic growth rate) and a life table from age-at-death distributions has been developed (D. Holman, personal communication, 2007) that is also compatible with the Rostock Manifesto. Some have argued that even the assumption of stability may be flawed for the purpose of examining paleodemographic assemblages. Bonneuil (2005) has suggested a possible solution to this problem. These recent developments may revolutionize our understanding of paleodemography. However, to our knowledge they have not been practically applied. To date, most paleodemographic mortality estimates assume that the population is stationary.

If it can be assumed that population growth fluctuated around $r = 0.0$, which is often done (Cohen 2009, in this issue), then averaging a series of paleodemographic life tables might provide more reasonable results than using a single paleodemographic life table. Averaging rates across 29 paleodemographic life tables indicates that hunter-gatherers have a mean expectation of life of 21.6 years, horticulturalists one of 21.2 years, and agriculturalists one of 24.9 years. None of these differences is statistically significant (Gage 2000); thus, these data do not support the hypothesis that the mortality of agriculturalists was higher or lower than that of hunter-gatherers.

Fertility

Sattenspiel and Harpending (1983) have shown that mean age at death (expectation of life if a population is stationary) is a better indicator of fertility than of mortality, at least in stable populations. Consequently, it has become popular to use the changes in mean age at death of a skeletal sample or ratios of several broad age-at-death categories (Bocquet 1979; Buikstra, Konigsberg, and Bullington 1986) to indicate changes in fertility rather than changes in mortality. While this seems counterintuitive, the original method (Sattenspiel and Harpending 1983) works reasonably well under certain conditions (Horowitz, Armelagos, and Wachter 1988), specifically, Coale and Demeny Model West mortality at low expectations of life and low growth rates. It is unclear whether these assumptions are correct. The empirical evidence suggests low expectations of life (20–30 years), but, as noted above, these empirical estimates are flawed. Similarly, Coale and Demeny Model West mortality is frequently assumed (whenever better information is unavailable) because it is "average" for industrial-era populations; (Coale, Demeny, and Vaughan 1983; Gage 1990). Coale and Demeny considered available life tables with expectations of life at birth lower than 35 years to be flawed (and eliminated them from the analysis) because they displayed unusual age patterns of mortality. Their model life tables with expectations of life between 20 and 35 years are extrapolated from regressions on life tables with expectations of life of 35 years or more. The empirical paleodemographic life tables are clearly divergent from all the Coale and Demeny model life tables, but they most closely resemble the Coale and Demeny Model South life table, not the Model West table (Gage 1990). Horowitz, Armelagos, and Wachter (1988) conclude that good estimates of the birth rate, like good estimates of mortality, require an estimate of *r*.

How robust are the ratio approaches for estimating fertility from the real (and currently unobserved) variation in the shape of the human mortality curve? There is no doubt that death ratios (Bocquet 1979; Bocquet-Appel 2002; Bocquet-Appel and Naji 2006; Buikstra, Konigsberg, and Bullington 1986) pick up consistent, albeit weak, signals indicating a change in demographic regime during the transition to agriculture. It is even likely that this is due to changes in fertility, because ethnographic analogies suggest that the fertility of sedentary agriculturalists is higher than that of foragers (Bently, Jasienska, and Goldberg 1993; Hewlett 1991). The mean completed fertility for a sample of 47 populations of various economies is 6.2 children, with a range from 3.0 to 10.0. The mean fertility for hunter-gatherers is 5.6, with a range of 3.5–8.0; that of horticulturalists is 5.4, with a range of 3.0–7.0; and that of agriculturalists is 6.6, with a range of 3.5–10.0. Statistical examination among the subgroups suggests no differences in the level of fertility between hunter-gatherers and horticulturalists but supports differences between agriculturalists and both hunter-gatherers and horticulturalists. However, other possible explanations for the death ratio results remain, such as age-specific changes in mortality.

Health

Skeletal samples have been used as a source of data regarding the health consequences of changes in subsistence strategies. Such samples provide data on skeletal health (i.e., the presence or absence of skeletal lesions or stress markers), which is interpreted in terms of general health. Several researchers have observed a higher frequency of certain skeletal lesions or stress markers in agricultural populations than in hunter-gatherer populations, and they view these changes in apparent skeletal health as persuasive evidence of a decline in general health at the transition to and/or intensification of agriculture. Many of the contributors to Cohen and Armelagos's (1984*b*) seminal volume present evidence of increases in frequencies of skeletal lesions and a decrease in stature in agricultural samples, compared to hunter-gatherer samples. Despite caveats from some contributors regarding small sample sizes and the lack of clear patterns with respect to certain skeletal stress markers, the editors argue that there is sufficient evidence to conclude that the adoption of agriculture was generally detrimental to human health and quality of life (Cohen and Armelagos 1984*a*). Since the publication of the Cohen and Armelagos volume, many researchers have continued to find similar evidence of a decline in skeletal health associated with agriculture.

Until relatively recently, most good data on the effect of the transition to agriculture came from North American sites (Cohen 1989; Larsen 2002), and little was known about the consequences of the transition for much of Europe, Africa, Asia, and South America. This is changing as paleopathologists widen their geographic focus; several studies summarized in the Cohen and Crane-Kramer (2007*b*) volume provide evidence from these neglected areas, much of which confirms the pattern of declining skeletal health.

Some researchers question what skeletal health really tells us about general health conditions. As mentioned above, general health can be defined in several ways. If we define health by using the standard medical definition of an absence of disease, then an increase in the prevalence of skeletal lesions (i.e., a decline in skeletal health) might indicate a decline in general health. However, changes in lesion frequencies capture only changes in diseases that cause skeletal lesions, and important determinants of health and mortality in past populations are potentially undetected in skeletal samples; for example, according to Cook (2007), in premodern populations, the most common causes of death were pneumonia and gastrointestinal infections, which do not cause bone lesions. If we define health as the ability to perform the activities of daily life, concluding that an increase in skeletal lesions indicates a decline in health assumes that those lesions are associated with factors that reduce an individual's ability to perform daily activities. But is this assumption always valid? If health is defined as the lack of conditions that are known to increase an individual's risk of death, a decline in the general health of a population would be indicated by a decline in skeletal health accompanying a decrease in life expectancy. To examine temporal trends in health, Steckel and Rose (2002) developed a health index that incorporates information about the presence of several skeletal lesions and individual age at death; age-specific rates of lesions are weighted by the distribution of person-years lived by age in a Model West level 4 reference population. According to Steckel and Rose (2002), comparing the health index with the estimated life expectancy for a particular sample can reveal whether the prevalence of lesions is associated with good or poor health, thereby addressing one aspect of the "osteological paradox" (Wood et al. 1992).

The osteological paradox, however, calls into question whether poor skeletal health is necessarily a sign of declining general health within a population. The perhaps counterintuitive argument is that in some contexts, increases in the frequency of certain lesions might indicate general improvements in health (Ortner 1991; Wood et al. 1992). This argument is based on the fact that visible skeletal lesions do not form immediately in response to trauma or disease but take weeks or months to become detectable. Individuals with skeletal lesions might therefore have been healthier than their peers without lesions, given that they were able to survive malnutrition, trauma, or disease long enough for the skeletal lesions to form. Absence of a certain skeletal lesion might indicate relatively poor health, as individuals without lesions were in such poor health that they succumbed to illness, trauma, or malnutrition and died before lesions ever formed, consistent with the observed trends during the industrial demographic transition.

Cohen and Crane-Kramer (2007*a*) argue that concerns about potential paradoxes in skeletal samples are unwarranted because multiple lines of evidence, including paleopathological and ethnographic data, often match theoretical expectations. Similarly, Steckel, Sciulli, and Rose (2002) claim a positive correlation between skeletal health and expectation of life in paleodemographic data, although these data are based on biased age estimation methods and expectation of life is based on guesstimates of population growth. Using a multistate model developed for paleodemographic studies by Usher (2000) and the Rostock Manifesto for age estimation, DeWitte and Wood (2008) found that skeletal lesions were associated with increased risk of death in both normal and catastrophic mortality samples. However, not all researchers are explicit about the relationship between the lesions they observe and health (however they define it). We do not deny that there is a general trend of increasing prevalence of skeletal lesions with the transition to agriculture; however, important links between the presence of certain lesions and their effect on survival and/or health remain to be clarified.

Conclusions

Given what we know, how do we arrive at the model of the agricultural demographic transition outlined above? We know that population size and density increased during the transition to agriculture. This is based on empirical archeological evidence and secondarily inferred from genetic evidence of population expansions dated to the transition to agriculture. We then assume that fertility increased with the advent of (at least) intensive agriculture, on the basis of ethnographic analogies and inferences from the ratio methods of fertility estimation discussed above, although contemporary horticulturalists (incipient agriculturalists?) appear to have low fertility. If it is further assumed that population growth before and after the agricultural transition was essentially 0.0 (a Malthusian assumption contrary to von Foerster's analysis), then mortality must have increased among postagricultural populations. Of course, if we accept the hypothesis that growth before and after the agricultural transition was essentially 0.0, then we can accept the paleodemographic mortality estimates as well, up to the assumption of stability. These estimates are not consistent with higher mortality among even intensive agriculturalists. On the other hand, if human population growth has increased at an accelerating rate through time, as suggested by von Foerster's analysis and Bosrupian theory, then it is possible that fertility increased and mortality decreased with the agricultural transition. If mortality decreased and the negative relationship between mortality and health is correct, then health might have declined, as suggested by paleopathological data. Note that this model is not a simple empirical model like the industrial demographic transition. Current models of the agricultural demographic transition are largely based on assumptions. We do not reject the description of the agricultural demographic transition as generally outlined, nor do we wish to declare a farewell to paleodemography. We do want to point out that this scenario is based on assumptions that are all questionable (at best). We hope that these preconceived notions of the agricultural demographic transition do not delay acceptance of more rigorous empirical evidence when it becomes available. Given the recent advances in "formal paleodemography," we expect that this evidence may become available soon.

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