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Abstract

Archaeological demography investigates the structure and dynamics of past human populations using evidence from traces of human activities and remnants of material culture in the archaeological record. Research in this field is interdisciplinary, incorporating findings from anthropology, paleogenetics, and human ecology but with a remit that extends beyond the primarily biological focus of paleodemography. Important questions addressed by archaeological demography include the establishment of methods for inferring past population structure, the timing of the emergence of modern human demographic systems, the relative importance of attritional and catastrophic patterns of mortality, and the search for adaptive explanations for demographic transitions, colonization events, and population extinctions. Archaeological evidence, including the extent of settlements and site catchment areas as well as measures of the exploitation, consumption, and discard of materials and artifacts, have traditionally been used as proxies for estimating past population size and density. In recent years this evidence has been supplemented by increasingly large data sets compiled from radiocarbon dating programs. These data sets have been used to investigate demographic waves of advance during continental-scale periods of colonization and cultural change and to detect episodes of population decline, extinction, and hiatuses in settlement history. By considering studies of human genetic diversity that indicate temporary but drastic reductions in effective population size, I hypothesize that catastrophic mortality may have had an important role in long-term population processes and may have limited long-term rates of growth, particularly in prehistoric populations.

Keywords

archaeological demography, paleodemography, human longevity, population size, population growth, senescence, mortality, fertility, juvenility index.

Archaeological Demography

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Abstract Archaeological demography investigates the structure and dynamics of past human populations using evidence from traces of human activities and remnants of material culture in the archaeological record. Research in this field is interdisciplinary, incorporating findings from anthropology, paleogenetics, and human ecology but with a remit that extends beyond the primarily biological focus of paleodemography. Important questions addressed by archaeological demography include the establishment of methods for inferring past population structure, the timing of the emergence of modern human demographic systems, the relative importance of attritional and catastrophic patterns of mortality, and the search for adaptive explanations for demographic transitions, colonization events, and population extinctions. Archaeological evidence, including the extent of settlements and site catchment areas as well as measures of the exploitation, consumption, and discard of materials and artifacts, have traditionally been used as proxies for estimating past population size and density. In recent years this evidence has been supplemented by increasingly large data sets compiled from radiocarbon dating programs. These data sets have been used to investigate demographic waves of advance during continental-scale periods of colonization and cultural change and to detect episodes of population decline, extinction, and hiatuses in settlement history. By considering studies of human genetic diversity that indicate temporary but drastic reductions in effective population size, I hypothesize that catastrophic mortality may have had an important role in long-term population processes and may have limited long-term rates of growth, particularly in prehistoric populations.

What Is Archaeological Demography?

Archaeological demography is the investigation of the structure and dynamics of past human populations using the broad spectrum of evidence provided by the traces of human activities and remnants of material culture in the archaeological record. Such evidence includes site and artifact data that provide proxies for human population distribution and density, buried human remains

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KEY WORDS: ARCHAEOLOGICAL DEMOGRAPHY, PALEODEMOGRAPHY, HUMAN LONGEVITY, POPULATION SIZE, POPULATION GROWTH, SENESCENCE, MORTALITY, FERTILITY, JUVENILITY INDEX.

from which mortality patterns, genetic relationships, and migratory behavior can be reconstructed, and paleoenvironmental records that can inform models of resource availability and carrying capacity. Research in archaeological demography is typically interdisciplinary in character; it makes use of relevant historical and ethnographic data and frequently capitalizes on the insights provided by paleogenetics, human ecology, and other cognate fields. In many respects archaeological demography can be considered synonymous with paleodemography, although perhaps with a subtle emphasis on the cultural (as opposed to biological) implications of modeling past human populations. The development of demographic archaeology has been driven in part by the importance that qualitative demographic models have played in theoretical archaeology, in particular, the hypothesized role of population processes in the precipitation of cultural change and the emergence of cultural diversity. In contrast, paleodemographers, particularly in recent decades, have tended to focus their efforts on more explicitly scientific concerns, including addressing methodological challenges to the estimation of demographic parameters in past populations and the implications of paleodemographic research for our understanding of the evolution of human life histories.

The key population parameters that demographers seek to determine include the size, structure, and spatial distribution of populations together with their rates of fertility, mortality, and migration. These different properties of populations have varying levels of visibility in the archaeological record; for instance, when all members of a population receive normative burial rites, it is possible to infer age-specific mortality from assemblages of human skeletal remains, whereas births typically do not generate an archaeological signature and so fertility must be estimated indirectly from its effects on population age structure. Several measurable aspects of material culture, including house dimensions and settlement sizes, accessibility and productivity of site catchment areas, and quantities of subsistence-related cultural remains, can provide useful proxies for population size and density. These avenues of inference from material culture are particularly important in the investigation of ancient populations for which assemblages of human remains are scarce or absent.

Research questions addressed by archaeological demography include the establishment of reliable methods for inferring past population structure (Bocquet-Appel 2008; Hoppa and Vaupel 2002), the timing of the emergence of modern human demographic systems (Caspari and Lee 2004; Smith et al. 2007), the balance between attritional and catastrophic patterns of mortality in prehistoric and early historic times (Boone 2002), and the search for adaptive explanations for demographic transitions, colonization events, and population extinctions (Rockman and Steele 2003). My aim in this paper is to report on and assess recent work that has been undertaken on some of these research questions, from both an archaeological and a paleodemographic perspective, and to provide some indications of where further research effort might be fruitful.

Evolution of the Modern Human Demographic Pattern

A key challenge for archaeological demographers, especially for those studying prehistoric populations, is to determine the extent to which uniformitarian models can be applied in paleodemography. From research on human life history variables it is apparent that milestones in both development and senescence, such as age at weaning, age at reproductive maturation, the timing of female fertility decline, and maximum potential life span, are subject to stabilizing selection and are relatively invariant across present-day human populations (Robson and Wood 2008). Some life history variables (e.g., fertility and longevity) are difficult to measure in past populations, but one life-history-related feature of skeletal development that provides a reliable chronological marker in both extant and fossil species is the time taken for the crowns of the teeth to form before the teeth erupt into the mouth (Dean 2006). Studies of the chronology of tooth development based on the counting of incremental growth markers in dental enamel have shown that fossil hominin species achieved dental maturity in approximately two-thirds the time that modern humans require to reach an equivalent developmental stage (Dean et al. 2001); in addition, modern human tooth formation times appear to have been established more than 150,000 years ago in the earliest representatives of anatomically modern *Homo sapiens* (Smith et al. 2007).

Because life history variables are strongly intercorrelated, at least at the level of species comparisons, the distinctive pattern of delayed maturation that is characteristic of anatomically modern *Homo sapiens* is expected to be accompanied by increased longevity and maximum life span. The estimation of longevity in fossil hominins is not straightforward because, unlike the situation with enamel growth, adult age at death is not directly measurable and must be inferred from skeletal indicators that have only an imprecise correlation with the chronological age of the individual. The hypothesis that human longevity has increased is supported by comparison with closely related primate species. Maximum potential life span in great apes appears to be between 50–60 years (wild populations) and 60 years (captive animals), with wild individuals exhibiting physical and behavioral signs of senescence from their mid-30s onward (Hill et al. 2001; Robson and Wood 2008; Thompson et al. 2007; Wich et al. 2004). At some stage in the human evolutionary lineage a delayed onset of senescence and an extension of longevity appear to have evolved, perhaps concurrently with the extended period of maturation evident from the record of dental development.

Caspari and Lee (2004) investigated the evolution of human longevity by calculating the ratio of older to younger adults in samples of fossil hominins belonging to the genera *Australopithecus* and *Homo*. Older adults were defined as those individuals estimated from dental wear to be more than twice the age at which skeletal maturity was achieved. Caspari and Lee determined that the proportion of older adult individuals in their fossil species samples increased from

10% in *Australopithecus* to 20% in early *Homo* and 28% in *Homo neanderthalensis*. In contrast, a much higher proportion of older adults (approximating contemporary modern human values of about 70%) was found in their sample of European early Upper Paleolithic *Homo sapiens*. From these findings Caspari and Lee (2004) concluded that substantially increased longevity was directly linked to population growth and cultural innovation at the start of the European Upper Paleolithic.

The results of Caspari and Lee's analysis are contingent on their underlying assumption that the pattern of mortality exhibited by vertebrate paleontological samples is one of attritional mortality, but at least two lines of evidence suggest that for the available samples of extinct hominin species this is unlikely to be the case. First, model life tables calculated for wild populations of chimpanzees (*Pan troglodytes*) show that these apes have attritional mortality patterns in which most adult deaths fall into the "older adult" category as defined by Caspari and Lee [see data in Hill et al. (2001: 443)]. If we assume that chimpanzees reach skeletal maturity at 12 years, their slow decline in survivorship from 12 to 24 years implies that 61% of the adult deaths in wild chimpanzee populations occur in older adults (Chamberlain 2006). This proportion of older adult mortality in chimpanzees is closer to modern human values than to any of the proportions calculated for the extinct hominin species. If *Pan troglodytes* is taken to represent the ancestral condition for early hominins, then Caspari and Lee's model would imply an evolutionary reversal toward reduced longevity before the evolution of extended longevity in *Homo sapiens*.

Second, among earlier species of *Homo* for which samples are sufficiently large to ascertain distributions of ages at death, the resulting distributions are quite unlike those depicted in modern human life tables, which are based on attritional mortality models for stable populations. The Pliocene-Pleistocene assemblage of *Homo habilis* from Olduvai Gorge (Tobias 1991), the late Pleistocene sample of *Homo heidelbergensis* from Sima de le Huesos in Spain (Bermúdez de Castro et al. 2004), and the *Homo neanderthalensis* specimens from Krapina in Croatia (Trinkaus 1995) are all dominated by high proportions of adolescent individuals (30–64% of these samples). Adolescents constitute the age category least expected to be present in attritional mortality assemblages because they represent the age at which risk of death is minimized in model life tables. The presence of adolescents in the hominin mortuary assemblages is actually a signature of catastrophic mortality, as the adolescent age category forms a substantial proportion of the living population, a fact that has been noted previously by Trinkaus (1995) and Bocquet-Appel and Arsuaga (1999). The distinctive hominin pattern of excess adolescent and young adult mortality is predicted if predation (either by large carnivores in the case of early hominin species or through inter- and intraspecific violence in the case of later species of *Homo*) made a significant contribution to the formation of the fossil hominin assemblages. Both large carnivores and human hunter-gatherers commonly use hunting methods that select prey in proportion to encounter rates, a practice that generates age distributions in the prey assemblages

that mirror the living age structure of the prey population (Stiner 1991). If catastrophic rather than attritional mortality was a major contributor to the formation of these fossil assemblages, then the ratio of older to younger adults could not be used as a proxy measure of longevity in these species unless the mortality model was more precisely ascertained. Further consequences of the role of catastrophic mortality in long-term population histories are considered in the next section.

Estimating Demographic Parameters from Archaeological Evidence

Population Size. A disparate range of archaeological evidence, including the number and sizes of houses within settlements, the areal extent of settlements, the economic potential of the catchment areas around population centers, and various measures of the exploitation, consumption, and discard of raw materials and artifacts, can be used as proxies for estimating population size and density (Gallivan 2002; Kolb 1985; Roper 1979; Schact 1981). Such proxies usually provide relative rather than absolute values for population numbers, but in some instances they can be calibrated against historical and ethnographic data that allow investigators to estimate the carrying capacities for particular combinations of ecological and cultural conditions, thereby allowing estimates of maximum population size to be calculated. For example, Bocquet-Appel et al. (2005) modeled population sizes in Upper Paleolithic Europe using the spatial density of archaeological sites (a proxy measure of population density) combined with numerical estimates of population density taken from ethnographic studies of North American foragers who lived under similar bioclimatic conditions to those experienced in Europe during the late glacial period. By assuming that the average population density derived from the ethnographic data represented the carrying capacity of the late glacial environments (i.e., the maximum population density for the European late glacial period), Bocquet-Appel and co-workers were able to convert their archaeological data into estimates of actual population density from which population size and growth over time could be modeled.

Measures of relative population size based on artifact discard rates have also been used to determine correlations between large-scale environmental changes and hominin population density during the middle and upper Pleistocene in Britain. Hosfield (1999, 2005) and Ashton and Lewis (2002) identified relative changes in human population density in late middle Pleistocene Britain by quantifying the density of accumulations of bifacial stone tools in gravel terraces in southern Britain from oxygen isotope stages (OISs) 13 to 2, a period of approximately 500,000 years. Their calculations take into account the spatial extent of commercial minerals extraction and urban development in their study areas (two of the principal factors affecting the archaeological data through their influence on the discovery potential of stone artifacts). The results of these studies indicate a sharp decline in evidence for human activity in the Middle Thames valley after OIS 10 (350,000 years ago), although 100 km to the south, in the area surrounding the former Solent

River, the population appeared to increase during late OIS 9/early OIS 8 (Hosfield 2005), suggesting some regional variations in population processes during this time period.

Population Growth. The increasingly large data sets compiled from radiocarbon dating programs provide an index of changes through time in human population density, an approach that has been used to ascertain the timing of the extinction of Neanderthal populations and the subsequent colonization and recolonization of Europe by modern humans during the late Pleistocene (Barton et al. 2003; Bocquet-Appel and Demars 2000; Bocquet-Appel et al. 2005; Gamble et al. 2005; Housley et al. 1997; Pettitt 1999). Where the data are particularly dense, the existence of hiatuses in human occupation can be demonstrated, for example, during the early and middle Holocene on the southeastern pampas of Argentina (Barrientos and Perez 2005), during the middle Holocene in Britain (Blockley 2005), and during the late Holocene in southeastern Australia (Holdaway et al. 2002). Distributions of radiocarbon dates are potentially affected by sample selection and by a range of factors that condition the probability that archaeological remains are deposited, survive, and are then discovered. A note of caution relating to the uncritical use of temporal distributions of radiocarbon dates has been raised by Surovell and Brantingham (2007). They pointed out that a monotonic increase in the frequency of dates through time can be generated by a systematic taphonomic bias if (as may often be the case) the probability of archaeological site survival is negatively correlated with the age of the site.

A useful application of spatial databases of radiocarbon dates is to determine the rates of spread of demographic waves of advance during continental-scale periods of colonization and cultural change. The proxy data on population numbers provided by radiocarbon dating can be combined with estimates of fertility and migration in the construction of colonization models. The rates of advance of Paleolithic hunter-gatherer populations reentering northwest Europe after the last glacial maximum have been estimated to be 0.5–2 km/yr (Housley et al. 1997), values that are similar to those established for the spread of early farming (Fort et al. 2004; Hazelwood and Steele 2004); the higher migration rates of foragers presumably compensate for their lower fertility and longer intergeneration intervals, which would otherwise slow demographic expansion rates.

Age at Death Distributions and Mortality Patterns. The levels and age distributions of mortality (i.e., mortality profiles) for past populations have been reconstructed through the application of life table methods and/or hazards modeling to age at death distributions estimated from assemblages of human skeletal remains. Such approaches rely on the use of skeletal indicators of growth and senescence that show consistent correlations with age at death across samples and populations. Traditional anthropological methods for estimating age at death from the skeleton have typically used measures of the central tendency of age for particular skeletal indicators, or these methods have relied on regressions of age

on skeletal indicator state (so-called inverse regressions) to predict age at death in cemetery populations. The biases introduced by the influence of reference population age structure on the outcome of skeletal age estimation (Bocquet-Appel and Masset 1982) are now widely recognized, and alternative methods that use Bayesian and maximum-likelihood approaches are increasingly favored in paleodemographic research (Bocquet-Appel 2008; Hoppa and Vaupel 2002; Konigsberg and Frankenberg 1992). Nonetheless, ascertaining age at death profiles from adult skeletons is still problematic because of the imprecise nature of the association between skeletal morphology and chronological age.

Many archaeological assemblages of human remains are available as a result of normative human burial practices in which most categories of individuals are included in the mortuary assemblage and most deaths are the result of attritional mortality in which the youngest (infant) and oldest (senescent) individuals experience the greatest risks of death. Model mortality schedules can be assumed for such samples and can be incorporated into the models as informative prior probability density functions or as parameterized hazards models in Bayesian and maximum-likelihood procedures for estimating age at death distributions (Hoppa and Vaupel 2002). However, deaths resulting from catastrophic mortality, such as pandemic outbreaks of fatal diseases, large-scale natural disasters, and violent conflicts, may also have contributed substantially to mortality in past populations, although the social disruption caused by such events may militate against structured burial of the dead, and as a consequence, deaths from catastrophic mortality are likely to be much less salient in the archaeological record.

Studies of human genetic diversity suggest that some present-day populations have experienced genetic bottlenecks (i.e., sudden reductions in genetic diversity) attributable to temporary but drastic reductions in effective population size, some of which may be attributable to episodes of catastrophic mortality. The short-term potential for human population growth in small populations is often high, with instantaneous population growth rates of between 0.5% and 2% per year documented for hunter-gatherer groups such as the Ache (Hill and Hurtado 1995: 101), Agta (Early and Headland 1998: 84), Asmat (Van Arsdale 1978: 457), Hadza (Blurton Jones et al. 1992: 172–173), and Yanomama (Neel and Weiss 1975: 34). However, estimates of long-term population growth rates based on historical and archaeological data are typically much closer to 0 (e.g., Pennington 2001: 195), suggesting that episodes of catastrophic mortality that cause substantial losses to living populations and that occur every few generations may account for the balance between short-term and long-term population growth (Biraben 1969; Boone 2002; Hill and Hurtado 1995; Keckler 1997; Watkins & Menken 1985). Although there is historical evidence for the heightened role of catastrophic mortality in limiting population growth in vulnerable island communities in recent times (e.g., Tomasson 1977), the challenge for archaeologists is to investigate whether this hypothesis has more general applicability by seeking more widespread evidence for the limiting effects of catastrophic mortality, particularly in prehistoric populations.

Fertility. Unlike mortality (which frequently leaves an archaeological signature in the form of skeletal remains accompanied by evidence of funerary ritual), fertility is much less visible in the archaeological record and estimates of fertility are usually derived indirectly from measures of mortality and population growth. The material traces of the birth process are ephemeral in the archaeological record; birth events do not often result in a recognizable depositional event, and neonatal mortality especially is often underrepresented in mortuary assemblages (Lewis and Gowland 2007). Proposed skeletal indicators of maternal parity, such as pitting on the posterior aspect of the pubic symphysis, are thought to be insufficiently reliable to be used as direct indicators of fertility (Cox and Scott 1992; Snodgrass and Galloway 2003).

Variations in fertility can be investigated indirectly through their effects on the age distribution of deaths, and a simple paleodemographic measure that is responsive to fertility is the juvenility index, in which the numbers of deaths of older children are expressed as a ratio of their deaths to the number of adult deaths in the population (Bocquet and Masset 1977; Bocquet-Appel and Naji 2006). The deaths of infants and younger children are excluded from the calculation of the juvenility index to avoid the biasing effects of differential mortuary practices and postdepositional preservation potential that adversely affect the proportions of these age categories in skeletal samples. The juvenility index is responsive to changes in population growth rates because intrinsic population growth shifts the age structure of the population in the direction of the younger age categories, thereby increasing the proportion of juvenile deaths, but the index is generally more sensitive to the overall level of mortality than it is to population growth per se. Because fertility is closely correlated with overall mortality, the juvenility index is regarded as a suitable proxy for estimating fertility in past populations.

In communities practicing agriculture, female total fertility is on average higher than that in foraging populations (Bentley et al. 1993; Sellen and Mace 1997), with age-specific female fertility peaking in the early 20s rather than in the late 20s or early 30s, as observed in foraging populations, and annual birth rates are generally higher at all maternal ages in agriculturalists (Chamberlain 2006: 68). There are several explanations for the pattern of higher fertility in agriculturalists, encompassing the benefits accruing to mothers from sedentary residence, increased security of food supply, wider availability of weaning foods, and the potential for children to contribute to household economies at a younger age. These alternative hypotheses are difficult to test from archaeological evidence alone, but infant age at weaning is amenable to study from dietary isotopic signatures in skeletal remains (Herring et al. 1998).

Problems for the Future

Archaeological and paleoenvironmental evidence indicates that human populations have the capacity to expand rapidly in response to opportunities provided by increased access to resources (see, e.g., Lanata et al. 2008; Steele et al.

1998) and have the potential to recover quickly following catastrophic falls in population size (see, e.g., Cole and Flenley 2008). Where historical data exist for the recovery of urban populations following conflicts and natural disasters, the evidence sometimes shows rates of increase that exceed the community's intrinsic capacity for exponential growth as population recovery is augmented by immigration from neighboring regions (Me-Bar and Valdez 2004). In contrast, where there are constraints on intrinsic growth and either restricted capacity for inward migration or reduced incentives to attract migrants to the depopulated region, affected populations may enter terminal decline, an interpretation advanced to explain the depopulation of the medieval Norse settlements in Greenland (Lynnerup 1998). Such processes are presumed to be responsible for the hiatuses that are occasionally detected in sequences of radiocarbon dates, and it is noteworthy that these discontinuities in human occupation have tended to be found in geographically isolated or ecologically marginal populations. The increased targeting of radiocarbon dating exercises to focus more intensely on specific episodes of population change is likely to generate more evidence for short-term, large-scale population fluctuations (Shennan and Edinborough 2007).

Recent research on the reconstruction of mortality profiles from assemblages of human skeletal remains has addressed the principal methodological problems that have afflicted earlier paleodemographic work, including statistical biases in techniques of age estimation and taphonomic factors that can influence the demographic structure of skeletal samples. These advances have allowed more robust inferences to be drawn from skeletal evidence, for example, in detecting patterns of catastrophic mortality and distinguishing between the demographic signatures of pandemic disease, natural disasters, and armed conflict (Chamberlain 2006). Continuing research into skeletal indicators that can serve as proxies for life history variables is required to achieve a fuller understanding of the evolution of the modern human pattern of biological development, maturation, and senescence, a particularly important task if we are to gain insights into the demographic systems of premodern hominins. In conjunction with the investigation of skeletal and fossil evidence for demographic structures and processes, the analysis of spatial and temporal distributions of material culture provides an independent source of evidence for fluctuations in population density that can potentially be extended back to the lower Pleistocene, more than 1 million years ago.

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