The Little Ice Age and Health:
Europe from the Early Middle Ages to the Nineteenth Century

by

Richard H. Steckel
Economics, Anthropology, and History Departments
Ohio State University
Columbus, OHn43210
Steckel.1@osu.edu

And many others (see Figure 1)

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Abstract

In recent years economic historians have analyzed data from skeletal remains for insights into long term trends in health. A large project underway in Europe has collected information on stature (from femur length), infections, degenerative joint disease, dental disease, iron/vitamin deficiencies, trauma, and specific diseases such as TB, rickets, and leprosy. Earlier literature reveals a long-term U-shaped pattern in stature from the early Middle Ages to the nineteenth century. Northern Europeans were remarkably tall during the early Middle Ages, at the height of the Medieval warm period, and did not regain this stature until the turn of the twentieth century, after the little ice age subsided. The minimum occurred near the middle of the seventeenth century, during the coldest period. This paper analyzes the consequences of climate change on seven measures of health gathered from the remains of 17,250 individuals who lived in Europe at 100 localities from 200 to 1900 A.D, finding that cool temperatures and temperature variability were bad for health. Impacts on the production and distribution of food and lags in making adaptive investments are plausible mechanisms.

At some level, virtually all researchers are aware of the significant processes of bio-cultural evolution that gave rise to modern societies over the past 10,000 years. They understand that the roots of many modern problems reach deep into the human past, and current conditions were often created by complex interdependent processes that unfolded over very long periods of time. As a result, the research of many social and medical scientists would benefit greatly from access to a very long-term historical perspective on fundamental issues relating to health and the human condition (Coatsworth 1996; Cordain 1999; Eaton and Eaton III 1997; Eaton et al. 1988; Popkin 1998). Working with numerous collaborators, we have designed a project to create that perspective for an important dimension of the quality of life, chronic morbidity as measured from skeletal remains. The project combines the skeletal data with contextual information about sites where people lived for use in reinterpreting the causes and consequences of changing health along the historical path leading to modern societies.

The approach is generic and can be implemented in many times and places, and here we discuss one aspect of results pertaining to climate and health in Europe. Because the methods are unfamiliar to many social scientists, the paper discusses skeletal measures of health and a device called the health index, which summarizes community health by converting the skeletal data into age-specific rates of morbidity. Next, the paper considers features of the sample, including issues of selectivity, and measures of climate used in the analysis. The grand sweep of the little ice age created an unanticipated, exogenous source of climate change that provides the laboratory for this study. By analyzing conditions of climate and health from the post-Roman era to the nineteenth century we learn that lower temperatures and fluctuations in temperature were bad for health.

Background of the Project

The diversity of human experience, and the corresponding variation in our health, has been enormous since the late Paleolithic era. These profound changes are highlighted by four pivotal transitions in the last ten millennia of human history: (1) the shift from foraging to farming, (2) the rise of cities and complex polities, (3) European expansion and colonization, and (4) industrialization. Each of these transitions had an enormous impact on health and the human condition. With the rise of farming, human population became larger and more sedentary, which resulted in crowding and the creation of conditions conducive to the spread and maintenance of infectious diseases (Cohen 1989; Cohen and Armelagos 1984; Larsen 1995; Smith 1995; Steckel and Rose 2002). During and following the transition to farming, pathogenic organisms causing highly contagious diseases evolved significantly. The diversity of foods eaten also diminished, eventually resulting in the modern worldwide dependence on a handful of super-crops (maize, wheat, rice) that lack specific nutrients essential for growth and development (Cordain 1999). Many believe that with the rise of cities, health deteriorated further as a result of crowding, inadequate sanitation, growing inequality, and conflict (Cartwright 1972; Cohen 1989). Although colonization offered new opportunities for the rapidly growing European population, it also led to the devastating spread of new pathogens to formerly isolated populations in areas such as in North and South America (Cook 1998; Crosby 1972; Kiple and Beck 1997; Larsen 1994; Merbs 1992; Verano 1992). The spread of measles, smallpox, and other acute infectious diseases resulted in huge population losses throughout the world, not just in the Western Hemisphere. Finally, the industrial age often brought new health costs, and many workers faced diets inadequate to sustain them in their hard work and heightened exposure to diseases spread at crowded places of work and living (Steckel and Floud 1997).

Physical anthropologists and archaeologists are best equipped to provide the evidence necessary to measure very long-term health changes. Over the past several decades, they have excavated thousands of sites and studied hundreds of thousands of skeletons and their contexts. Because of its biological basis in the physiological processes of growth, development, and acclimatization to environmental change, the information about interactions with past environments encoded in these human remains provides a valuable comparative basis for evaluating interpretations of the past based on artifacts, documents, and other sources (Walker 2000).

These basic sources of information on the lives and living conditions of our ancestors are often accessible, but for various historical, political, and logistic reasons have not been assembled into a truly comprehensive, detailed and coherent mosaic adequately depicting the evolution of health. Our efforts create such a resource for basic health indicators readily obtainable from human skeletal remains. While it builds upon a small project completed for the Western Hemisphere (Steckel and Rose 2002), the immediate focus is Europe and the Mediterranean, with a goal of measuring the influence of ecological and socioeconomic change on health over the millennia.

Skeletal Measures of Health

Human skeletal and dental tissues are highly sensitive to the environment. They provide a storehouse of information on health from conception through adulthood that can be combined with estimates of sex and age at death to provide detailed individual health histories, which can be merged to form a valuable picture of community health (Larsen 1997). For this investigation, we have developed and tested laptop-based software to collect the following commonly accepted general health indicators for each skeleton, which are depicted in Figure 2 below:

• <u>Adult height</u>. Substantial evidence from the study of modern populations reveals that impoverished environments (i.e., poor diets, heavy disease loads, and hard work) suppresses growth in childhood and, if chronic and severe, substantially reduce final adult stature (Eveleth and Tanner 1976; Eveleth and Tanner 1990). A large historical literature based on anthropometric records explores the relationship between height and economic wellbeing (Floud et al. 1990; Komlos 1989; Steckel 1995; Steckel and Floud 1997). We will greatly expand this research by using established procedures to estimate stature from long bone lengths (Krogman and Iscan 1986; Sciulli et al. 1990).

• <u>Enamel hypoplasias</u>. Hypoplasias are lines or pits of enamel deficiency commonly found in the teeth (especially incisors and canines) of people whose childhood was biologically stressful. They are caused by disruption to the cells (ameloblasts) that form the enamel. The disruption is usually environmental, due to poor nutrition, infectious disease, or a combination thereof. Although nonspecific, hypoplasias have proven enormously informative about physiological stress in childhood in archaeological settings (Goodman and Rose 1991; Hillson 1996).

• <u>Evidence of iron/vitamin deficiencies</u>. Iron is essential for many body functions, such as oxygen transport to the body's tissues. In circumstances where iron is deficient—owing to nutritional deprivation, low body weight, chronic diarrhea, parasite infection, and other factors—the body attempts to compensate by increasing red blood cell production (Walker 1986). The skeletal manifestations of childhood anemia appear in those areas where red blood cell production occurs, such as in the flat bones of the cranium. The associated pathological conditions are sieve-like lesions called porotic hyperostosis and cribra orbitalia for the cranial vault and eye orbits, respectively. In infancy and childhood, iron deficiency anemia is associated with impaired growth and delays in behavioral and cognitive development. In adulthood, the condition is associated with limited work capacity and physical activity (Scrimshaw 1991). We are aware that not all examples of porotic hyperostosis and cribra orbitalia are indicators of anemia (Schultz 1982; Schultz 1993).

• Trauma. Fractures, weapon wounds and other skeletal injuries provide a record of accidents or violence. Accidents such as ankle fractures, reflect difficulty of terrain and the hazards of specific occupations. Injuries caused by violence, such as weapon wounds or parry fractures of the forearm, provide a barometer of domestic strife, social unrest and warfare (Martin and Frayer 1997; Walker 1989; Walker 2001).

• Infectious disease. Skeletal lesions of infectious origin, which commonly appear on the major long bones, have been documented worldwide. Most of these lesions are found as plaque-like deposits from periosteal inflammation, swollen shafts, and irregular elevations on bone surfaces (Ortner and Putschar 1985). Most are nonspecific (the circumstances causing the infection cannot be determined) but they often originate with *Staphylococcus* or *Streptococcus* organisms. These lesions in archaeological skeletons have proven very informative about patterns and levels of community health (Larsen 1997).

• Dental health. Dental health is an important indicator both of oral and of general health. The most accessible dental health indices in archaeological skeletons are carious lesions and antemortem tooth loss (Larsen 1997; Ortner and Putschar 1985). The former result from a disease process characterized by the focal demineralization of dental hard tissues by organic acids produced by bacterial fermentation of dietary carbohydrates, especially sugars. In the modern era, the introduction and general availability of refined sugar caused a huge increase in dental decay. In the more distant past, the adoption of agriculture led to a general decline in dental health, especially from the introduction of maize. The agricultural shift and the later use of increasingly refined foods have resulted in an increase in periodontal disease, caries, and tooth loss. The patterns of tooth decay and linkages with dietary and lifestyle changes have been studied in the Western Hemisphere but few have examined the timing and scope of regional differences elsewhere.

• Degenerative joint disease. Degenerative joint disease (DJD) is frequently observed in archaeological skeletal remains. The condition commonly results from mechanical wear and tear on the joints of the skeleton due to physical activity (Hough and Sokoloff 1989). Generally speaking, populations engaged in physically demanding activities have more skeletal manifestations of the disease (especially buildup of bone along joint margins and deterioration of bone on articular joint surfaces) than populations that are relatively sedentary. Studies of DJD have been valuable in documenting levels and patterns of activity in past populations (Larsen 1997).

• Robusticity. Skeletal robusticity refers to the general size and morphology of skeletal elements (Ruff 2000). It is well known that bones are highly sensitive to mechanical stimuli, especially with regard to the ability of bones to adjust their size and shape in response to external forces. For example, foragers tend to be highly mobile, leading to elongated or oval femoral midsections, whereas farmers are more sedentary and have circular midsections (Ruff 2000). These and other morphological differences reveal much about habitual patterns of physical activity and behavioral change over time (Bridges 1995; Larsen 1997; Ruff et al. 1993).

• Specific infections and metabolic diseases. Tuberculosis, leprosy, scurvy, rickets, and treponamel infections (e.g. syphilis) are examples of diseases that often leave significant evidence on the skeleton (Larsen 1997; White 2000). As these were major European diseases over past millennia, we record their presence or absence.

• Age and sex. The human skeleton exhibits many different age-related changes (Bass 1995; Konigsberg and Hens 1998; Stewart 1979; Ubelaker 1989; White 2000). Juvenile age-at-death is best estimated from dental development. The extent of long bone epiphysis fusion is also a valuable age indicator for older juveniles. Adult age-at-death is typically determined based on assessments of data on a variety of age-related changes. Pubic symphyseal development is one of the more reliable age indicators for people between 18 and 50. Although they show considerable individual variation, cranial suture closure patterns can also prove useful for aging older adults. Tooth wear exhibits a regular increase with increasing age.

The Sample

The time period over which burials occurred varied widely across the sites in the sample. Some, such as military battlefield sites, were used for a matter of days, while other cemeteries were employed for as much as three of four centuries. Unfortunately we cannot organize the individuals by birth cohorts (at least without the extensive expense of carbon dating), which raises the issue of how to represent the chronological shape of the data. In the table below it is assumed that burials were evenly distributed across the dates that depositions occurred, and the results organized by centuries. For example if 125 burials too place from 1525 to 1650 (125 years), it is assumed that 75 of them occurred in the 15th century and 50 of them in the 16th century.

In linking the data to the chronological record of climate (semi-annual average temperature), I conducted sensitivity analyses on the maximum allowable duration of the burial ground. In a procedure explained in the analysis section, sites with exceptionally long intervals of use were omitted. The chronological distribution of the skeletal database (17,250 individuals) is given in Table 1.

One can also see from Table 2 that our sample is widely distributed over space. The map in Figure 2 gives greater detail on the spatial distribution of the evidence, which is widely distributed across Europe with the exception of the south-central Mediterranean. In the future we plan to fill this gap.

Measuring Community Health

Demographers and medical personnel quantify health in many ways, but all agree that it has two important elements: length of life and morbidity. The methodology for measuring the first, using life expectancy at birth (and at other ages), was refined during the nineteenth century but much less agreement exists on principles for the second. While death is usually well-defined, morbidity is much less precise. The incidence of various chronic diseases, days lost from school or work, and assessments of physical capacity are used, but all have conceptual limitations. Moreover, gathering reasonably comprehensive morbidity information that is accurate is often time-consuming and expensive. Significant progress on the problem may be made eventually by using devices that transmit information from receptors implanted in the body.

How effective are skeletons in capturing the elements of health? At most localities or burial sites, a useful but incomplete picture is available for morbidity. Estimates of life expectancy will be improved by new techniques of aging, but remain hazardous without good contextual information about the population from archaeological and other sources. Lack of information on life expectancy is less damaging than it might appear for the study of health, however. To the extent that morbidity and mortality are positively correlated, health can still be indexed or ranked across sites by using morbidity indicators from skeletons.

Life expectancy. Research on life expectancy from skeletons is limited by reliable estimates of age at death at advanced ages. The ages of children and young adults can be accurately determined from dental development and from the pattern of fusion in various growth plates, but the chronological sequence of skeletal changes is more subtle at older ages, and sometimes these changes are obscured by poor skeletal preservation following burial. Using techniques such as systematic changes in the public bone, some physical anthropologists lump ages beyond 50 into a single category. Others believe that the pattern of cranial suture closures is provides useful information at advanced ages. From one point of view, this limitation is modest because few people were likely to have survived beyond age 50 in most pre-modern societies. On the other hand, death rates rise rapidly at older ages, and the lack of reliable ages in this range significantly constrains the information available for estimating model life tables, thereby increasing confidence intervals.[1] The outlook is promising, however, because new techniques based on systematic growth in tooth cementum (a hard tissue that covers the external surface of tooth roots) can provide highly accurate estimates of ages, even for very old adults. Another method, called “expert judgment” intuitively blends numerous visual markers of age into a quantitative impression

[1] There is also the problem of selecting a suitable model life table, which is complicated by lack of detailed information on age patterns of death in ancient populations. One can make informed conjectures but this adds to the uncertainty of results.

that has proven successful in estimating age at death in populations where the age of the individual was known from other sources, such as hospital records.

Physical anthropologists know that the bones of infants and very young children are soft and frequently deteriorate after burial. Careful excavation is required to recount the deaths at these ages. Sometimes more limiting is the geographic dispersion of burials, so that excavations associated with new roads, buildings and other development projects recover only a portion of the deaths in any society. This is not a problem if people are missing at random, but it is an issue if infants or young children were buried in separate locations or there were seasonal patterns of death and residence.

Population growth rates were probably small in pre-modern times for continents or large regions, and on this scale the assumption of a stationary population is plausible. If correct and if all burials of a society are recovered and accurately aged, then life expectancy simply equals the average age at death. Any particular society, however, may have grown or shrunk from fluctuations in fertility or mortality relative to the regional or continental average. High birth rates, for example, increase the relative number of deaths at young ages. Compensation for these effects can be made if archaeological or other information is available as an ingredient to estimating fertility rates. While this is a new area of paleodemography, it is likely that considerable information gaps will remain for many burial sites.

One may reasonably suppose that life expectancy ranged from roughly 20 to 40 years for most societies prior to the late nineteenth century. Populations close to 20 years were highly stressed and would have vanished quickly without very high fertility, which would have been unlikely under the environmentally stressful conditions that produced high mortality. Life expectancy in excess of 40 years is rarely observed without good nutrition, or in its absence, is usually accompanied by aspects of the health revolution such as improved sanitation or other practices inspired by the germ theory of disease. With complete excavation of a society's burials, accurate age estimates and considerable archaeological information, it is reasonable to hope that life expectancy could be reliably placed into one of three categories within this range: low-to-mid 20s, high 20s to low 30s and mid-to-high 30s. Yet, even this is quite useful information for understanding the quality of life in the past.

Morbidity. Skeletons are good at summarizing several types of chronic morbidity, with the exception of various soft-tissue conditions such as hernias or torn ligaments. Degenerative joint disease and dental disease often develop over many years, and both have adverse functional consequences. DJD is painful and limits mobility, whereas dental disease limits the ability to chew and digest a coarse diet, which impairs net nutrition, weakens the immune system, and increases vulnerability to illness. Dental disease is also correlated with systemic inflammation that is associated with heart disease, diabetes, and cancer (Friedman and Herd 2010). Signs of anemia and/or vitamin B_{12} deficiency (cribra orbitalia and porotic hyperostosis) usually appear early in childhood and the adverse environmental conditions that created these bony malformations tend to persist thereafter (Walker et al. 2009). Skeletal infections are often painful and signal a weakened immune system that can lead to illness and functional loss. Broken bones and weapon wounds are painful and require time to heal, and the loss of mobility or dexterity associated with them can be permanent if they heal in a misaligned fashion.

Stunting and linear enamel hypoplasias (LEH) are not direct measures of morbidity, but they signal a loss of functional capacity. Hunger is painful and limits physical activity in the fashion of anemia, and hypoplasias are usually the direct result of severe bouts of disease or malnutrition in early childhood. These skeletal lesions therefore index various types of morbidity.

Sampling issues. Physical anthropologists may have little control over the location and extent of an excavation if it is the result of a development project that clears a small area of ground. With the exception of the removal of entire cemeteries containing reasonably closed populations, one can seldom argue that skeletons represent an entire society. Many collections in Europe, for example, are disproportionately from cities and towns, where much construction has occurred relative to rural areas.

These constraints hinder research but are far from disabling. In formulating a large comparative project involving numerous sites, one may stratify to obtain adequate representation from rural and urban areas. Post-weighting samples is a second option. As discussed below, one may sidestep age bias by converting information to age specific rates if the age distribution of deaths has been skewed by fertility, migration, or excavation.

A health index. At this stage of research, numerous simplifying assumptions and approximations are required to distill diverse skeletal data into a single number for comparative ranking and study of populations.[2] Ideally both life expectancy and morbidity would be available, so that one might roughly approximate a measure such as quality-adjusted life years. Unfortunately, most sites in our sample, which is the largest comparative skeletal study undertaken to date, lack reliable estimates of life expectancy. Therefore the health index discussed here includes only morbidity as expressed in the frequency and severity of skeletal lesions, but the index could be modified to incorporate length of life. A positive correlation between morbidity and mortality is likely, however, which mitigates the lack of data on life expectancy in ranking health across sites. The health-index procedure used here follows that in the Western Hemisphere project (Steckel et al. 2002).

The index was estimated from the 17,250 skeletons of individuals who lived at 100 localities in Europe over the past 1800 years. For each individual, the 7 skeletal measures discussed above were graded on a scale of 0 (most severe expression) to 100 (no lesion or deficiency). Age-specific rates of morbidity pertaining to the health indicators during childhood (stature, LEH and anemia) were calculated by assuming that conditions persisted from birth to death, an assumption justified by knowledge that childhood deprivation is correlated with adverse health as an adult.[3] The duration of morbidity prior to death is in fact unknown for the remaining 4 components (infections, trauma, DJD, and dental disease)

[2] A short paper necessarily conveys only a flavor of the methodology; for additional details and justification see Steckel RH, Sciulli PW, and Rose JC. 2002. A health index from skeletal remains. In: Steckel RH, and Rose JC, editors. The backbone of history: health and nutrition in the Western Hemisphere. New York: Cambridge University Press. p 61-93.. Presumably future research will lead to more appropriate assumptions and an improved health index.

[3] The effect of fetal and early childhood health on adult health is sometimes called the Barker hypothesis Barker DJP. 1998. Mothers, Babies, and Health in Later Life. Edinburgh: Churchill Livingstone.. For a general discussion see Fogel RW, and Costa DL. 1997. A theory of techniophysio evolution, with some implications for forecasting population, health care costs, and pension costs Demography 34(2):49-66..

and will be the subject of future research, but was approximated by an assumption of 10 years. Results are grouped into age categories of 0-4, 5-9, 10-14, 15-24, 25-34, 35-44 and 45+.

Next, the age-specific rates for each skeletal measure were weighted by the relative number of person-years lived in a reference population that is believed to roughly agree with pre-modern mortality conditions in Europe (Model West, level 4), and the results were multiplied by life expectancy in the reference population (26.4 years) and expressed as a percent of the maximum attainable (26.4, which corresponds to a complete lack of skeletal defects or lesions). The 7 components of the index were then weighted equally to obtain the overall index.

Numerous assumptions underlying the index can be challenged, modified and refined, which cannot be pursued in a short paper. It would be appropriate to weight the elements of the index, such as dental disease and trauma, by their functional consequences but this is complicated by the nature of the social safety net, medical technology and other factors that vary in unknown ways across societies. Thus, equal weighting is questionable but it is also difficult to justify an alternative scheme given the present state of knowledge. In addition, the index is an additive measure that ignores interactions, but having both a skeletal infection and trauma could have been worse than the sum of their independent effects on health.

A key step in the procedure is calculating functional loss by age for observed skeletal lesions or defects. Figure 4 illustrates the procedure for someone who died at age 40. The numerator of the age-specific rates equal the attribute scores, which range from 0 (worst case) to 100 (no defect or deficiency) and the denominator equals the years lived with those scores (functional losses), which range from birth to death (childhood indicators) to 10 years prior to death (other lesions). Community health is then estimated by summing the numerators and denominators within each age group for the population (technically, the skeletal collection) across all individuals. The procedure is summarized in Figure 5. Obviously one must have at least some individuals in each age group to calculate the health index.

The Contextual Database

This database is extracted from site reports prepared by the researchers who coded skeletal data for each site. The reports summarize the relevant archaeological and historical information available for the locality. Because latitude and longitude have been recorded, we can access Geographic Information System databases that provide information, or enable us to construct variables on the physical environment such as elevation, terrain, access to navigable water, and distance to the coast--the kinds of variables thought important for social performance by Jeffrey Sachs and other who emphasize geographic conditions (Mellinger et al. 2000; Sachs 2001). Other researchers such as Douglass North and Daron Acemoglu emphasize that good institutions can overcome limitations imposed by geography, and presumably improve health (Acemoglu et al. 2001; North 1990). The socioeconomic variables include size of settlement (converted initially into rural-urban), technologies in use; livestock available; socioeconomic status of the group (nobility, military, monastery, poor, and so forth); and religious affiliation.

Temperature estimates that we could potentially use are available from many sources including tree rings, lake sediments, ocean deposits and the advance or retreat of glaciers(Bradley 1999; Lamb 1995). It would be ideal to obtain local climate records, which is still a work in progress for our research team. Here I use a temperature record inferred from the oxygen isotopic composition of calcite in a stalagmite from Spannagel Cave in the Central Alps (see Figure 6). The elevation of the cave is approximately 2500 meters. Precision dating is possible from the high uranium content of the sample, which was divided into 700 increments or time periods. The estimates were derived from the ratio O-18/O-16, or $\delta 18$O, which is widely used by paleoclimatologists to determine the temperature of precipitation through time. The researchers converted values of $\delta 18$O into temperatures using a transfer function that relates temperatures, observed from instruments or reconstructed from other sources, in this region of the Alps to the ratio of isotopic values. Temperature maxima during the Medieval Warm Period between 800 and 1300 AD were on average about 1.7°C higher than the minima in the Little Ice Age and similar to present-day values (Mangini et al. 2005).

Results

It is useful to compare broad findings from the European and the Western Hemisphere projects. The latter was based on 12,520 individuals, who were distributed in time from approximately 4500 BC to the late 19th century (Steckel and Rose 2002). In ethnic composition, the sample included 80 per cent Native Americans and 10 per cent each of Euro-Americans and African-Americans. The mean and standard deviation of the health index were 72.6 and 8.0, respectively, whereas the corresponding numbers for Europe are 77.6 and 5.89. It is worth noting that relatively more sites in the Western Hemisphere had very poor health; the share falling below a score of 60 was 10.8 per cent in the Western Hemisphere whereas none were this low in Europe. It is too early in our research program to determine whether Europeans were on average "healthier" (or at least had less morbidity as we can measure it), because we have not yet controlled for sample composition. General categories of items relevant to an explanation include diet; exposure to pathogens; social stratification; and work effort. Possibly the diet was worse for pre-Columbian natives, who lacked livestock, poultry and small grains and consumed a low protein mixture of foods. With the exception of the equestrian Plains nomads, who consumed large amounts of bison, the Native Americans, and especially those who lived in pre-Columbian times, were relatively short. On the other hand, Europeans endured major diseases such as smallpox, typhus, measles, whooping cough, and TB.

Table 3 compares components of the health index in Europe and the Western Hemisphere, which may suggest possible explanations. According to these data, Europeans had less degenerative joint disease (9.34 points), fewer infections (8.26 points), less trauma (8.56 points), and were taller (7.74 points). Europeans had a small advantage in dental disease but more hypoplasias. On net, Europeans had a moderate advantage in childhood indicators (6.86 points), which is the sum of the difference in scores for stature, hypoplasias and anemia.

Time Trends. Figure 7 gives values of the health index organized by the mean date of burials at the site, which are not strictly comparable because the time interval over which burials occurred varied across sites. That said, the general trend was downward from the 7th century onward. A major dip and recovery occurred from 650 to 900 AD, but the sample size is relatively small during this period and so the fluctuation may not be statistically significant. A second dip took place during the late Middle Ages when the Little Ice Age was underway. If this alone was the major factor governing health, however, it is puzzling that recovery occurred during the 15th century. Interestingly, in the Western Hemisphere the long-term trend in the health index was downward (by nearly two standard deviations) during the 3 millennia prior to Columbus.

Figures 8 through 14 give time trends in the components of the health index. The first three of these graphs depict childhood conditions (anemia, hypoplasias, and stature), the next two figures, degenerative conditions (dental disease and degenerative joint disease, or DJD), and the last two infections (periostitis) and trauma. Among the childhood indicators, stature (femur length) and hypoplasias declined with fluctuations over the period but anemia tended to improve. We have yet to formulate an explanation for the contrast. Notably all three childhood indicators worsened during the major declines of the pre-Medieval and late medieval periods.

Among the degenerative conditions, dental had no trend from the late Roman period to the early Middle Ages, but did share in the pre-Medieval dip. After 1100 AD, the dental index plunged by more than 3 standard deviations, an outcome possibly associated with the introduction of more carbohydrates and later, sugar in the diet.

Degenerative joint disease was roughly unchanged over the long haul, from the late Roman era to the 19th century. Like many other conditions, DJA had a pronounced dip in the pre-Medieval era and improved slightly from the early Middle Ages to modern times. Possibly, growing use of draft animals and later, machines, reduced wear and tear on joints, although it should be noted that lighter but repetitive motions are also associated with joint degeneration.

The trauma index fluctuated less than the other components of the health index, but worsened slightly over the entire time period. This component of the index has two parts: fractures associated with accidents (broken wrists and ankles) and deliberate trauma (fractures to the skull and weapon wounds). We have not yet separated the two elements, but it will be interesting to examine their time trends, and to further delineate patterns for men and women.

Regression analysis helps control for composition effects. Up to this point we have collected markers for region of Europe, whether the place of residence was rural or urban, and social status (elite, monastery or convent, military or other). Tables 4-6 give three specifications, using 25-year moving averages of temperature alone, the coefficient of variation in temperature alone, and both measures of weather.

One can see that both temperature (mean and s.d. of 1.38 and 0.42 respectively) and the CV of temperature (mean and s.d. of 0.39 and 0.21, respectively) were statistically significant and important to health in a practical sense. In specification I (Table 4) increases in the CV of temperature were bad for the health index and most of its components, particularly infections. For some as yet unknown reason, anemia improved with fluctuations in temperature.

On average, urban residence was bad for health, particularly for children as evidenced by shorter stature and especially heavy physiological stress in early childhood (measured by hypoplasias). Notably, degenerative joint disease was lower but dental disease higher in urban areas. At this point in the analysis we do not have good separation or identification of rural and urban areas and up to this point many sites have been classified as other or unknown, which is the omitted class.

With regard to regional differences, morbidity was greatest in the Southwest (the omitted class), and of similar but lesser magnitude in the other regions. Regional contrasts were particularly large for childhood conditions of hypoplasias and stature. Possible explanations for these contrasts are under investigation.

Among the social groups, the omitted class is laborers, and the church populations had a distinct advantage in morbidity, even scoring 3.4 points over the elite. The elite and the soldiers were particularly tall (the latter possibly from selection) but they had high levels of hypoplasias. The advantage of the church groups came from high scores on dental disease and infections. One might think that the military would show high rates of trauma but many soldiers were assigned to forts and apparently saw little combat, and possibly those killed in combat were buried at the battle site.

The results are similar in the specification involving temperature alone (Table 5). In a statistical sense this is unsurprising because the correlation between the two variables is -0.82. When the temperature was relatively warm, fluctuations were low and vice versa. In the third specification both variables are highly significant but the CV of temperature dominates average temperature in practical terms (beta coefficient of 0.355 vs. 0.31). Weather data from the regional or local level would help clarify the impact of average temperature and its coefficient of variation on morbidity measured from skeletal remains.

We may face challenges, however, in locating comparable measures of temperature for multiple regions.

Concluding Remarks

Our team of collaborators has been working on the project for over a decade. We have made considerable progress in developing methods for collecting health data from skeletal remains, and have assembled the largest database of its type, an effort that was completed only a few months ago. Construction of the contextual database is a work in progress, but we have enough information in hand, that with preliminary study suggests an exciting future for this research agenda.

Figure 1: A Poster Presentation on the Project, April 2009

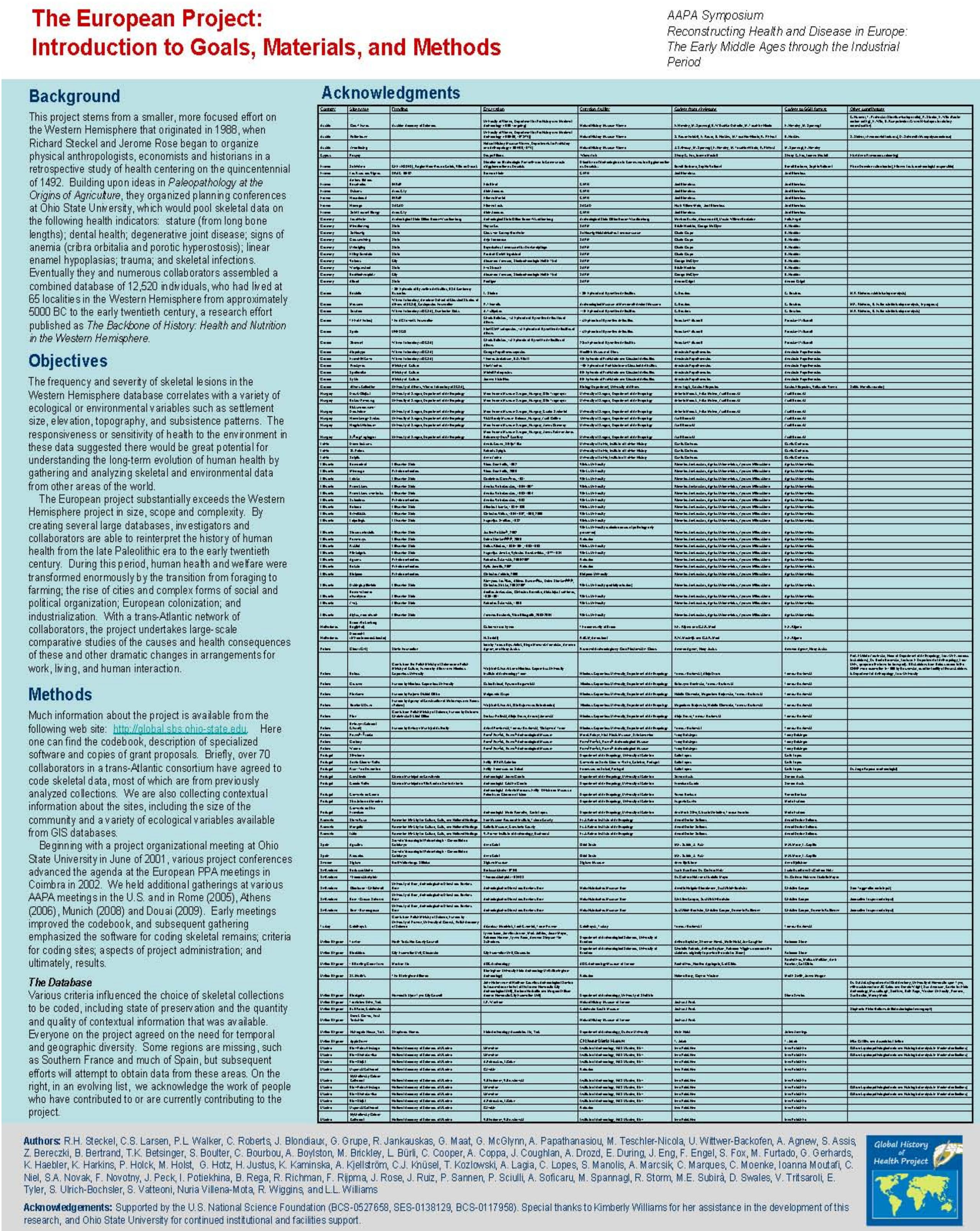


Figure 2: Map of Site Locations

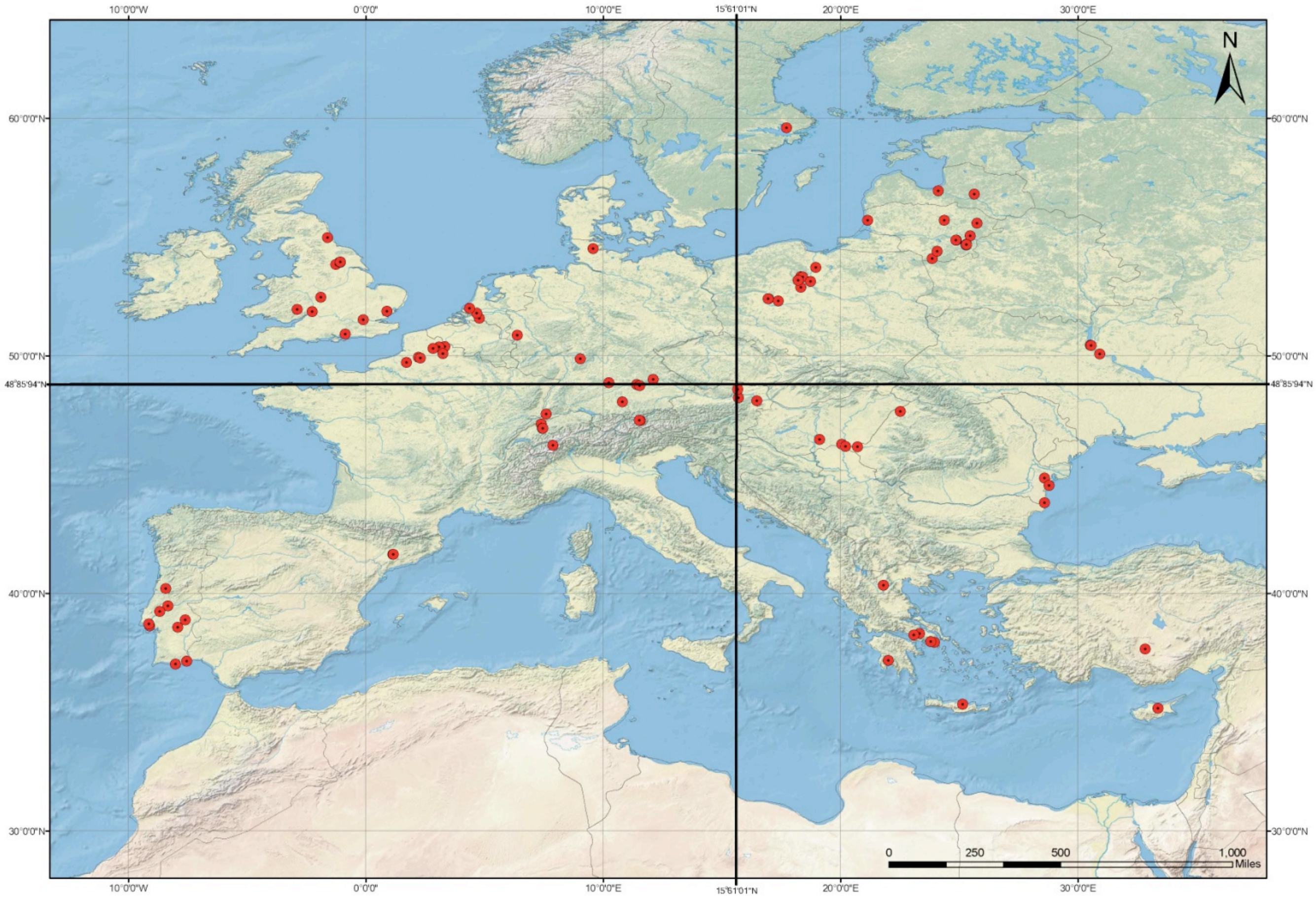
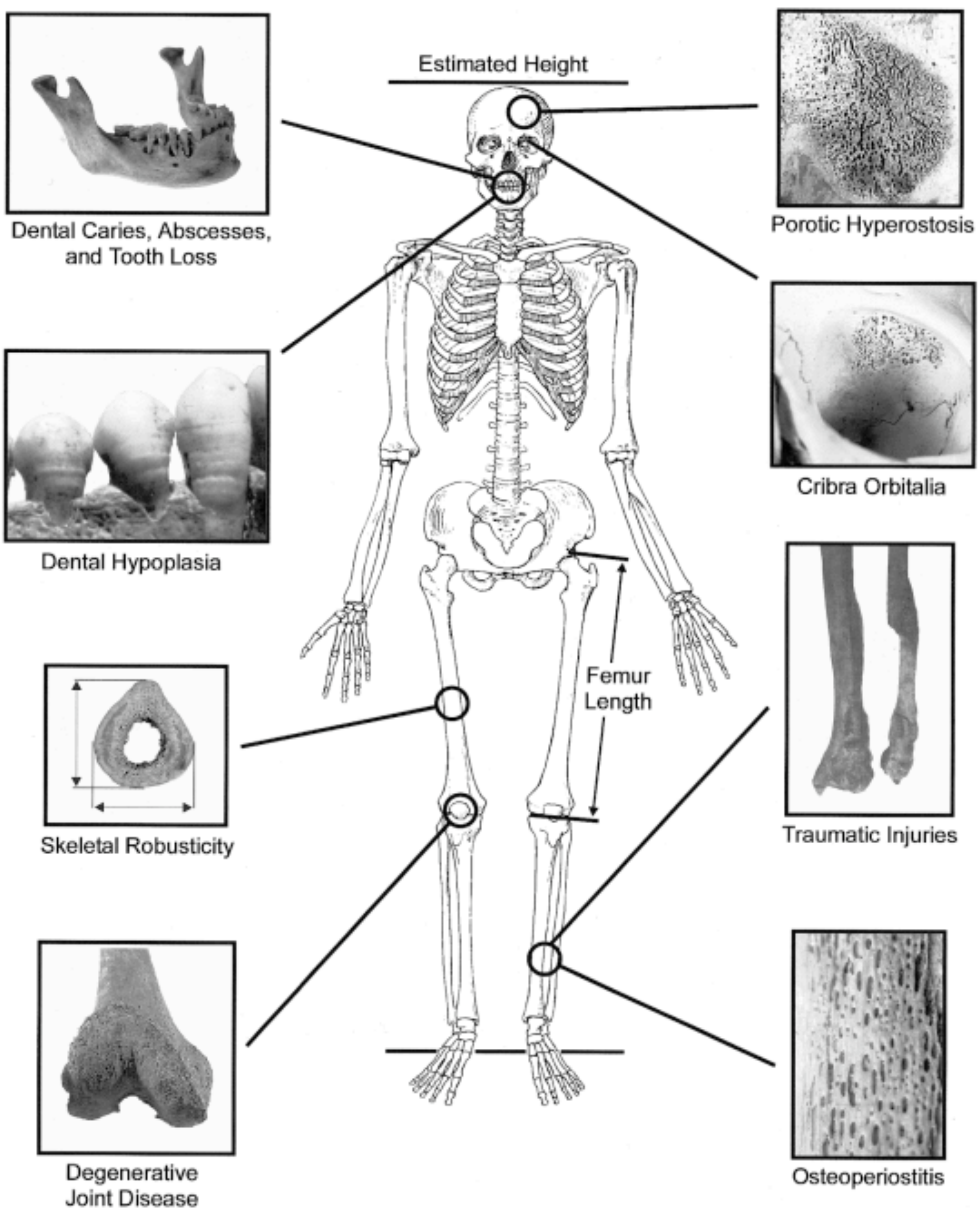


Figure 3: Skeletal measures of health



Infectious diseases: tuberculosis, leprosy, treponematosis (e.g. syphilis)
Metabolic diseases: rickets, scurvy

Figure 4: Calculating Years at Risk

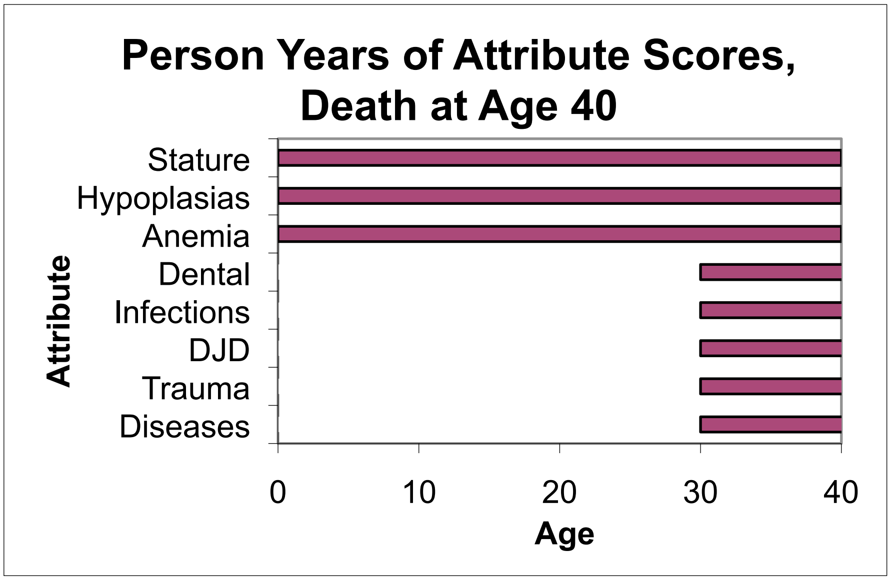
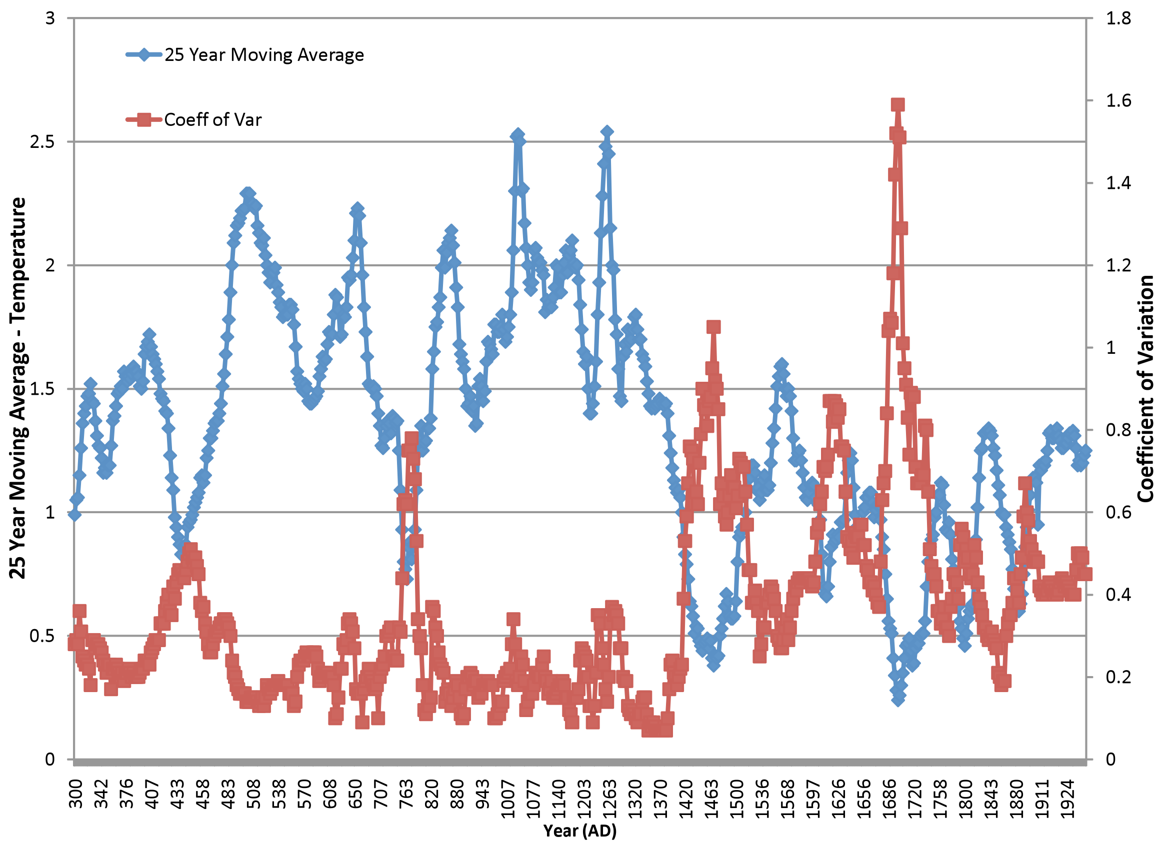


Figure 5: The Health Index is Constructed from Age-specific Rates of Morbidity

- A multiple-attribute measure of health
  The attributes are stature; signs of iron-deficiency anemia; enamel hypoplasias; dental health; degenerative joint disease; trauma; skeletal infections; and specific diseases such as TB and leprosy.
- The index is an additive measure, ignoring the effects of interactions among attributes on functional capacity.
- Attributes are scored for individuals by severity on a scale of 0 (worst) to 100% (best).
- Scores for each attribute are converted to age-specific rates in six age categories: 0–4; 5–14; 15–24; 25–34; 35–44; and 45.
- Age-specific attribute scores are multiplied by the relative number (proportion) of person-years lived within each age group in a synthetic population (Model West level 4, with life expectancy of 26.4 years and growth rate of 0).
- The sum is multiplied by 26.4 years and expressed as a percent of the maximum attainable, which is 26.4.
- The results for each attribute are averaged (weighted equally) in the overall index.
- The current version incorporates pathological lesions only.
- Length of life could be added in a modified version.

Figure 6: Average Temperature and Coefficient of Variation in Europe



Source: Temperature Reconstructed from Spannagel Cave Stalagmite Oxygen Isotope Data, available at ftp://ftp.ncdc.noaa.gov/pub/data/paleo/speleothem/europe/austria/spannagel2005.txt. Temperature is measured in centigrade in degrees above or below

Figure 7: Health Index by Average Date

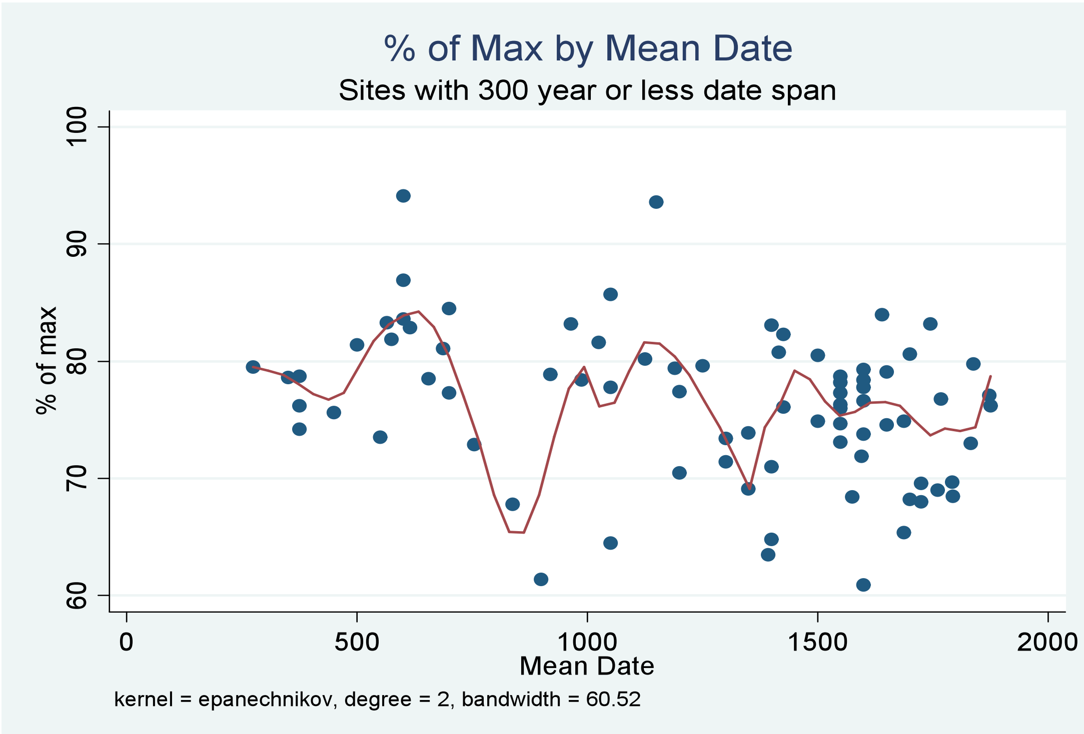


Figure 8: Stature Index by Average Date

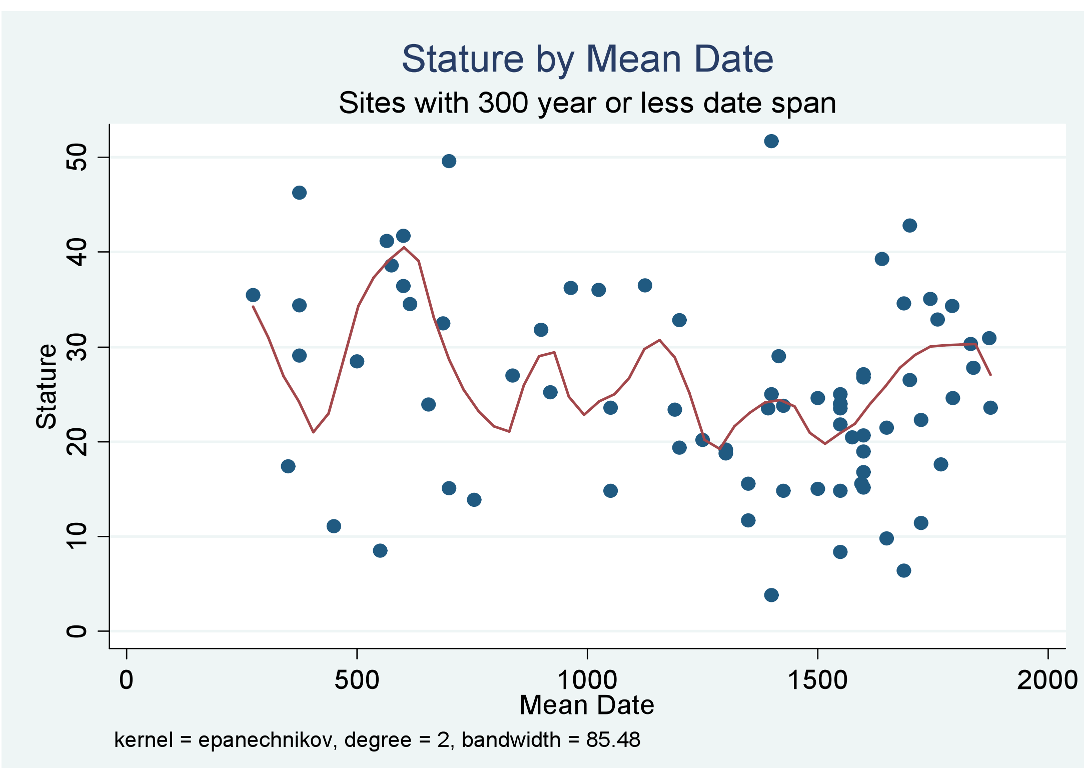


Figure 9: Anemia Index by Average Date

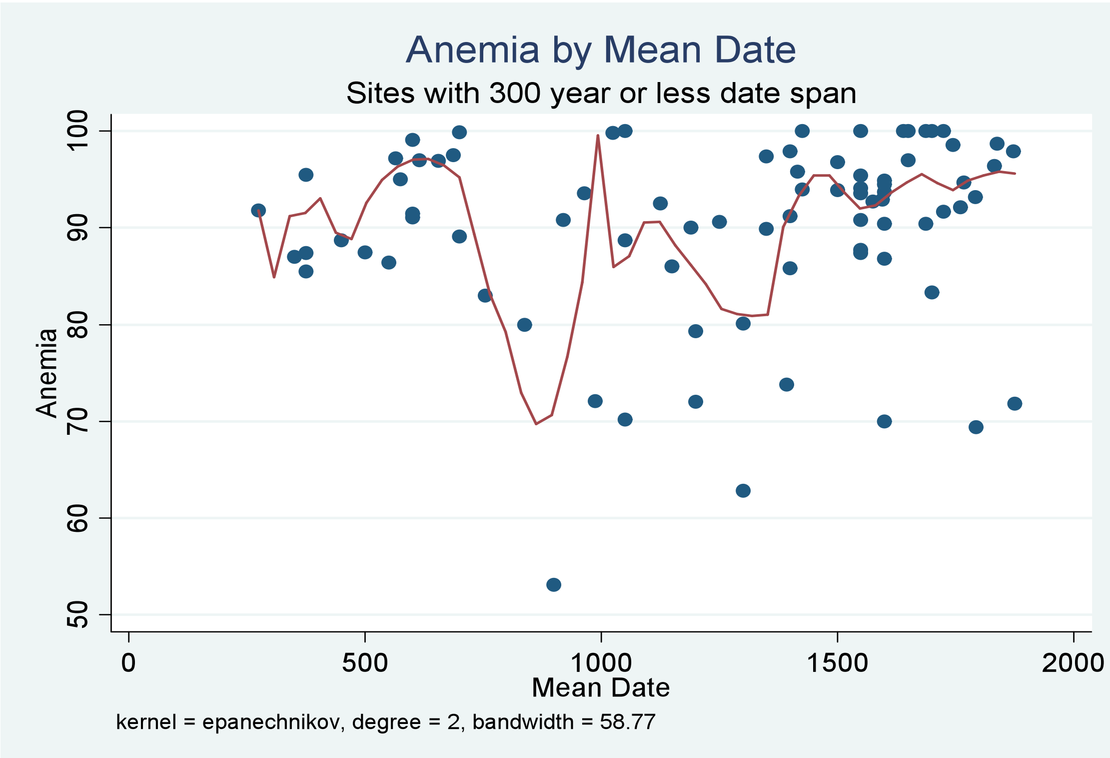


Figure 10: Hypoplasia Index by Average Date

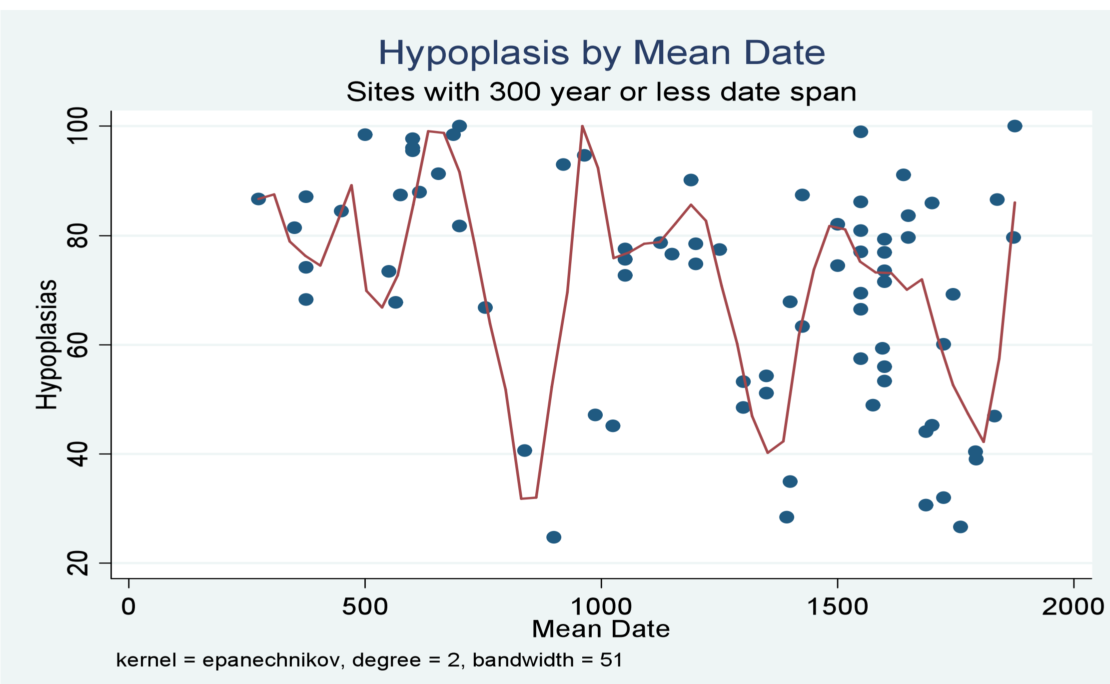


Figure 11: Infections (Periostitis) Index by Average Date

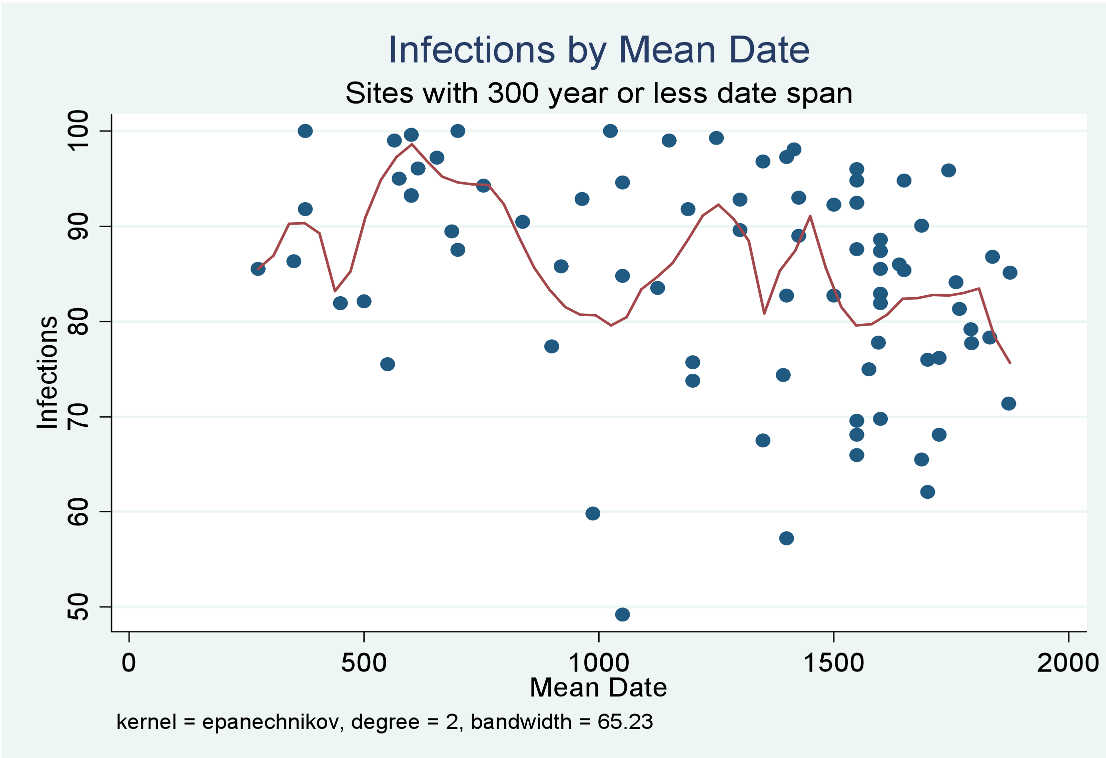


Figure 12: Dental Index by Average Date

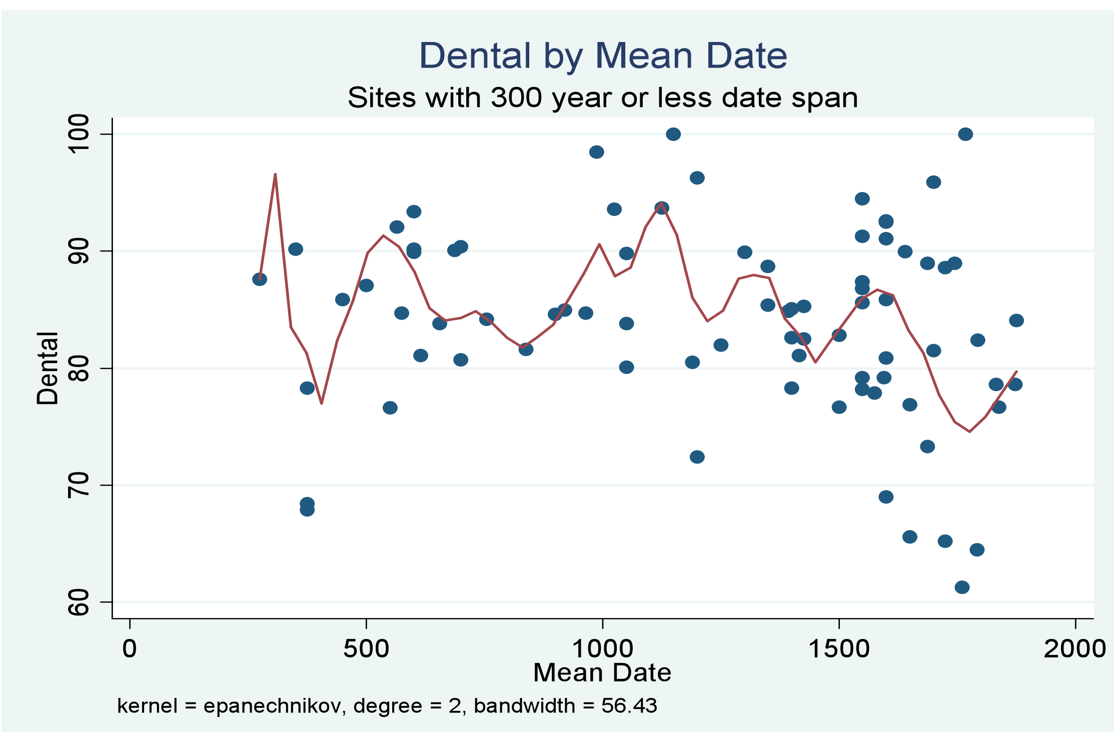


Figure 13: DJD Index by Average Date

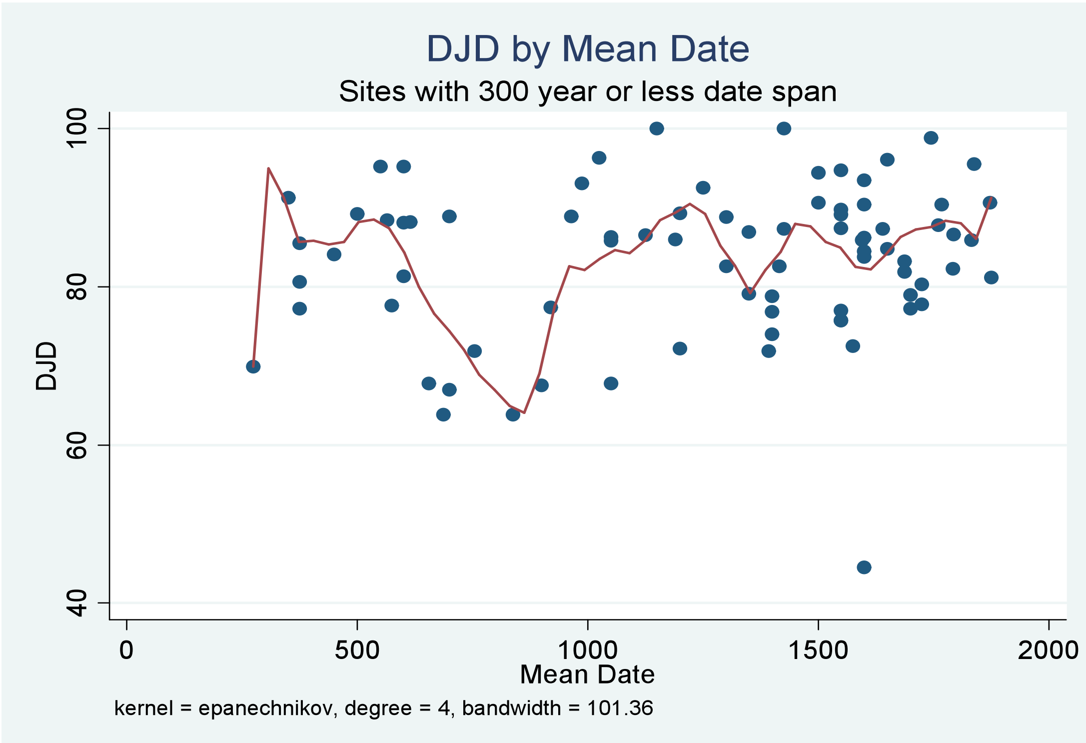


Figure 14: Trauma Index by Average Date

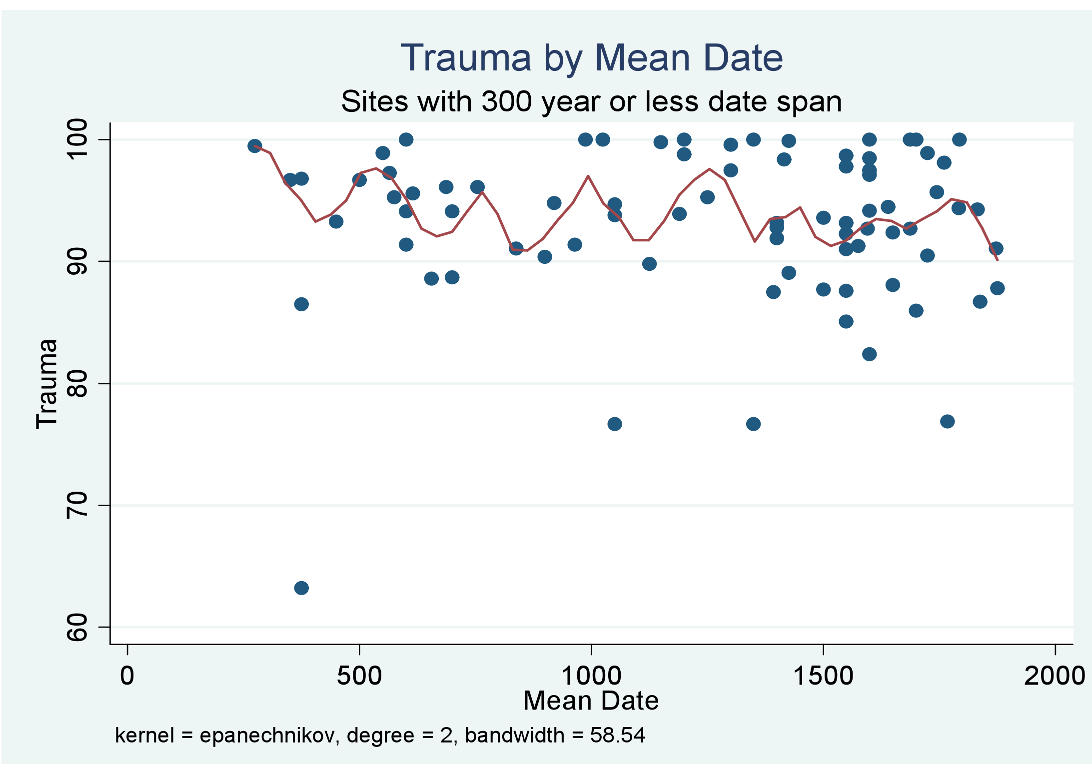


Table 1: Distribution of Burials by Century

Time Period (years AD)	Per cent of sample
100-199	0.81
200-299	0.29
300-399	0.90
400-499	1.81
500-599	4.59
600-699	6.25
700-799	6.63
800-899	3.06
900-999	3.92
1000-1099	6.32
1100-1199	4.63
1200-1299	5.53
1300-1399	7.39
1400-1499	8.22
1500-1599	9.49
1600-1699	7.99
1700-1799	7.97
1800-1899	10.86
1900-1999	3.35
Total	100.01

Table 2: Frequency distribution by geographic region

Region of Europe	Per cent of Burials
Northeast	28.43
Northwest	38.81
Southeast	18.63
Southwest	14.13
Total	100.00

Table 3: Explaining the Health Index and Its Components, Specification I

Table 3: Comparing Europe and the Western Hemisphere

Dimension	Europe	Western Hemisphere	Europe – W.H.	z
Health Index	77.58	72.6	4.98	4.32
Stature	28.44	20.7	7.74	3.32
Hypoplasias	68.87	71.1	-2.23	-0.61
Anemia	91.85	90.5	1.35	0.82
Dental	84.92	81.8	3.12	2.07
DJD	84.44	75.1	9.34	4.09
Infections	87.16	78.9	8.26	5.57
Trauma	94.26	85.7	8.56	4.20

Table 4: Explaining the Health Index and Its Components, Specification I

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
VARIABLES	ofmax	stature	hypoplasias	anemia	dental	infections	djd	trauma
CVTemp	-6.763***	-6.274***	-4.472***	6.201***	-5.705***	-17.113***	-5.710***	-3.284***
	(0.031)	(0.039)	(0.092)	(0.043)	(0.035)	(0.049)	(0.043)	(0.022)
urban	-1.427***	-0.157***	-17.027***	1.275***	-4.439***	0.471***	5.698***	-0.209***
	(0.014)	(0.018)	(0.041)	(0.020)	(0.016)	(0.022)	(0.020)	(0.010)
rural	1.070***	4.784***	-13.043***	-0.598***	1.279***	8.579***	3.904***	0.510***
	(0.013)	(0.017)	(0.037)	(0.018)	(0.015)	(0.021)	(0.018)	(0.009)
SE	2.705***	-2.839***	15.178***	-3.546***	9.823***	1.697***	-2.752***	-1.464***
	(0.019)	(0.025)	(0.056)	(0.028)	(0.023)	(0.031)	(0.027)	(0.014)
NE	2.886***	-1.181***	14.037***	-1.131***	8.865***	-2.529***	1.813***	-2.504***
	(0.017)	(0.022)	(0.050)	(0.024)	(0.020)	(0.027)	(0.024)	(0.012)
NW	3.581***	10.452***	6.686***	3.999***	6.167***	-0.371***	-1.978***	-0.644***
	(0.016)	(0.020)	(0.047)	(0.023)	(0.019)	(0.026)	(0.022)	(0.011)
elite	0.315***	9.301***	-9.791***	-1.033***	2.433***	4.115***	1.119***	0.982***
	(0.030)	(0.038)	(0.086)	(0.042)	(0.035)	(0.048)	(0.042)	(0.021)
church	4.830***	3.248***	-2.030***	-3.996***	12.448***	16.943***	-3.877***	0.359***
	(0.029)	(0.037)	(0.108)	(0.041)	(0.033)	(0.046)	(0.041)	(0.020)
military	1.376***	11.169***	-9.002***	-2.838***	6.316***	9.644***	-0.359***	0.174***
	(0.025)	(0.032)	(0.071)	(0.035)	(0.029)	(0.040)	(0.035)	(0.017)
other	2.866***	3.882***	0.535***	2.630***	6.911***	7.772***	1.503***	-0.632***
	(0.015)	(0.020)	(0.044)	(0.022)	(0.018)	(0.025)	(0.022)	(0.011)
Constant	75.359***	22.522***	74.453***	87.219***	75.714***	84.298***	82.787***	97.108***
	(0.024)	(0.031)	(0.068)	(0.033)	(0.027)	(0.038)	(0.033)	(0.017)
Observations-Weighted	1138396	1123248	1111198	1138396	1138396	1138396	1138396	1138396
Observations-Unweighted	101	100	99	101	101	101	101	101
Adjusted R-squared	0.201	0.540	0.286	0.199	0.383	0.382	0.153	0.121

Standard errors in parentheses
*** p<0.001, ** p<0.01, * p<0.05, + p<0.10

Table 5: Explaining the Health Index and Its Components, Specification II

VARIABLES	(9) ofmax	(10) stature	(11) hypoplasias	(12) anemia	(13) dental	(14) infections	(15) djd	(16) trauma
meantemp	4.562***	4.388***	4.938***	-5.133***	6.301***	8.634***	3.570***	2.546***
	(0.016)	(0.021)	(0.047)	(0.023)	(0.018)	(0.026)	(0.023)	(0.011)
urban	-0.461***	0.851***	-15.520***	-0.041+	-2.516***	1.602***	6.386***	0.410***
	(0.015)	(0.019)	(0.044)	(0.021)	(0.017)	(0.024)	(0.021)	(0.010)
rural	0.617***	4.385***	-13.378***	-0.165***	0.852***	7.487***	3.527***	0.284***
	(0.013)	(0.016)	(0.037)	(0.018)	(0.014)	(0.021)	(0.018)	(0.009)
SE	1.964***	-3.511***	14.074***	-2.552***	8.387***	0.783***	-3.285***	-1.934***
	(0.020)	(0.025)	(0.057)	(0.028)	(0.022)	(0.032)	(0.028)	(0.014)
NE	2.314***	-1.704***	13.663***	-0.605***	8.379***	-3.971***	1.331***	-2.782***
	(0.017)	(0.021)	(0.049)	(0.023)	(0.019)	(0.027)	(0.024)	(0.012)
NW	3.028***	9.895***	5.940***	4.711***	5.175***	-1.150***	-2.385***	-0.983***
	(0.016)	(0.021)	(0.047)	(0.023)	(0.018)	(0.026)	(0.023)	(0.011)
elite	0.329***	9.214***	-10.250***	-0.810***	1.836***	4.873***	1.201***	0.906***
	(0.029)	(0.038)	(0.085)	(0.041)	(0.033)	(0.048)	(0.042)	(0.021)
church	3.768***	2.265***	-2.162***	-3.223***	12.068***	13.644***	-4.833***	-0.087***
	(0.027)	(0.035)	(0.099)	(0.038)	(0.031)	(0.044)	(0.039)	(0.019)
military	1.834***	11.515***	-9.140***	-3.037***	6.131***	11.480***	0.093**	0.319***
	(0.024)	(0.031)	(0.069)	(0.034)	(0.027)	(0.039)	(0.034)	(0.017)
other	2.359***	3.355***	-0.198***	3.289***	5.984***	7.079***	1.131***	-0.946***
	(0.015)	(0.021)	(0.045)	(0.022)	(0.018)	(0.025)	(0.022)	(0.011)
Constant	67.084***	14.656***	66.534***	96.008***	65.633***	67.035***	76.157***	92.671***
	(0.029)	(0.038)	(0.086)	(0.041)	(0.033)	(0.047)	(0.041)	(0.020)
Observations-Weighted	1138396	1123248	1111198	1138396	1138396	1138396	1138396	1138396
Observations-Unweighted	101	100	99	101	101	101	101	101
Adjusted R-squared	0.222	0.547	0.291	0.219	0.428	0.375	0.158	0.141

Standard errors in parentheses
*** p<0.001, ** p<0.01, * p<0.05, + p<0.10

Table 6: Explaining the Health Index and Its Components, Specification III

	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)
VARIABLES	ofmax	stature	hypoplasias	anemia	dental	infections	djd	trauma
meantemp	4.955***	4.916***	9.556***	-7.536***	11.908***	3.372***	3.294***	3.448***
	(0.029)	(0.037)	(0.084)	(0.040)	(0.032)	(0.046)	(0.041)	(0.020)
CVTemp	0.889***	1.180***	10.746***	-5.438***	12.685***	-11.904***	-0.623***	2.041***
	(0.054)	(0.069)	(0.162)	(0.076)	(0.059)	(0.087)	(0.076)	(0.038)
urban	-0.427***	0.902***	-15.279***	-0.247***	-2.036***	1.152***	6.363***	0.487***
	(0.015)	(0.020)	(0.044)	(0.021)	(0.017)	(0.024)	(0.021)	(0.011)
rural	0.561***	4.312***	-14.049***	0.176***	0.057***	8.233***	3.566***	0.156***
	(0.013)	(0.017)	(0.038)	(0.019)	(0.015)	(0.021)	(0.019)	(0.009)
SE	1.935***	-3.546***	13.613***	-2.374***	7.972***	1.173***	-3.264***	-2.000***
	(0.020)	(0.026)	(0.057)	(0.028)	(0.022)	(0.032)	(0.028)	(0.014)
NE	2.239***	-1.804***	12.607***	-0.147***	7.311***	-2.969***	1.383***	-2.954***
	(0.017)	(0.022)	(0.051)	(0.024)	(0.019)	(0.028)	(0.024)	(0.012)
NW	2.999***	9.855***	5.424***	4.885***	4.767***	-0.768***	-2.365***	-1.049***
	(0.016)	(0.021)	(0.048)	(0.023)	(0.018)	(0.026)	(0.023)	(0.011)
elite	0.382***	9.282***	-9.595***	-1.135***	2.595***	4.161***	1.164***	1.028***
	(0.030)	(0.038)	(0.085)	(0.042)	(0.033)	(0.048)	(0.042)	(0.021)
church	3.585***	2.024***	-5.525***	-2.103***	9.455***	16.096***	-4.704***	-0.508***
	(0.029)	(0.038)	(0.111)	(0.041)	(0.033)	(0.048)	(0.042)	(0.021)
military	1.942***	11.659***	-7.775***	-3.700***	7.677***	10.029***	0.017	0.568***
	(0.025)	(0.032)	(0.072)	(0.035)	(0.027)	(0.040)	(0.035)	(0.017)
other	2.334***	3.324***	-0.493***	3.440***	5.632***	7.410***	1.149***	-1.002***
	(0.016)	(0.021)	(0.045)	(0.022)	(0.017)	(0.025)	(0.022)	(0.011)
Constant	66.258***	13.549***	56.908***	101.063***	53.840***	78.103***	76.736***	90.774***
	(0.058)	(0.075)	(0.169)	(0.081)	(0.064)	(0.093)	(0.082)	(0.041)
Observations-Weighted	1138396	1123248	1111198	1138396	1138396	1138396	1138396	1138396
Observations-Unweighted	101	100	99	101	101	101	101	101
Adjusted R-squared	0.222	0.547	0.294	0.223	0.451	0.385	0.158	0.143

Standard errors in parentheses
*** p<0.001, ** p<0.01, * p<0.05, + p<0.10

References

Acemoglu D, Johnson S, Robinson JA, and National Bureau of Economic Research. 2001. Reversal of fortune : geography and institutions in the making of the modern world income distribution. Cambridge, MA: National Bureau of Economic Research.

Barker DJP. 1998. Mothers, Babies, and Health in Later Life. Edinburgh: Churchill Livingstone.

Bass WM. 1995. Human osteology : a laboratory and field manual. Columbia: Missouri Archaeological Society.

Bradley RS. 1999. Paleoclimatology: Reconstructing Climates of the Quaternary San Diego: Academic Press.

Bridges PS. 1995. Skeletal biology and behavior in ancient humans. Evolutionary Anthropology 4(4):112-120.

Cartwright FF. 1972. Disease and history. New York: Crowell.

Coatsworth JH. 1996. Welfare. American Historical Review 101(1):1-12.

Cohen MN. 1989. Health and the rise of civilization. New Haven: Yale University Press.

Cohen MN, and Armelagos GJ. 1984. Paleopathology at the origins of agriculture. New York: Academic Press.

Cook ND. 1998. Born to die: disease and New World conquest, 1492-1650. New York: Cambridge University Press.

Cordain L. 1999. Cereal grains: humanity's double-edged sword. World Review of Nutrition and Dietetics 84:19-73.

Crosby AW. 1972. The Columbian exchange: biological and cultural consequences of 1492. Westport, Conn.: Greenwood Pub. Co.

Eaton SB, and Eaton III SB. 1997. Paleolithic nutrition revisited: A twelve-year retrospective on its nature and implications. European Journal of Clinical Nutrition 51(4):207-216.

Eaton SB, Konner M, and Shostak M. 1988. Stone agers in the fast lane: chronic degenerative diseases in evolutionary perspective. The American Journal of Medicine 84(4):739-749.

Eveleth PB, and Tanner JM. 1976. Worldwide Variation in Human Growth. Cambridge: Cambridge University Press.

Eveleth PB, and Tanner JM. 1990. Worldwide variation in human growth Tanner JM, editor. Cambridge: Cambridge University Press.

Floud R, Wachter KW, and Gregory A. 1990. Height, health and history: nutritional status in the United Kingdom, 1750-1980. Cambridge: Cambridge University Press.

Fogel RW, and Costa DL. 1997. A theory of techniophysio evolution, with some implications for forecasting population, health care costs, and pension costs Demography 34(2):49-66.

Friedman EM, and Herd P. 2010. Income, Education, and Inflammation: Differential Associations in a National Probability Sample (The MIDUS Study). Psychosomatic Medicine 72:290-300.

Goodman AH, and Rose JC. 1991. Dental enamel hypoplasias as indicators of nutritional status. In: Kelley MA, and Larsen CS, editors. Advances in dental anthropology New York: Wiley-Liss. p 279-293.

Hillson S. 1996. Dental anthropology. Cambridge: Cambridge University Press.

Hough AJ, and Sokoloff L. 1989. Pathology of osteoarthritis. In: McCarty DJ, and Koopman WJ, editors. Arthritis and allied conditions. 12th ed. ed. Philadelphia: Lea & Febiger.

Kiple KF, and Beck SV. 1997. Biological consequences of the European expansion, 1450-1800 Kiple KF, and Beck SV, editors. Aldershot, Hampshire: Ashgate/Variorum.
Komlos J. 1989. Nutrition and economic development in the eighteenth-century Habsburg monarchy: an anthropometric history. Princeton: Princeton University Press.
Konigsberg LW, and Hens SM. 1998. Use of Ordinal Categorical Variables in Skeletal Assessment of Sex from the Cranium. American Journal of Physical Anthropology 107(1):97-112.
Krogman WM, and Iscan MY. 1986. The human skeleton in forensic medicine. Springfield, Ill.: C.C. Thomas.
Lamb HH. 1995. Climate, history and the modern world. New York: Routledge.
Larsen CS. 1994. In the Wake of Columbus: Native Population Biology in the Postcontact Americas. Yearbook of Physical Anthropology 37:109-154.
Larsen CS. 1995. Biological changes in human populations with agriculture. Annual Review of Anthropology 24:185-213.
Larsen CS. 1997. Bioarchaeology: interpereting behavior from the human skeleton. New York: Cambridge University Press.
Mangini A, Spötl C, and Verdes P. 2005. Reconstruction of temperature in the Central Alps during the past 2000 yr from a δ18O stalagmite record. Earth and Planetary Science Letters 235:741-751.
Martin DL, and Frayer DW. 1997. Troubled times: violence and warfare in the past. Martin DL, and Frayer DW, editors. Amsterdam: Gordon and Breach.
Mellinger AD, Sachs JD, and Gallup JL. 2000. Climate, Coastal Proximity, and Development. In: Clark GL, Feldman MP, and Gertler MS, editors. The Oxford Handbook of Economic Geography. New York: Oxford University Press.
Merbs CF. 1992. New world of infectious disease. Yearbook of Physical Anthropology 35:3-42.
North DC. 1990. Institutions, institutional change, and economic performance. New York: Cambridge University Press.
Ortner DJ, and Putschar WGJ. 1985. Identification of pathological conditions in human skeletal remains. Putschar WGJ, editor. Washington: Smithsonian Institution Press.
Popkin BM. 1998. The nutrition transition and its health implications in lower-income countries. Public Health Nutrition 1(1):5-21.
Ruff CB. 2000. Biomechanical analyses of archaeological human skeletons. In: Katzenberg MA, and Saunders SR, editors. Biological anthropology of the human skeleton New York: Wiley.
Ruff CB, Walker A, Larsen CS, and Trinkaus E. 1993. Postcranial robusticity in Homo. I: temporal trends and mechanical interpretation. American Journal of Physical Anthropology 91(1):21-53.
Sachs JD. 2001. Tropical Underdevelopment. Cambridge, MA: National Bureau of Economic Research working paper No. 8119.
Schultz M. 1982. Krankheit und Umwelt des vor-und frühgeschichtlichen Menschen. In: Wendt H, and Loacker N, editors. Kindlers Enzyklopädie der Mensch Zürich: Kindler Verlag. p 259-312.
Schultz M. 1993. The initial stages of systematic bone disease. In: Grupe G, and Garland AN, editors. Histology of ancient human bone : methods and diagnosis: proceedings of the "Palaeohistology Workshop" held from 3-5 October 1990 at Gottingen. Berlin: Springer-Verlag. p 185-203.
Sciulli PW, Mahaney MC, and Schneider KN. 1990. Stature estimation in prehistoric Native Americans of Ohio. American Journal of Physical Anthropology 83(3):275-280.

Scrimshaw NS. 1991. Iron Deficiency. Scientific American 265(4):46-52.
Smith BD. 1995. The emergence of agriculture. New York: Scientific American Library.
Steckel RH. 1995. Stature and the Standard of Living. Journal of Economic Literature December 33(4):1903-1940.
Steckel RH, and Floud R, editors. 1997. Health and welfare during industrialization. Chicago: University of Chicago Press.
Steckel RH, and Rose JC, editors. 2002. The backbone of history: health and nutrition in the Western Hemisphere. New York: Cambridge University Press.
Steckel RH, Sciulli PW, and Rose JC. 2002. A health index from skeletal remains. In: Steckel RH, and Rose JC, editors. The backbone of history: health and nutrition in the Western Hemisphere. New York: Cambridge University Press. p 61-93.
Stewart TD. 1979. Essentials of forensic anthropology, especially as developed in the United States. Springfield: Thomas.
Ubelaker DH. 1989. Human skeletal remains : excavation, analysis, interpretation. Washington: Taraxacum.
Verano JW, and Ubelaker, Douglas H. 1992. Disease and demography in the Americas / edited by John W. Verano and Douglas H. Ubelaker. Verano JW, Ubelaker DH, and National Museum of Natural H, editors. Washington :: Smithsonian Institution Press. x, 294 p. : p.
Walker PL. 1986. Porotic hyperostosis in a marine-dependent California Indian population. American Journal of Physical Anthropology 69(3):345-354.
Walker PL. 1989. Cranial injuries as evidence of violence in prehistoric southern California. American Journal of Physical Anthropology 80(3):313-323.
Walker PL. 2000. Bioarchaeological ethics: a historical perspective on the value of human remains. In: Katzenberg MA, and Saunders SR, editors. Biological anthropology of the human skeleton
New York: Wiley. p pp. 3-39.
Walker PL. 2001. A bioarchaeological perspective on the history of violence. Annual Review of Anthropology 30:573-596.
Walker PL, Bathurst RR, Richman R, Gjerdrum T, and Andrushko VA. 2009. The Causes of Porotic Hyperostosis and Cribra Orbitalia: A Reappraisal of the Iron-Deficiency-Anemia Hypothesis. American Journal of Physical Anthropology 139:109-125.
White TD. 2000. Human osteology. San Diego: Academic Press.