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Between Famine and Death: England on the Eve of the Black Death—Evidence from Paleoepidemiology and Manorial Accounts

The fourteenth-century Black Death was one of the most devastating epidemics in human history. Lasting only a few years, it killed an estimated 30 to 50 percent of affected populations. In England, the population fell from approximately 4.8 to 2.6 million between 1348 and 1351. Recent paleodemographic and paleoepidemiological research has shown that despite such tremendously high levels of mortality, the Black Death killed selectively—similar in kind, if not in scale, to normal, nonepidemic causes of mortality—targeting mainly older adults and frail individuals with a history of physiological stress. This evidence of selective mortality during the Black Death raises questions about the factors that might have affected patterns of heterogeneous frailty in the pre-epidemic population of Europe.[1]

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1 Stephen Broadberry, Bruce M. S. Campbell, Alexander Klein, et al., "English Economic Growth, 1270–1700," working paper (University of Warwick, 2011), 51; DeWitte and Gail Hughes-Morey, "Stature and Frailty during the Black Death: The Effect of Stature on Risks of Epidemic Mortality in London, A.D. 1348–1350," *Journal of Archaeological Science,* XXXIX (2012), 1412–1419; DeWitte and James W. Wood, "Selectivity of the Black Death with Respect to Preexisting Health," *Proceedings of the National Academy of Sciences of the United States of America,* CV (2008), 1436–1441; DeWitte, "Age Patterns of Mortality during the Black Death in London, A.D. 1349–1350," *Journal of Archaeological Science,* XXXVII (2010), 3394–3400.

Many scholars view famine as a possible factor in the emergence of the Black Death in the mid-fourteenth century. Indeed, between 1315 and 1317, England and other parts of northern Europe were ravaged by the Great Famine, the result of both ceaseless torrential rains that ruined three back-to-back harvests and purely institutional factors, including market failure, a disproportionate allocation of crop resources across different social strata, and persistent warfare. It is hardly surprising that the famine strongly discriminated between social echelons, claiming disproportionately high tolls among the poorer peasants and urban paupers. Complicating the immense demographic and economic impact of both the famine and the plague, another biological disaster of catastrophic proportions stood between the two crises, representing, to some degree, their missing link. The Great Bovine Pestilence, most likely caused by rinderpest, ravaged England in 1319/20, claimed about 62 percent of the bovine population. Apart from the colossal losses of oxen and cows, the pestilence created a widespread scarcity of milk resources, which persevered until at least 1332.[2]

This article examines the effects of the Great Famine and the Great Bovine Pestilence on patterns of health in the pre-Black Death population of London. It is the first attempt to integrate paleoepidemiological data, based on a sample of 491 skeletons from a plague cemetery in London, and a vast corpus of contemporary documentary data (chiefly from manorial accounts) produced between 1315 and 1350 at various locations in England. The most obvious advantage of such an interdisciplinary methodology is the explanatory light that the skeletal and documentary data can shed on one another, alleviating their individual limitations. We examine temporal trends in skeletal markers of physiological stress to assess

2 David V. Herlihy, *The Black Death and the Transformation of the West* (New York, 1997), 32; Josiah C. Russell, "Effects of Pestilence and Plague, 1315–1385," *Comparative Studies in Society and History,* VIII (1966), 464–473; William Chester Jordan, *The Great Famine: Northern Europe in the Early Fourteenth Century* (Princeton, 1996); Timothy P. Newfield, "A Cattle Panzootic in Early Fourteenth-Century Europe," *Agricultural History Review,* LVII (2009), 155–190; Slavin, "The Great Bovine Pestilence and Its Economic and Environmental Consequences in England and Wales, 1318–50," *Economic History Review,* LXV (2012), 1239–1266; *idem,* "The Fifth Rider of the Apocalypse: The Great Cattle Plague in England and Wales and Its Economic Consequences, 1319–1350," in Simonetta Cavaciocchi (ed.), *Le interazioni fra economia e ambiente biologico nell'Europa preindustriale secc. XIII–XVIII, Proceedings of the 41st Study-Week of the Fondazione Istituto Internazionale di Storia Economica 'F. Datini'* (Florence, 2010), 165–179.

whether individuals who survived the Great Famine or those born during or after the Great Bovine Pestilence faced reduced general levels of health before ultimately succumbing to the Black Death. The guiding idea is that people who were at the ages vulnerable to developing particular skeletal stress markers during the Great Famine would have exhibited higher frequencies of those stress markers than would have individuals who were at those ages either before or after the Great Famine. Furthermore, given the dairy deprivations associated with the Great Bovine Pestilence, we also submit that stress-marker frequencies in the post-famine sample will be intermediate between those of the pre-famine and famine samples.

THE EAST SMITHFIELD CEMETERY SAMPLE The skeletal material for this study comes from the East Smithfield cemetery in northeastern London, near the Tower of London. This cemetery is one of only a few excavated cemeteries with both documentary and archaeological evidence clearly linking it to the fourteenth-century Black Death. According to records from the Church of the Holy Trinity, which include the exact location, dimensions, and purpose of the burial ground, the East Smithfield cemetery was founded in the autumn of 1348 in anticipation of the overwhelming mortality associated with the Black Death, which arrived in London at around the same time. The Museum of London's Department of Greater London Archaeology completed archaeological excavation of the cemetery during the 1980s, revealing several rows of individual graves and mass-burial trenches. These trenches further indicate that the site was used as an emergency burial ground. Stratigraphical evidence indicates that the burials were completed in a single phase; there is no evidence of interments in East Smithfield after 1350. In other words, most, if not all, of the individuals interred in East Smithfield cemetery died during the Black Death.[3]

The well-established and narrow chronology of the East Smithfield cemetery means that its age-at-death data can reveal those who were born before and during the Great Famine and those who survived it, as well as those who were born after the famine and during or after the Great Bovine Pestilence. Thus, we

3 Ian Grainger et al., *The Black Death Cemetery, East Smithfield, London* (London, 2008), 19, 31; Duncan Hawkins, "Black Death and the New London Cemeteries of 1348," *Antiquity,* LXIV (1990), 637–638.

can trace the effects of the famine and the milk deficiency on patterns of health in the period before the Black Death. A sample of 491 individuals was selected from the East Smithfield cemetery collection and analyzed under the auspices of the Museum of London Centre for Human Bioarchaeology. It includes all of the excavated individuals from the cemetery who were preserved well enough to provide data on age, sex, and the presence of skeletal stress markers using the methods described below.

Age Estimation Adult ages were estimated using transition analysis, which avoids the biases associated with traditional methods and provides point estimates of age, even for older adults (rather than a broad terminal adult-age category, as is typical of other methods). In transition analysis, data from a known-age reference sample are used to obtain the conditional probability, $Pr(c_j \mid a)$, that a skeleton will exhibit a particular age indicator stage, or a suite of age indicator stages, c_j, given the individual's known age a. This conditional probability is combined, using Bayes' theorem, with a prior distribution of ages at death to determine the posterior probability that a skeleton (of unknown age) in the cemetery sample died at a certain age, given that it displays particular age-indicator stages, $Pr(a \mid c_j)$.

In transition analysis, the prior distribution of ages at death can either be informative, based on documentary data, or uniform. This approach avoids imposing the age distribution of a known-age reference sample on the target sample as occurs with traditional methods of age estimation. For this study, transition analysis was applied to skeletal-age indicators on the pubic symphysis and the iliac auricular surface, as well as to cranial suture closure as described by Boldsen et al. The Anthropological Database, Odense University (ADBOU), age estimation software was used to determine individual ages at death and the standard errors associated with those point estimates. The ADBOU program employs conditional probabilities estimated from the Smithsonian Institution's Terry Collection of known-age individuals and an informative prior distribution of ages at death based on data from seventeenth-century Danish rural parish records. Ages for individuals younger than twenty years were estimated based on epiphyseal fusion and dental development and eruption.[4]

4 Jepser L. Boldsen et al., "Transition Analysis: A New Method for Estimating Age from

Sex Estimation Sex was determined on the basis of sexually dimorphic features of the skull and pelvis using the standards described in Buikstra and Ubelaker. The dimorphic features of the skull and pelvis that were scored included the glabella/supraorbital ridge, supraorbital margin, mastoid process, external occipital protruberance/nuchal crest, mental eminence, ventral arc of the pubis, subpubic concavity, ischiopubic ramus ridge, and the greater sciatic notch. Whenever the skull and pelvis of individuals in this study indicated different sexes, the pelvic scores were subjectively weighted more heavily than features of the skull.[5]

Skeletal Stress Markers To assess the effect of famine and cattle pestilence on patterns of health in the population of London, we examined temporal trends in a variety of skeletal stress markers that previous studies have shown to be associated with episodes of malnutrition or disease and with elevated risks of mortality—adult stature, cribra orbitalia, porotic hyperostosis, and linear enamel hypoplasia.[6]

Adult stature reflects, among other things, exposure to chronic stress during development. Because the interest herein is stature as a measure of health, not adult stature per se, this study uses measurements of the femur and tibia as proxies for adult stature (only complete femora and tibiae were measured). By directly comparing long bone lengths, by sex, within the cemetery sample, we avoid

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Skeletons," in Robert D. Hoppa and James W. Vaupel (eds.), *Paleodemography: Age Distributions from Skeletal Samples* (New York, 2002), 73–106; J. Louise Scheuer, Jonathan H. Musgrave, and Suzanne P. Evans, "The Estimation of Late Fetal and Perinatal Age from Limb Bone Length by Linear and Logarithmic Regression," *Annals of Human Biology,* VII (1980), 257–265; Louise Scheuer and Sue M. Black, *Developmental Juvenile Osteology* (San Diego, 2000); G. Gustafson and G. Koch, "Age Estimation up to 16 Years of Age Based on Dental Development," *Odontologisk Revy,* XXV (1974), 297–306; Coenraad F. Moorrees et al., "Growth Studies of the Dentition: A Review," *American Journal of Orthodontics,* LV (1969), 600–616; B. Holly Smith, "Standards of Human Tooth Formation and Dental Age Assessment," in Mark A. Kelley and Clark S. Larsen (eds.), *Advances in Dental Anthropology* (New York, 1991), 143–168; Jane E. Buikstra and Douglas H. Ubelaker (eds.), *Standards for Data Collection from Human Skeletal Remains: Proceedings of a Seminar at the Field Museum of Natural History* (Fayetteville, Ark., 1994), 39–44.

5 Buikstra and Ubelaker (eds.), *Standards for Data Collection,* 15–21.

6 DeWitte and Hughes-Morey, "Stature and Frailty," 1412–1419; DeWitte and Wood, "Selectivity of the Black Death,"1436–1441; Bethany M. Usher, "A Multistate Model of Health and Mortality for Paleodemography: Tirup Cemetery," unpub. Ph.D. diss. (Pennsylvania State Univ. 2000); Charlotte A. Roberts and Keith Manchester, *The Archaeology of Disease* (Ithaca, 2005); Clark Spencer Larsen, *Bioarchaeology: Interpereting Behavior from the Human Skeleton* (New York, 1997).

the potential problems associated with estimating stature using population-specific regression formulae derived from known-stature reference samples. The maximum lengths of the femur and tibia were measured using an osteometric board. Analyses were performed on the sum of each individual's femur and tibia lengths. Individuals were considered "short" if their femur + tibia measurements were more than one standard deviation below the mean for their sex; individuals whose measurements were less than one standard deviation below the mean, or were higher than the mean for their sex, were considered to be of "average or tall" stature.[7]

Porotic hyperostosis and cribra orbitalia are lesions on the cranial vault bones and orbital roofs, respectively. They are characterized by a porous appearance of the cortical bone that is often associated with expansion of the underlying diplöic bone. Both porotic hyperostosis and cribra orbitalia are usually associated with anemia or other causes during childhood that result in an expansion of the bone marrow and thus an expansion of the surrounding diplöic bone, or with such conditions as scalp infections or subperiosteal hematomas that can occur at any age. Porotic hyperostosis and cribra orbitalia were scored as present if at least 1 square cm of porosity was visible on the cranial vault or orbital roofs.[8]

Linear enamel hypoplasias, which appear as horizontal lines of varying width on the enamel of an affected tooth, are caused by the disruption of enamel formation in response to infection or malnutrition. For this study, linear enamel hypoplasias were identified macroscopically on the buccal surface of the mandibular canines, which have a relatively long developmental time span and are highly sensitive to physiological stress. Linear enamel hypoplasia was scored as "present" if one or more depressions on the surface of

7 Usher, "Multistate Model"; William A. Haviland, "Stature at Tikal, Guatemala: Implications for Ancient Maya Demography and Social Organization," *American Antiquity,* XXXII (1967), 316–325; Mary Lucas Powell, *Status and Health in Prehistory: A Case Study of the Moundville Chiefdom* (Washington, D.C, 1988); Buikstra and Ubelaker (eds.), *Standards for Data Collection.*

8 Robert P. Mensforth et al., "The Role of Constitutional Factors, Diet, and Infectious Disease in the Etiology of Porotic Hyperostosis and Periosteal Reactions in Prehistoric Infants and Children," *Medical Anthropology,* II (1978), 1–58; Donald J. Ortner, *Identification of Pathological Conditions in Human Skeletal Remains* (Amsterdam, 2003); Phillip L. Walker et al., "The Causes of Porotic Hyperostosis and Cribra Orbitalia: A Reappraisal of the Iron-Deficiency-Anemia Hypothesis," *American Journal of Physical Anthropology,* CXXXIX (2009), 109–125.

the tooth were palpable and visible to the naked eye under good lighting.[9]

For all stress markers, age estimates (with standard errors) were used to identify the time period during which an individual would have been in the age range most vulnerable to developing a particular stress marker (the exact age interval varied by stress marker, as detailed below). The three groups analyzed were those individuals within the age interval vulnerable to developing a particular stress marker (1) before ("pre-famine"), (2) during ("famine"), and (3) after ("post-famine") the Great Famine. For stature, we considered growth from conception to age twenty to capture as much of the effects of famine and bovine pestilence on growth as possible. The famine group, with respect to stature, includes individuals born between 1296 and 1319 whose growth from birth to twenty years might have been negatively affected during the Great Famine. We included individuals born in 1319 in this group because their growth in utero might have been adversely affected during the Great Famine. People born before 1296 (those twenty years old or older during the Great Famine and thus fully grown before the famine) were relegated to the "pre-famine" group and those born after 1319 (those whose growth occurred after the famine) to the "post-famine" group.

Both cribra orbitalia and porotic hyperostosis form predominantly between the ages of six months and twelve years of age. With respect to these two lesions, individuals aged twelve years or younger during the Great Famine (born between 1303 and 1318) were included in the famine group, and those twelve years or younger before and after the Great Famine were included in the pre- and post-famine groups, respectively. Enamel forms on the mandibular canine from approximately six months to six years of

9 DeWitte and Wood, "Selectivity of the Black Death,"1436–1441; Rebecca Huss-Ashmore, Alan H. Goodman, and George J. Armelagos, "Nutritional Inference from Paleopathology," *Advances in Archaeological Method and Theory,* V (1982), 395–473; Albert A. Dahlberg, "Interpretations of General Problems in Amelogenesis," in Donald J. Ortner and Arthur C. Aufderheide (eds.), *Human Paleopathology: Current Syntheses and Future Options* (Washington, D.C., 1991), 269–272; Alan H. Goodman, George J. Armelagos, and Jerome C. Rose, "Enamel Hypoplasias as Indicators of Stress in Three Prehistoric Populations from Illinois," *Human Biology,* LII (1980), 515–528; Richard V. Santos and Carlos E. Coimbra, Jr., "Hardships of Contact: Enamel Hypoplasias in Tupi-Monde Amerindians from the Brazilian Amazonia," *American Journal of Physical Anthropology,* CIX (1999), 111–127.

age. With respect to mandibular canine enamel hypoplasia, individuals six years old or younger during the Great Famine (those born between 1309 and 1318) were included in the famine group, and those six years old or younger before and after the Great Famine were included in the pre- and post-famine groups, respectively.[10]

Given that the standard errors associated with point estimates of age were large for some individuals, for the sake of more accurate comparisons, we assigned people to the pre- , post- , and famine groups using the interval defined by the point estimate of age plus and minus 1 standard error (using each individual's estimated standard error) rather than using just point estimates of age. The temporal trends in the frequencies of all skeletal stress markers were assessed using Fisher's exact test with SPSS version 19. Variation in stature before and after the Great Famine was assessed using an F-test. Although major epidemiological and medical journals do not recommend the reporting of statistical significance, we consider *p*-values less than 0.10 to be suggestive of a real effect.[11]

RESULTS

Skeletal Stress Markers The frequencies of the skeletal stress markers and the results of the Fisher's exact tests are shown in Table 1. The Fisher's exact test reveals that the differences among the pre-famine, famine, and post-famine groups are not statistically significant for any of the skeletal stress markers considered. The lack of significant results, which may be an artifact of small sample sizes, means that neither of our expectations is supported by the existing data.

The means and standard deviations for the long-bone measurements of the adult males and females born before versus those born after the Great Famine are shown in Table 2. Those born after

10 Diane M. Mittler and Dennis P. Van Gerven, "Developmental, Diachronic, and Demographic Analysis of Cribra Orbitalia in the Medieval Christian Populations of Kulubnarti," *American Journal of Physical Anthropology,* XCIII (1994), 289; Don J. Reid and M. Christopher Dean, "Variation in Modern Human Enamel Formation Times," *Journal of Human Evolution,* L (2006), 339.

11 Kenneth J. Rothman, "Writing for Epidemiology," *Epidemiology,* IX (1998), 333–337; Janet M. Lang, Rothman, and Cristina I. Cann, "That Confounded P-Value," *ibid.,* 7–8; Hillel W. Cohen, "P Values: Use and Misuse in Medical Literature," *American Journal of Hypertension,* XXIV (2011), 18–23; Steven N. Goodman, "Toward Evidence-Based Medical Statistics. 1: The *P* Value Fallacy," *Annals of Internal Medicine,* CXXX (1999), 995–1004.

Table 1 Frequencies of the Skeletal Stress Markers and Results of the Fisher's Exact Tests

STRESS MARKER	ABSENT	PRESENT	%	FISHER'S EXACT TEST
Porotic hyperostosis	3	16	84	
	0	4	100	
	6	65	92	$p = 0.596$
Cribra orbitalia	12	1	7.7	
	3	1	25	
	61	15	18	$p = 0.532$
Enamel hypoplasia	3	9	75	
	—	—	—	
	21	65	76	$p = 1.00$
Short stature	9	0	0	
	7	1	13	
	23	4	15	$p = 0.661$

NOTE "%" refers to the percentage of each sample with a stress marker.

the Great Famine evinced more variation in long-bone length (and thus stature) than did those born before it; the difference is statistically significant for females (female $p = 0.01$, male $p = 0.23$). These results suggest that, at least for females, mortality during the Great Famine targeted shorter (and thus frailer) individuals. By weeding shorter individuals out of the population, such selective mortality resulted in decreased variation in stature among the famine survivors. DeWitte and Hughes-Morey similarly suggested that selective mortality associated with the Great Famine affected patterns of adult stature among victims of the Black Death, since they found no significant difference in stature between those who were growing during the Great Famine and those who were not (the DeWitte/Hughes-Morey study used a broader time frame for the famine, 1315 to 1322).[12]

Although the sample sizes are small, and the results of these analyses are, for the most part, nonsignificant, the post-famine sample shows a general trend of higher frequencies for all stress markers than the pre-famine sample does. The general increase in stress-marker frequencies from the pre- to post-famine samples might suggest that people who were at the ages vulnerable to forming these stress makers after the Great Famine were more likely to de-

12 DeWitte and Gail Hughes-Morey, "Stature and Frailty," 1412–1419.

Table 2 Comparison of Male and Female Stature before and after the Great Famine (mm)

		BORN BEFORE GREAT FAMINE	BORN AFTER GREAT FAMINE	*f*-TEST
Male	Mean	806.25	823.93	
	Standard deviation	40.56	54.55	$p = 0.23$
Female	Mean	754.00	758.25	
	Standard deviation	10.65	33.26	$p = 0.01$

velop them than were people who were at those ages before the famine.

Another possibility is that people who had these stress markers—namely, those who were frail—at the time of the Great Famine died during the famine before the Black Death struck, thereby decreasing the frequency of stress markers in the pre-famine or famine groups within the East Smithfield cemetery. Mortality during the famine could have targeted individuals with the highest frailty (those whose risk of dying was greater than that of others in the populations), just as it typically does under normal mortality conditions, thus weeding out the weakest individuals who were exposed to the severe malnutrition of the famine. If such selective mortality occurred, individuals managed to survive the Great Famine because they were not frail in the relevant respect. Hence, the cohort of individuals who survived the Great Famine would have had lower frailty on average than the original cohort exposed to the Great Famine.[13]

The cohort of individuals who were born after the Great Famine was not subjected to a similar episode of crisis mortality before the Black Death. Because they did not experience such strong selective mortality, the post-famine cohort likely included many more frail individuals, thus raising the average level of frailty higher than that of the pre-famine or famine cohorts. Given evidence from previous studies that the skeletal stress markers in this analysis are associated with elevated risks of mortality, as well as relatively high frailty, such selective mortality (the disproportionate deaths of

13 James W. Vaupel, K. G. Manton, and E. Stallard, "The Impact of Heterogeneity in Individual Frailty on the Dynamics of Mortality," *Demography,* XVI (1979,) 439–454.

individuals with stress markers) could have reduced the frequencies of these markers and variation in stature among the famine survivors within the Black Death cemetery, compared to the post-famine sample that did not experience the selective sweep of the Great Famine.[14]

By removing the frailest individuals from the population, the Great Famine could have created a cohort of individuals who were less likely to die from a variety of causes, including the Black Death, than were the individuals who never experienced the famine. Though the post-famine individuals likely experienced deprivations during the Great Bovine Pestilence, the long-term shortage of dairy products described below might not have had the same dramatic effects on population-level variation in frailty as did the Great Famine.

THE GREAT FAMINE AND THE GREAT BOVINE PESTILENCE: A QUANTITATIVE APPROACH A proper understanding of the temporal trends in skeletal pathologies suggested by these results requires an in-depth analysis of England's economic and nutritional condition during the period between the famine and the plague, with particular attention to the role of the bovine pestilence of 1319/20. A vast corpus of contemporary data compiled chiefly from more than 3,000 annual manorial accounts—as commissioned by local manorial lords between c.1315 and 1350—provides a wealth of extremely detailed information about England's agriculture and economics at the time.

Although both the Great Famine and the Black Death were disasters on a catastrophic scale with devastating long-term consequences, the first half of the fourteenth century witnessed another devastating biological event—the Great Bovine Pestilence, which killed a large proportion of northern Europe's bovids, including those of the British Isles. The exact nature of the pestilence is still unclear, but both narrative and statistical sources suggest rinderpest—a highly viral cattle disease, transmitted mainly through sexual and respiratory means—as a possible cause. Given the dire consequences of the Great Famine and the Great Bovine

14 DeWitte and Hughes-Morey, "Stature and Frailty," 1412–1419; DeWitte and Wood, "Selectivity of the Black Death,"1436–1441.

Pestilence, we would do well to consider the impact of each disaster on the nutritional patterns and health of the early fourteenth-century English (and northern European) populations.[15]

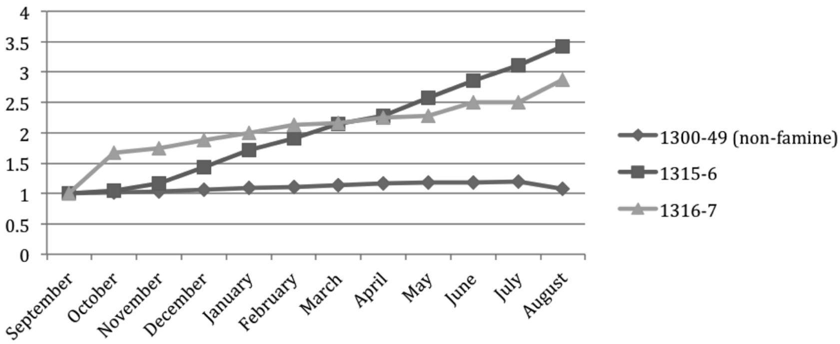
The Great Famine was initially a weather-induced event, resulting from torrential rain falling almost ceaselessly from the autumn of 1314 to the spring 1317, together with fiercely cold winters. The harsh weather resulted in three back-to-back harvest failures, affecting especially wheat, rye, and legumes. The composite yields for these crops stood, respectively, at about 40, 60, and 10 percent below the "normal level" during the harvests of 1315, 1316, and 1317. These low yields increased crop prices much more quickly than they did in nonfamine years. Between the harvests of 1315 and 1316, wheat prices, which usually did not rise more than 25 to 30 percent within a particular agricultural year, jumped by about 250 percent, due largely to market failure and the grain hoarding policy of wealthy manorial lords. Left to their own devices, the rustic masses starved. Indirect evidence from manorial court rolls suggests that England and Wales lost between 10 and 15 percent of their population between 1315 and 1317; these figures agree with some continental data. The famine had ended by the harvest of 1317, which, although a bit worse than average, was good enough to relieve the starvation. Grain prices remained slightly higher than usual, but they hardly fluctuated between the harvests of 1317 and 1318, contrary to the pattern in the two previous years. The harvest of 1318 was bountiful, driving grain prices down to the pre-famine levels. By that time, crop deficiency and, to a great extent, famine was a thing of the past, at least in England and Wales.[16]

The end of the famine did not, however, necessarily mean the end of the food crisis. The bovine mortality of 1319/20 seems to have wreaked even more havoc, at least in the longer term. In England and Wales, the only lands for which robust quantitative evidence is available, the pestilence killed, on average, about 62 per-

15 Newfield, "Cattle Panzootic," 155–190; Slavin, "Fifth Rider of the Apocalypse," 165–179; Slavin, "Great Bovine Pestilence," 1239–1266

16 Jordan, *Great Famine,* 48–59; Ian Kershaw, "The Great Famine and Agrarian Crisis in England 1315–1322," *Past and Present,* 59 (1973), 6–16; Campbell, "Nature as Historical Protagonist: Environment and Society in Pre-Industrial England," *Economic History Review,* LXIII (2010), 284–289; Henry S. Lucas, "The Great European Famine of 1315, 1316, and 1317," *Speculum,* V (1930), 352–355.

Fig. 1 Seasonal Crop Prices in England, 1300–1349



cent of the local cattle, though fatalities varied from place to place. In some manors, the entire bovine stock perished, whereas in others, all of it was spared. Moreover, death tolls tended to vary across different sex groups and age cohorts (see Table 3). Cows tended to be much more susceptible to the pestilence than were other groups; between 70 and 80 percent of them were lost in England and Wales. The mortality rate for oxen and young cattle was about 54 and 60 percent, respectively. In general, female animals were more prone to the pathogen than were males. On average, nearly two-thirds of all cows and heifers died; the figure for oxen, bulls, and bullocks stood at about 53 percent.[17]

The Impact of the Great Bovine Pestilence on Nutritional Patterns before the Black Death The colossal losses in bovine stock deprived both lords and peasants of not only their "tractors" and fertilizing agents but also their most vital protein and calcium resources, as well as an important source of Vitamin B_{12}. Since arable husbandry, which was by far the single most predominant element of early fourteenth-century agriculture, relied on animals to plow, oxen had to be restocked first. It took about ten years for oxen to reach about 85 percent of their pre-pestilence levels. Dairy cattle, however, were replenished through purchases, intermanorial transfer, and biological reproduction at a much slower pace: By 1332, they had barely reached 85 percent of their pre-1319 levels. Not until the Black Death did the number of cattle attain its pre-pestilence

17 Slavin, "Great Bovine Pestilence," 1241–1249.

Table 3 Death Rates across Different Sex and Age Cohorts

ANIMAL COHORT	% OF DEATHS THROUGH MURRAIN	% OF DEATHS THROUGH MURRAIN AND BUTCHERIES	% OF TOTAL LOSSES (THROUGH MURRAIN + PANIC SALES + BUTCHERY)	% OF ALL BOVIDS
Oxen	49.69	49.93	54.05	40.50
Mature cattle	68.34	68.95	79.39	27.04
Young cattle	54.63	55.47	59.58	13.10
Calves	58.13	58.27	61.42	18.87
Male bovids	52.69	52.90	56.90	65.81
Female bovids	63.75	64.64	74.73	34.19
Observations (demesnes)	142			
Observations (animals)	7,214			

NOTE Slavin, "The Great Bovine Pestilence and Its Economic and Environmental Consequences in England and Wales, 1318–50," *Economic History Review,* LXV (2012), 1239–1266.

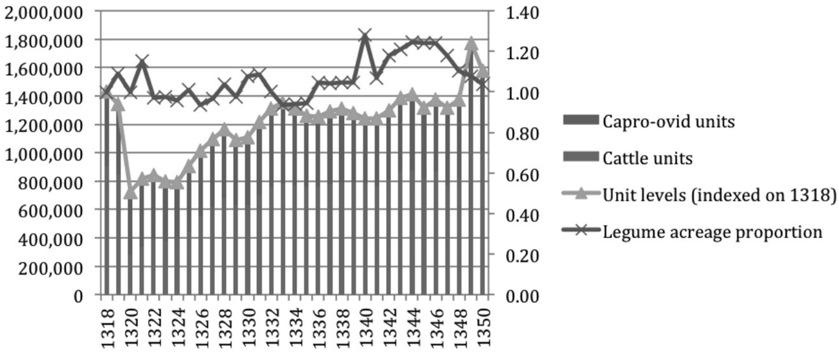
levels. The strategy of replenishing oxen more steadily and quickly than dairy cattle had serious consequences for nutrition between c.1320 and 1340.

In the pre-Black Death era, grain-based products were paramount in the nutrition of commoners, contributing between 70 to 80 percent of their daily caloric intake. But dairy-based products—including fresh milk, cheese, and butter—represented the single most important source of protein, calcium, and B12. Meat consumption was limited among the lower social echelon, which represented the vast majority of late medieval English society. Roughly speaking, dairy products may have contributed between 10 and 15 percent of daily caloric intake. The gargantuan losses of dairy cattle meant that the population of England and Wales was deprived of its single most important source of protein and calcium until the stocks returned to their pre-1319 levels, relative to the size of population.

As Figure 2 shows, on the eve of the pestilence, England stocked a good number of milk-producing animals, including about 820,000 dairy cows, 6 million dairy sheep, and 21,000 dairy goats. Converting each group into its equivalent "milk animal unit," as determined by respective milk yields, results in a total of 1.43 million dairy units. By 1320, the figures had fallen to about 727,000 units, 50 percent of of the pre-1319 level. The share of cattle within the dairy sector fell from about 65 percent to below 40 percent. Some manorial officials attempted to alleviate the slow process of replenishing dairy units by temporarily augmenting sheep stocks, but this strategy had several flaws. First, a cow can render ten-times more milk than can one ewe. Second, expanding sheep flocks required that at least some arable land be converted into pasture, which could have been a long, tedious, and expensive procedure. Third, replacing one cow with ten ewes was, in most case, unprofitable; the price ratio between the two animals was usually about 8 to 1 (10 *s.* per cow to 1.25 *s.* per ewe). Finally, peasants rarely had enough grazing resources to sustain a growing sheep population. Furthermore, dams (she-goats), which yield more milk per animal than ewes do, were in too short supply to contribute much.

Although the cow population had risen to 90 percent of its pre-pestilence level by 1332, accounting for about 60 percent of the entire dairy force, cow stocks were not replenished completely

Fig. 2 Available Dairy Power and Legume Acreage in England, 1318–1350



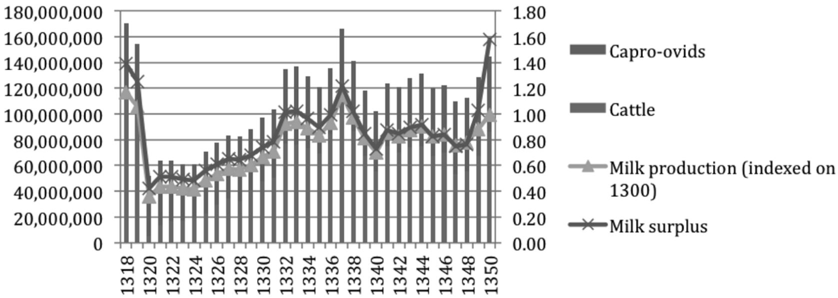
NOTE Dairy power measured in dairy-animal units relative to each group's lactage capacity (adult cows=1, heifers=0.7, dams=0.125, young does=0.09, ewes=0.10, gimmers=0.07).

until the Black Death years. To make matters worse, there is no evidence that people made any attempt to seek alternative sources of protein. Evidence from manorial accounts indicates that the proportion of arable acreage devoted to legumes did not increase until the late 1330s—hardly surprising, given that fourteenth-century producers did not perceive legumes as an alternative source of protein.

The decline in the number of dairy animals did not mirror the decrease in England's total milk output. After all, the former was determined not only by the actual number of healthy and fertile animals but also by annual lactage yields, which, just as with crop and wool yields, tended to fluctuate from year to year. To a large degree, lactage yields were dictated by purely environmental factors, primarily the availability of sufficient grassland. Pasture dearth, stemming from either torrential rain or excessive drought, could seriously depress the ability of dairy animals to provide sufficient amounts of milk. Unfortunately, since the vast majority of manorial accounts did not record detailed statistics about dairy production, our series of milk yields is based upon a small sample of demesnes, mostly those belonging to Winchester Bishopric, with several necessary extrapolations. Nevertheless, this sample likely reflects the general trends, thus offering insight into the yearly fluctuations of dairy yields.

As Figure 3 indicates, between 1318 and 1320, annual milk

Fig. 3 Milk Production Levels (by Gallons of Raw Milk) in Absolute and Relative Numbers (indexed on 1318) and Estimated Rates of Available Milk Production Surplus in England, 1318–1350



NOTE See Appendix 1 for the detailed calculation.
SOURCE Manorial accounts database.

production output in England fell from about 170 to 52 million gallons. In 1318 and 1319, however, milk yields seem to have been exceptionally high when compared to average years, in which total output was around 130 million gallons. Sheer levels of milk output were depressed until 1332, the start of seven highly productive years, 1337 and 1338 being particularly noteworthy. This significant elevation in production derived mostly from exceptionally high dairy yields, sustained by several back-to-back years of favorable weather and abundant vegetation growth, as well as from an increase in dairy animals.

The effect of dairy production on human nutrition and health is evident from an estimation of the ratio between sheer milk output and total dairy caloric requirements. We present the estimates herein as annual "milk surplus" levels—that is, the relationship between the supply and demand. Figure 3 indicates a chronic dearth of milk until the good lactage yields of 1332. By 1320, the total output was approximately 58 percent below the basic requirement. A decade later, it was 25 percent below. Although the total output levels between 1332 and 1338 seem to have matched the dietary needs of the populace, the low yields and, consequently, the reduced productivity in the 1340s (especially in 1340 and from 1345 through 1348) may mean that milk deficiency was once more widespread.

The low milk yields were not the only factor accounting for the gap between the total milk output and the overall dairy requirements of the population. The continuing population growth between the Great Famine and the Black Death also had something to do with it. Although England seems to have lost about 15 percent of its population during the famine years, between 1317 and 1348, the total population appears to have grown from approximately 4 to 4.8 million people. In other words, the human population grew exponentially faster than the available dairy resources, creating, at least to a certain extent, a classic Malthusian scenario.

The crop dearth of the famine years and the dairy deficiency stemming from the bovine pestilence created different patterns of food deprivation. The Great Famine's deprivation was relatively short-term, lasting for approximately two years (from about summer 1315 to summer 1317). The frailer proportion of the population likely perished, while the healthier majority survived beyond the famine years. With the exception of the disastrous harvest of 1321, when composite crop yields were 34 percent below average, not a single harvest failure that followed the famine can compare in magnitude to those of 1315 to 1317. The cattle plague, however, created a long-term deprivation of dairy products, which were at that time the single most important source of protein, calcium, and Vitamin B_{12}. As noted above, this deficiency continued at least until 1332, and the evidence suggests that the dearth returned again from 1339 until the Black Death. Three factors contributed to this deprivation in its own way—slow restocking rates of dairy cattle, low lactage yields, and human population growth.

Dairy Deficiency and Skeletal Stress Markers How is this long-term deprivation of dairy products reflected in the skeletal stress markers? The post-famine group exhibits higher frequencies of porotic hyperostosis and cribra orbitalia. Several causes of these two pathological conditions have been identified or suggested, including iron-deficiency anemia, vitamin B_{12} deficiency, scurvy, and scalp infections. Vitamin B_{12} deficiency is particularly relevant in the context of the bovine pestilence, given that dairy products were not only the single richest source of B_{12} but also the only one readily available to the medieval masses. Cheese and meat contain approximately the same amount of B_{12} by weight (around 2.5 μg per 100g), whereas crop-based products contain no B_{12} at all. Meat consumption, however, was only occasional, and its caloric contribution to the peasants' diet was meager. The total number of animals earmarked for slaughter was too low to ensure sufficient meat for peasants' nutrition. Beef, mutton, pork, lard, and poultry could not have sustained an average peasant for more than twenty days a year (See Appendix 2). Moreover, eggs, which may have been consumed more often than meat, are not the optimal source of B_{12} since they also tend to block absorption of this vitamin. The contribution of dairy products to B_{12} intake cannot be overstated.[18]

Higher frequencies of both enamel hypoplasia and short stature in the post-famine group may have been associated with insufficient calcium intake, which, in turn, links to milk shortage. A long-term calcium deficiency, especially in children and adolescents, can have negative consequences for the development of bones and teeth, coagulation of blood, contraction of muscles, and cardiac action, as well as for milk production in breast-feeding mothers. Enamel hypoplasia is often found in children and adolescents suffering from regular deprivation of calcium sources. The tentative evidence that the post-famine generations were more likely to develop enamel hypoplasia may well suggest that they also suffered from a lack of milk, as opposed to the pre-famine and famine cohorts who had better access to dairy products and so to calcium. Furthermore, the evidence that the post-famine group, or at least the females therein, exhibited a greater variation in stature, and a larger proportion of short individuals, seems to indicate a chronic deficiency of calcium-based products. At this point, however, the present skeletal sample is too narrow to establish such a connection conclusively.[19]

The Great Famine might also have had an effect on breast-feeding patterns. As recent archaeological studies have shown, the

18 Ortner, *Identification of Pathological Conditions;* Walker et al., "The Causes of Porotic Hyperostosis and Cribra Orbitalia," 109–125; Christopher Dyer, "Changes in Diet in the Late Middle Ages: The Case of Harvest Workers," *Agricultural History Review,* XXXVI (1988), 21–37; Simon Mays, *The Archaeology of Human Bones* (London, 1998); Marc F. Oxenham and Ivor Cavill, "Porotic Hyperostosis and Cribra Orbitalia: The Erythropoietic Response to Iron-Deficiency Anemia," *Anthropological Science,* CXVIII (2010), 199–200.

19 Julie Heringhausen and Kristen S. Montgomery, "Continuing Education Module—Maternal Calcium Intake and Metabolism during Pregnancy and Lactation," *Journal of Perinatal Education,* XIV (2005), 52–57; American Academy of Pediatrics (AAP), Committee on Nutrition, "Calcium Requirements of Infants, Children and Adolescents," *Pediatrics,* CIV (1999), 1152–1157; Karen S. Wosje and Bonny L. Specker, "Role of Calcium in Bone Health during Childhood," *Nutrition Reviews,* LVIII (2000), 253–268; J. Mellanby and C. L. G Pratt, "Calcium and Blood Coagulation," *Proceedings of the Royal Society of London. Series B, Biological Sciences,* CXXVIII (1940), 201–213; Gordon Nikiforuk and Donald Fraser, "Chemical Determinants of Enamel Hypoplasia in Children with Disorders of Calcium and Phosphate Homeostasis," *Journal of Dental Research,* LVIII (1979), 1014–1015; Gordon Nikiforu and Donald Fraser, "The Etiology of Enamel Hypoplasia: A Unifying Concept," *Journal of Pediatrics,* XCVIII (1981), 888.

duration of breast-feeding in medieval England lasted, on average, for about eighteen months, much to the benefit of infant health. A long-term deficiency of dairy products could have seriously depressed the levels of milk production and, consequently, the success of breast-feeding. Breast-feeding mothers need extra calcium both to produce sufficient milk and to maintain strong and healthy bones. A long-term calcium deprivation could have created a generation of weaker mothers, whose compromised immune systems could have exposed them to various pathologies and pathogens. Similarly, those infants who survived into adulthood in spite of insufficient breast-feeding could have been frail compared to their older siblings and parents who were born before 1319.[20]

Although the skeletal evidence from the East Smithfield cemetery, sampled in the current study, reveals at least four types of stress markers, all of which can reflect the effects of the post-1319 dairy crisis, the catastrophic insufficiency of milk products (and protein in particular) could have caused additional pathologies that are currently undetectable on the skeletal remains. The association between protein-energy malnutrition and epidemic diseases is common in human populations, both past and present. A shortage of protein from dairy products—including such vital types as casein and whey protein—or protein-energy malnutrition (PEM) can have disastrous consequences for human populations, especially childhood development. PEM usually results in growth failure, which manifests in low weight and short stature. More severe types of PEM, such as kwashiorkor and marasmus, can cause drastic weight loss; extensive tissue, muscle, and bone wasting; and loss of adipose tissue, often resulting in death. People afflicted with PEM show pronounced weakness and are susceptible to various pathogens of communicable diseases. The modern treatment of PEM often involves frequent milk consumption.[21]

Archaeological findings in conjunction with contemporary quantitative data from manorial records demonstrate that most of the English population before the Black Death, consisting mainly of

20 Benjamin T. Fuller, Michael P. Richards, and Simon A. Mays, "Stable Carbon and Nitrogen Isotope Variations in Tooth Dentine Serial Sections from Wharram Percy," *Journal of Archaeological Science,* XXX (2003), 1676; *idem,* "Bone Stable Isotope Evidence for Infant Feeding in Mediaeval England," *Antiquity,* LVI (2002), 656; Christopher S. Kovacs, "Calcium and Bone Metabolism in Pregnancy and Lactation," *Journal of Clinical Endocrinology and Metabolism,* LXXXVI (2001), 2344–2348.

21 Dionysios Stathakopoulos, *Famine and Pestilence in the Late Roman and Early Byzantine*

peasants, suffered from a chronic shortage of protein, calcium, and Vitamin B_{12} for at least one generation. This duration was over a much longer period than the three years of bad harvests and grain famine typically attributed to the Great Famine, and it is highly likely that its ramifications were severe. As the skeletal evidence suggests, the Great Famine could have reduced the proportion of the frailest individuals between 1315 and 1317. The Great Bovine Pestilence, which resulted in a catastrophic and long-term dearth of dairy products, did not produce high human mortality, whether selective or indiscriminate, but it could have created a generation of relatively weak people who were less resilient than those who survived the famine. Hence, the Great Bovine Pestilence, we suggest, could have been more responsible than the Great Famine for the high mortality associated with the Black Death.

The dairy-deficiency explanation is not without shortcomings, however. The cattle plague certainly also hit northern Europe, but there is no evidence that it affected the Mediterranean part of the continent. Yet, the Black Death respected neither boundaries nor regions, taking lives throughout Eurasia, North Africa, and beyond. Hence, dairy deprivation was not a prerequisite for the pestilence to devastate entire populations.

One issue that remains to be addressed is the possible existence of differences between the mortality rates of "milk-deficient" communities and "cattle plague-free" populations in Europe. So far, the available data suggest that the plague was equally devastating in the North and the South; recent estimates of mortality rates suggest similar figures for different parts of Europe. The methodology behind these estimates, however, is not without flaws. For example, it largely views the difference between pre- and post-Black Death populations within particular communities as a death-rate indicator without accounting for possible population loss through migration. Moreover, additional new archival and hitherto unpublished sources need to be collected, processed, and analyzed to reconstruct more reliable geographical patterns of mortality rates. Milk deficiency could be just one of several factors contributing to the high mortality rates of the Black Death. The chronic deficiency of dairy products and of all the vital vitamins that derived from them is an undeniable fact. The paleoepidemiological evidence

Empire (Aldershot, 2004), 155–161; Michael C. Latham, "Human Nutrition in the Developing World," *Food and Nutrition Series, XXIX* (New York, 1997), 127–146.

presented in this article suggests that this nutritional detriment helped to create a frail generation that was ill-equipped to withstand the disease. But this proposed connection between the three bioecological disasters of the first half of the fourteenth century, which is based for the first time on a broad interdisciplinary approach, must await additional research about not only the early fourteenth-century crisis but also the complex interactions between humans and their natural environment.[22]

APPENDIX 1: AGGREGATE MILK OUTPUT LEVELS IN ENGLAND, 1318–1350

All of the estimates in this article are based on the following assumptions, deriving from manorial accounts, peasant livestock inventories, and the scholarly literature. We distinguish between two sectors—the demesne (seigniorial) and the tenancy (peasants')—with respect to the population size of dairy animals.

Demesne Of the total number of cattle, 200,000, 76,500 were dairy cows (65 percent of cows were dairy and 35 percent beef), and 11,000 were two-year-old heifers. Of the total number of sheep,14.87 million, 5.2 million were ewes, and 744,000 were gimmers. Of the total number of goats,14,000, 5,000 were dams.

Tenancy Of the total number of cattle, 1.625 million (based on the assumption that each household held, on average, 1.77 cattle), 658,000 were dairy cows (75 percent of cows were dairy and 25 percent beef), and 104,000 were two-year-old heifers. Of the total number of sheep, 5.4 million, 1.89 million were ewes, and 270,000 were gimmers. Of the total number of goats, 46,000, 16,000 were dams.

In calculating the relative share of each cohort, we determined dairy cattle to equal 65 (demesne) and 75 (tenancy) percent of all adult cattle, two-year-old heifers to equal 16 percent of all immature cattle, ewes to equal 35 percent of all ovids, milk-yielding gimmers to equal 5 percent of all ovids, and dams and immature does to equal 35 percent of all caprids.

Milk Yields (Annual) The milk yield of cows was 100 gallons; heifers 75 gallons; sheep 10 gallons; gimmers 7 gallons; dams 18 gallons; young does 14 gallons. We determined sterile animals to comprise 6 percent of the total. A further 10 percent were assumed to have been wasted on lamb feeding and spoilage.

Human Population Change All of the estimates were based entirely upon Stephen Broadberry, Bruce M. S. Campbell, Alexander Klein, et al., "English Economic Growth, 1270–1700," working paper (University of Warwick, 2011), who suggest 4.75 million for 1290 and 4.12 million for 1325.

Animal Population Change Estimates Cattle population change for both the demesne and non-demesne sectors derives from the manorial-accounts sample, with the assumption that restocking rates within both sectors were similar, determined by the total availability of healthy animals in the markets. Sheep population change for the demesne population derives from the manorial-accounts database; for the non-demesne sector, it is assumed to have remained constant. The goat population within both sectors is assumed to have stayed constant.

22 Ole J. Benedictow, *Black Death, 1346–1353: The Complete History* (Woodbridge, U.K., 2004), 245–384.

APPENDIX 2: PRELIMINARY ESTIMATES OF MEAT CONSUMPTION BY PEASANTS ON THE EVE OF THE CATTLE PESTILENCE

Meat intake derived from cattle, sheep, pigs, and poultry. Horseflesh consumption was was forbidden by all three Abrahamic religions; it occurred only in the famine years. Game meat (rabbits, hares, and pheasants) was rarely consumed by lower social echelons. Approximate meat consumption by peasants is estimated after a deduction of calories consumed by nonrural consumers—religious houses, the aristocracy, the gentry, and the townsfolk. Around 1318, there were about 14,000 male clergy (both secular and religious) and 3,000 nuns, in addition to 42,000 nobles and gentry (given a denominator of 4.5 per each household). We assume that every clerical and noble male was offered a daily meat portion worth 2,500 kcal; the comparable figure for females would be about 1,800 kcal (for both sexes, only about half of the offered meat would have been eaten). About 64 percent of the meat was beef/veal and mutton/lamb; pork and bacon contributed a further 16 percent and poultry an additional 20 percent. Town dwellers constituted about 10 percent of England's population at that time; their consumption levels are assumed to have been similar to those of the rural population (see below). We conservatively estimate about 3.7 million peasants in England and an average peasant is presumed to have consumed about 2,000 kcal a day—a higher figure than proposed by Broadberry et al.[23]

Beef and Veal Consumption Approximate levels of annual beef consumption are based on the notion that on the eve of the cattle pestilence, the total number of mature cattle destined for consumption was about 400,000—67,000 oxen (out of the total 610,000), 250,000 beef cattle, and 82,500 dairy cows (out of the total 750,000). To this aggregation, we add 14,400 bullocks, heifers and yearlings, out of the total 360,000 immature cattle. Finally, each year about 1,086,000 cows were expected to birth 815,000 calves (calving rates were about 75 percent), before 285,000 of the mothers were slaughtered and converted into veal. Together, these animals may have yielded about 109,874 giga-calories per year, of which, after the deduction of calories for the aristocracy, religious houses, and (more modestly) town dwellers, only about 83,678 giga-calories would have remained for peasants. Thus, we arrive at about 22,600 kcal per capita per year (83,678 giga-calories/3.7 million consumers), enough to sustain one person for about eleven days per year (allowing a daily 2,000 kcal per capita).

Mutton and Lamb Consumption Around 1318, there were about 15 million sheep—including 11.4 million mature wethers, ewes, and rams—of which each year 2.05 million adult sheep were slaughtered and eaten. To this total we add 180,000 immature hogasters and gimmers, of which about 18,000 were slaughtered. Each year, about 5.13 million lambs were expected to be born from 5.7 million ewes (lambing rates were around 90 percent), about 1.59 million of which were culled and eaten while the remainder was kept in stock. These animals would have contributed another 67,047 giga-calories a year, of which 45,133 giga-calories may have been consumed by peasants—equal to about 12,200 kcal per person per year, enough to sustain one peasant for no more than six days.[24]

Pork Consumption Pigs, even though considered quintessentially peasant animals, were not consumed in considerable quantities. Our assumption is that England had about 1.3 million swine on the eve of the cattle pestilence. Each year, about 670,000 pigs, mostly mature porkers and baconers, were eaten, yielding approximately 36,150 giga-calories. Although the aristocracy seems not to have favored pork, they ate it nevertheless. After a deduction of pork intake

23 Broadberry et al., "English Economic Growth, 1270–1700," 51. Unless otherwise indicated, the sources for the data to follow in this Appendix are Slavin, MAME (Manorial Accounts of Medieval England) Database (in progress); *idem,* PIME (Peasant Inventories of Medieval England) Database (in progress).

24 Broadberry et al., "English Economic Growth, 1270–1700," 38.

by noble households, religious institutions, and townspeople, about 24,933 giga-calories a year, or about 6,740 kcal per capita, remained enough to sustain one peasant for three or four days.

Poultry Consumption The demesne sector appears to have stocked about 150,000 geese, 300,000 chickens, and 75,000 capons (castrated roosters) c. 1318. An estimate for the tenancy sector presents a greater problem, because of the scarcity of documentation. The available evidence, patchy as it is, indicates no more than five geese, seven chickens, and four capons per family, adding another 4.35 million geese, 6.09 million chickens, and 3.48 million capons to the total. Since few peasant households were likely to have kept ducks, calories from this fowl were too few to be reckoned. Fowls may have yielded a total of about 91,702 giga-calories, of which about 73,146 giga-calories were consumed by peasants, which would have provided an additional 9 or 10 days of meat consumption.

Combining all of the figures, we roughly estimate that meat contributed about 61,000 kcal to the annual food intake of each rural consumer, enough to sustain him/her for just one month—about 8.4 percent of the daily calorific intake. a level considerably lower than that afforded by higher social classes. Obviously, these crude estimates are subject to challenge and revision, but they are a starting point for continuing explorations into patterns of food consumption in late-medieval England.