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# Detecting plague: palaeodemographic characterisation of a catastrophic death assemblage

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*The archaeological definition of a plague should be possible from skeletal populations, because the age profile of a population afflicted by a catastrophe will be different to that of a community exposed to a more normal mortality. The authors show how this can be done using a Bayesian statistical analysis.*

*Keywords:* Black Death, Bayesian statistics, skeletal ageing, mortality

## Introduction

The palaeodemographic signatures of epidemics are of perennial interest to biological anthropologists. It has been demonstrated that patterns of human mortality generally demonstrate a high degree of uniformity across populations (Paine 2000: 181). This is referred to as *attritional mortality* and is characterised by a high number of infant deaths, low numbers of adolescent deaths and a gradual increase in mortality throughout adulthood. By contrast, an episode of *catastrophic mortality* refers to a short-term mortality crisis in which a high risk of death applies to all age categories. The identification of catastrophic as opposed to attritional mortality profiles in archaeological samples of human skeletons clearly has important social and palaeopathological implications (Paine 2000). A catastrophic mortality profile should mimic the age structure of the living population because all individuals have an approximately equal probability of dying irrespective of age or sex (Keckler 1997). Catastrophic mortality is almost by definition unusual, as a population subjected to frequent episodes of catastrophic mortality would rapidly become extinct.

The bubonic plague is an example of a disease that can cause catastrophic mortality because it is highly infectious and has a high case-fatality rate when untreated. Currently the demographic effects of pre-modern catastrophic events, such as the 'Black Death' plague that affected England in AD 1348-1350, are poorly understood. While the bubonic plague is strongly implicated as the cause of the Black Death, the event occurred prior to the detailed recording of mortality, and it is not known whether this plague episode resulted in a characteristic demographic signature that can be detected in samples of skeletal remains.

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The aim of our study was to examine the demographic structure of a sample of human skeletal remains that represent some of the victims of the 1348 plague, to test whether the skeletal sample exhibited a catastrophic age structure.

## The Black Death

The Black Death swept from China and across Europe during the fourteenth century, causing devastating mortality. The 'Great Mortality' or 'Great Pestilence' (as it was referred to then) reached England in AD 1348. This plague episode, like the Great Plague of 1664, is generally believed to have been bubonic and possibly pneumonic plague, caused by the bacterium *Yersinia pestis*. The DNA of this organism has been identified from the dental pulp cavity of individuals excavated from a contemporary plague pit in France (Drancourt *et al.* 1998; Raoult *et al.* 2000; but see Wood & DeWitte-Aviña 2003 and Mackenzie 2003 for critiques of this evidence). In bubonic plague the bacterium has an incubation period of approximately 2 to 8 days. Onset is acute with high fever, prostration and a characteristic infective lesion at the lymph nodes known as a bubo. In the pre-modern era there were no effective antibiotic treatments and the disease may have had a mortality of greater than 50 per cent (Benedictow 1987). Bubonic plague is a complex disease because it is primarily a zoonotic infection transmitted from animals: humans are incidental victims.

Some authors have questioned the interpretation of the Black Death as an outbreak of bubonic plague on the grounds that *Yersinia* infection could not have caused such massive and rapid mortality (Twigg 1984; Karlsson 1996; Scott & Duncan 2001; Wood *et al.* 2003). 'Plague' was (and still is) a generic word used to describe almost any fatal outbreak of disease. Contemporary descriptions tend to be embroidered, impressionistic affairs that hinder accurate diagnosis. This, coupled with the shortage of accurate mortality statistics, raises a number of epidemiological questions (Ell 1984). What is known is that from its port of entry in Dorset, the plague spread rapidly through England and reached London by 1348, finally abating in 1350. Estimates of mortality vary widely and the most often quoted figure is that one third of the total population of Western Europe died between 1346 and 1350 (McNeil 1976). Actual mortality varied greatly from place to place and is usually estimated at 20-50 per cent (Poos 1981; Frank 1999).

Epidemics due to new infectious diseases may emerge due to the introduction of an infectious pathogen into a population with no prior immunity or from the mutation of an existing pathogen into a more virulent form. When new diseases arise they can initially have a catastrophic effect upon a population (Ampel 1991). Virulence tends to diminish over time, however, as a result of changes in both the pathogen and host. As a result, epidemics are frequently viewed as cyclical in nature, beginning when a new disease emerges (Ampel 1991). With respect to the Black Death several authors have argued that the speed and virulence with which the disease spread, in particular across great expanses of country, are not compatible with the traditional rat-flea vector model of bubonic plague (Scott & Duncan 2001). It is argued instead that contemporary descriptions and evidence concerning the spread of the plague are more consistent with infectious diseases passed on from person

to person. Famine, typhus and anthrax have been postulated as the causes of the 'Great Mortality' (Twigg 1984, 1993). It is possible, and indeed quite likely, that diseases such as typhus were concurrent with the plague as famine and disease were already ravaging England throughout the fourteenth century (Wills 1997). In the plague epidemic of 1630 in Venice, smallpox was also prevalent and accounted for a significant number of the deaths (Ell 1989). In sixteenth- and seventeenth-century England bubonic plague and typhus alternated seasonally, and the Black Death may also have consisted of a similar alternation (Shrewsbury 1971: 125).

Clearly there are many unanswered questions and gaps in our knowledge of the Black Death. This is exacerbated by a lack of knowledge concerning the demographic impact on the affected population. However, the high mortality in the Black Death, coupled with the evidence that few communities escaped its effects, suggests that study of a contemporary cemetery may reveal the demographic signature for this episode of mass mortality. This paper presents a demographic analysis of age at death information obtained by the authors from a skeletal assemblage excavated from contexts interpreted as mass burial trenches associated with the Black Death in London.

## **The archaeological data: London and the Black Death**

Contemporary documents state that mass graves were constructed in a number of cities during the time of the Black Death (Creighton 1891). The only two to have been excavated in England are from Hereford Cathedral (Stone & Appleton-Fox 1996) and East Smithfield in London (Hawkins 1990). It is the latter site that provides the focus of this analysis. The mortality of London during the time of the Black Death was estimated at 20 000-30 000 (Creighton 1891), approximately one third to one half of the city's population. The relatively crowded living quarters of the citizens and the thriving rat population of cities are likely to have facilitated the spread of the disease more than in rural areas. When the disease was at its peak the demand placed on churchyards would have been overwhelming. In order to reduce the pressure on the severely affected London parishes, two cemeteries were established on the northern and eastern outskirts of the city (Grainger & Hawkins 1988; Hawkins 1990: 637). One of these cemeteries, the Royal Mint site (known in the fourteenth century as the Churchyard of the Holy Trinity), was excavated in the 1980s in advance of development (Hawkins 1990). The site lies to the north-east of the Tower of London and documentary sources show that the cemetery was selected in 1349 as an emergency burial site for plague victims. Historical records for the site are complete and none refer to the use of the grounds for burial of later plague victims (Hawkins 1990: 638).

Excavations revealed that only a small proportion of the total area had been used for burial, indicating that the epidemic abated before it became necessary to use the total area allotted (Hawkins 1990). The excavated portion of the cemetery consisted of 3 mass burial trenches and 15 grave rows; almost all burials were supine and orientated west-east (Figure 1). A total of 761 skeletons were excavated from the site, of which 600 individuals were analysed in the original skeletal report (Waldron 2001). It is estimated that the total number of burials at the site was originally in the region of 2400 individuals: many burials had been truncated by later activities on the site, and some burial features were only partially excavated



Figure 1. Excavations at the Royal Mint Site, East Smithfield, London (courtesy of MoLAS).

(Hawkins 1990: 640). There was no noticeable segregation within the trenches by age or sex.

## Age at death

A previous study of the Royal Mint data used conventional ageing methods to produce a mortality profile (Waldron 2001). An examination of Waldron's data by Margerison and Knüsel (2002) showed that this profile exhibited more young adults than would be expected from a catastrophic skeletal assemblage. However, deriving estimates of age at death from adult skeletal remains has been found to be problematic because conventional ageing methods suffer from inherent statistical biases. As a result of these biases, the age distributions of samples of archaeological skeletal remains tend to exhibit too many adults in the middle decades of life (Bocquet-Appel & Masset 1982, 1985; Molleson & Cox 1993).

In order to identify age-related patterns from the archaeological funerary record, it is vital that reliable and unbiased estimates

of skeletal age at death are achieved. Recent work has demonstrated that Bayesian statistics can be used to remove reference sample bias and to obtain more reliable age estimates (Konigsberg & Frankenberg 1994; Lucy *et al.* 1996; Aykroyd *et al.* 1997, 1999; Konigsberg *et al.* 1997; Hoppa & Vaupel 2002). Bayesian data analysis allows us to make inferences from data using probability models for observable quantities and for quantities that are unknown, but we wish to learn about (Gelman *et al.* 1995: 3). It essentially provides a formal framework whereby we may quantify and state our scientific preconceptions (Grayson 1998: 331). The application of Bayesian statistics in archaeology has primarily focused on dating techniques (e.g. radiocarbon) (Buck *et al.* 1996). However, several studies over recent years have also demonstrated the value of a Bayesian approach for addressing statistical biases associated with palaeodemography (e.g. Chamberlain 2000; Gowland & Chamberlain 2002; Hoppa & Vaupel 2002). This study uses a Bayesian approach to estimate adult skeletal age at death from the auricular surface (the part of the skeleton where the base of the spine meets the pelvis) and the pubic symphysis (where the two halves of the pelvis meet at the front). These methods were then applied to two archaeological skeletal samples: the Royal Mint site in London and a control sample, the attritional cemetery of Blackgate in Newcastle which is of similar size and of comparable date.

Table 1. Known age auricular surface data. Specimens of known age were assigned to one of eight morphological categories ('states') according to the criteria described by Lovejoy *et al.* (1985). The data are the numbers of individuals in each age category of the reference sample who exhibit a particular auricular surface state

Age	State								Total
	1	2	3	4	5	6	7	8	
16-24	35	12		1			1	1	50
25-34	7	21	18	21	6	6	3		82
35-44		10	10	19	9	18	5	3	74
45-54		3	9	15	29	17	5	4	82
55-64	1	1	2	10	13	17	21	3	68
65-74				12	9	13	16	5	55
75-99				4	4	4	21	9	42
Total	43	47	39	82	70	75	72	25	453

Table 2. Known age pubic symphysis data. Specimens of known age were assigned to one of six morphological categories ('states') according to the criteria described by Brooks and Suchey (1990). The data are the numbers of individuals in each age category of the reference sample who exhibit a particular pubic symphysis state

Age	State						Total
	1	2	3	4	5	6	
16-24	33	10	2				45
25-34	4	10	21	22	5	2	64
35-44		4	7	31	14	6	62
45-54		3	5	25	17	17	67
55-64			1	11	19	24	55
65-74			2	6	14	26	48
75-99		1		2	9	24	36
Total	37	28	38	97	78	99	377

## Ageing method

In order to produce a Bayesian ageing method, a large sample of known age auricular surface and pubic symphysis data is required so that we may produce a probability model to determine age at death given a skeletal indicator state. The required data were compiled from reference skeletons of known age of death collected from the Coimbra Identified Skeletal Collection, Portugal and the Spitalfields skeletal collection, London. Known age data from the auricular surfaces of 453 individuals (Table 1) and pubic symphyses of 377 individuals (Table 2) were obtained. The auricular surfaces and pubic symphyses were recorded using the stages described by Lovejoy *et al.* (1985) and Brooks and Suchey (1990) respectively. This information was then used as a source of likelihoods (the probability of possessing a particular skeletal indicator stage given known age). These likelihoods were then

inverted to provide probabilities of age given each skeletal indicator stage using a Bayesian calculation.\*

An important component of Bayesian statistics is the use of prior probabilities. In this context, the prior probability represents an opinion of the probability of being a particular age before any data have been observed. By using a prior probability we are explicitly stating our prior beliefs concerning the data. For example, when producing the demographic profile of a 'normal' cemetery (i.e. one used for the burial of natural deaths over a long time period) we would expect a natural attritional mortality. We can therefore incorporate our prior beliefs into our probability model (Gowland & Chamberlain 2002).

In the use of Bayesian statistics the choice of prior is important as it will impact upon the results, particularly so for those skeletal indicators that have a poor correlation with chronological age (Aykroyd *et al.* 1997). As a result, two different model priors were used in this study, one representing natural attritional mortality and the other catastrophic mortality (i.e. the age structure of the living population). The data for these priors were obtained from Coale and Demeny's level 5 model west life tables for stable populations with zero rate of growth (Coale & Demeny 1983). The probabilities of age given indicator state were then used to obtain age distributions from the adult archaeological skeletal remains from both the Royal Mint and Blackgate cemeteries.

Our approach to the choice of prior probabilities differs from the recommendations of Hoppa and Vaupel (2002: 6). The latter authors recommend that prior probabilities can be inferred from the frequencies of age indicator states in the target sample, but we avoid this procedure because it may be unduly influenced by taphonomic effects and recovery bias (Chamberlain 2003: 642). Instead we have chosen to base our prior probabilities on the Coale and Demeny model life tables which provide good models for pre-industrial populations and have been extensively used in palaeodemography (Chamberlain 2000: 103).

## Results

The auricular surfaces of 180 adults from Blackgate and 132 adults from the Royal Mint site were sufficiently preserved for scoring. The pubic symphyses of only 84 individuals from Blackgate and 70 individuals from the Royal Mint site were preserved. The pubic symphysis tends not to be as well preserved in archaeological specimens as it is more fragile and its position when the skeleton is supine is more susceptible to mechanical disturbance. Age distributions for the Royal Mint and Blackgate cemeteries were obtained using the method outlined above and adopting both the catastrophic and attritional priors in turn. When using the catastrophic prior we see that the age distribution obtained from the Royal Mint cemetery differs markedly from the Blackgate cemetery (Figures 2 and 3). Furthermore, the Royal Mint site is remarkably similar to the catastrophic age at death profile obtained from the model life table, and differs substantially from the model life table attritional

\* According to Bayes' theorem:  $p(A_i|I_j) = p(I_j|A_i) \times p(A_i) \div p(I_j)$ . In this equation 'A' represents age and 'I' represents skeletal indicator (e.g. auricular surface). The notation  $p(A_i|I_j)$  represents the probability of being in age category  $i$  given the particular skeletal indicator state  $j$  and in Bayesian statistics this is referred to as the 'posterior probability'. The probability of possessing a particular indicator state given age, shown in the equation as  $p(I_j|A_i)$ , is referred to as the 'likelihood', as it is the conditional probability of possessing indicator state  $j$  given a particular age category  $i$ . The overall probability of possessing a particular indicator state is represented by  $p(I_j)$ .

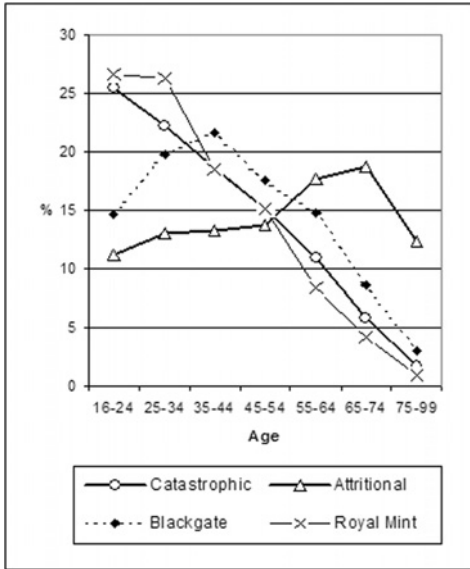


Figure 2. Age at death profile using the auricular surface and catastrophic priors.

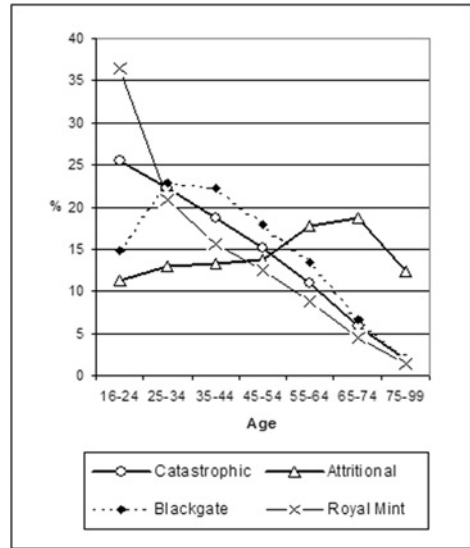


Figure 3. Age at death profile using the pubic symphysis and catastrophic priors.

profile. By contrast, the Blackgate cemetery exhibits an age at death distribution more akin to the attritional profile. Age distributions were comparable when age estimations were obtained using either the auricular surface or pubic symphysis. To ensure that these results were not biased as a result of the choice of prior, the same analyses were undertaken using an attritional prior (Figures 4 and 5). In this instance, the Royal Mint site still demonstrated a catastrophic age-at-death profile while the Blackgate site shows an age distribution that is almost identical to an attritional population. This similarity is remarkable given the potential biases in skeletal preservation (e.g. Walker *et al.* 1988; Paine & Harpending 1998) and the inherent imprecision of skeletal ageing techniques. Again, similar patterns of age distributions were obtained when using either the auricular surface or pubic symphysis.

## Discussion

When these data are compared to the original mortality profile obtained for the site (Figure 6), the biases in the use of conventional techniques can clearly be seen. Waldron (2001) obtained a very pronounced peak in the original analysis between the ages of 25 and 45 years. This peak is commonly observed in archaeological cemetery populations and, as demonstrated here, is eliminated when the biases in conventional skeletal age estimation techniques are removed using Bayesian statistics. These results strongly suggest that the Royal Mint cemetery exhibits a catastrophic mortality pattern as a result of the Black Death plague. Results suggest that all adult age groups, both young and old, were equally affected by the plague. By contrast, the Blackgate cemetery produced an attritional mortality profile, as one would expect from a burial population during non-catastrophic conditions.

Although no detailed documents relating to Black Death plague mortality exist, it is possible to make a comparison between the results obtained here and later plague



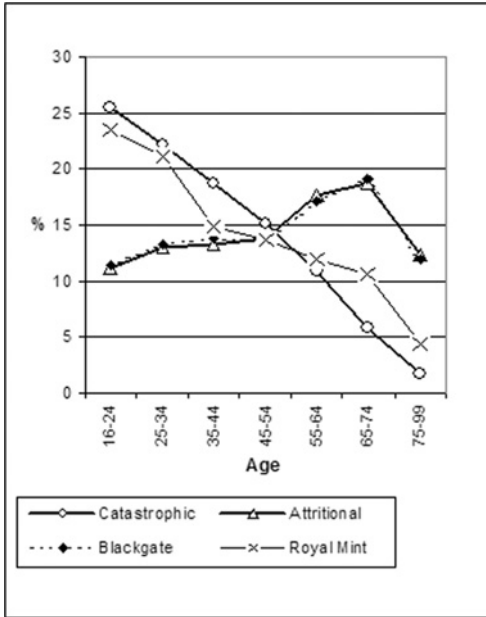


Figure 4. Age at death profile using the auricular surface and attritional priors.

epidemics in London. Detailed records are available from the parish of St Botolph in London during two plague episodes (Hollingsworth & Hollingsworth 1971) and in Venice in 1630 (Ell 1989). These historically documented plague episodes produce a similar catastrophic mortality profile as represented by the Coale and Demeny (1983) level 5 living age structure for zero growth rate (Figure 7). St Botolph has slightly more children and fewer adults, showing a close match with a level 5 living age structure for a population growing at 3 per cent, which is the estimated growth rate given during this time. The mortality at the parish of St Botolph in non-plague years also corresponds well to the attritional mortality expected from level 5 mortality (Figure 8). Therefore, the results from the Royal Mint site also correlate well with those expected from historical mortality records of later plague episodes in the same city.

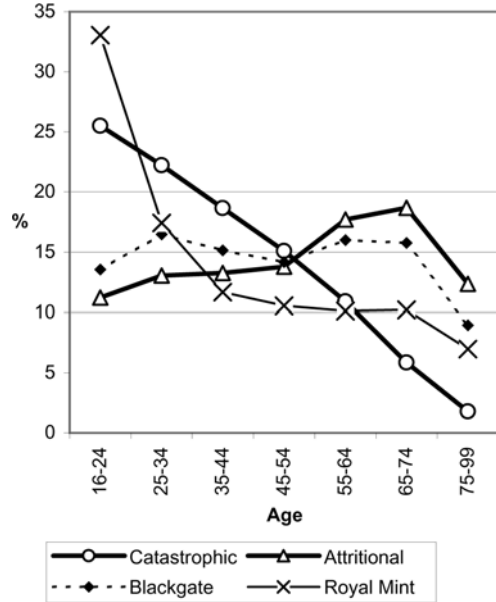


Figure 5. Age at death profile using the pubic symphysis and attritional priors.

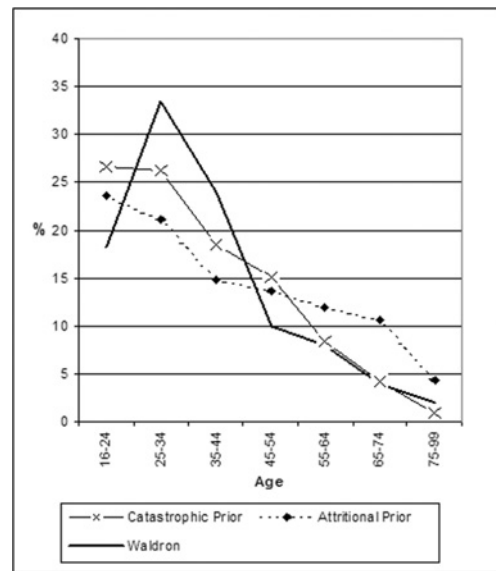


Figure 6. Comparison of mortality distributions obtained from the Royal Mint site using prior probabilities with the data obtained by Waldron (2001) using conventional ageing techniques.

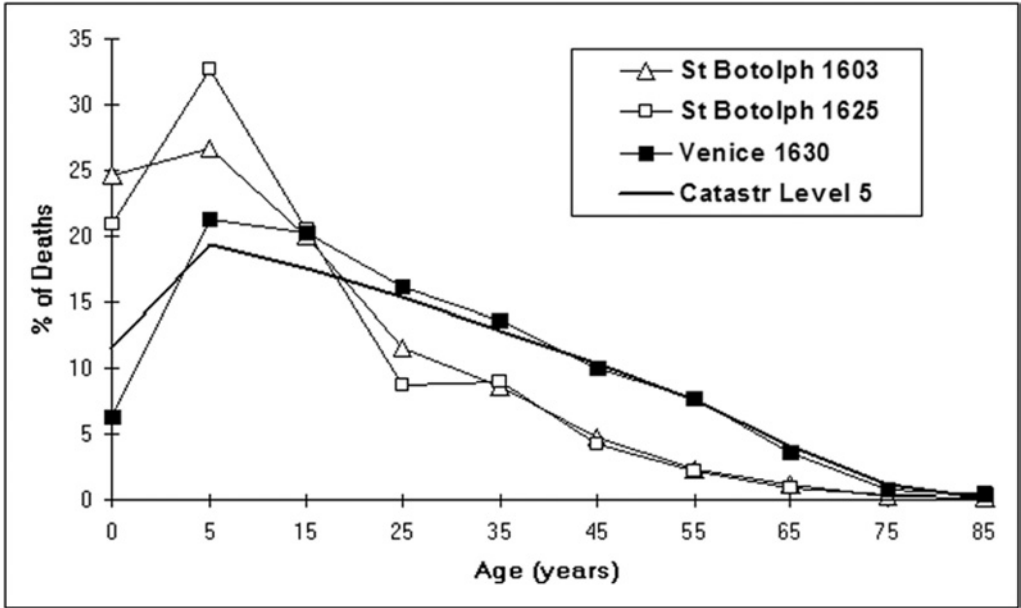


Figure 7. Comparison of historically recorded mortality distributions for several plague episodes and a catastrophic mortality distribution.

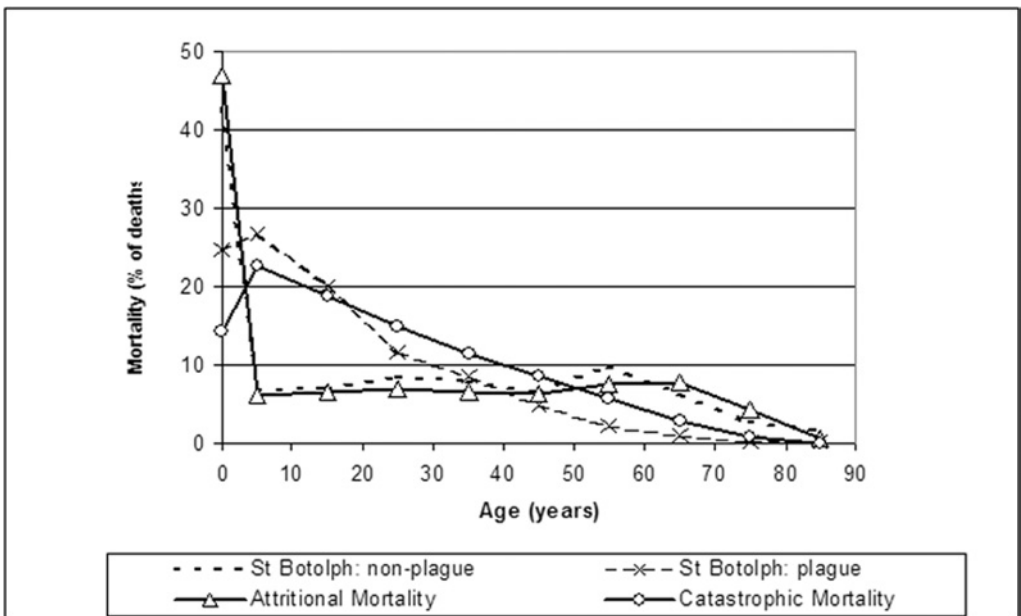


Figure 8. Historically recorded mortality for St Botolph during plague and non-plague years.

## Conclusion

This paper has examined the palaeodemography of a Black Death plague cemetery excavated from the Royal Mint site in London and has compared it to that of a contemporary attritional cemetery. We concur with Margerison and Knüsel (2002: 139) that the skeletal assemblage from the Royal Mint site represents an episode of catastrophic mortality, but we believe that the discrepancies that those authors noted between the model catastrophic profile and the skeletal age profile are attributable to biases in skeletal age estimation. We believe that by adopting a Bayesian methodology we have produced a more reliable demographic profile of the Royal Mint site, and that the age structure of the skeletal assemblage is comparable to that indicated by historical records of later plague events and with living population age structures taken from model life tables. The Royal Mint sample differed markedly to the mortality profile of a contemporary attritional cemetery where age at death was estimated using an identical methodology.

This study offers corroboration of contemporary historical evidence for the severe mortality of the Black Death, and our procedure has the potential to be applied to other Black Death cemeteries and to other hypothesised catastrophic mortality assemblages from earlier time periods. In broader terms, the application of this approach may enable us to assess the contribution that catastrophic mortality makes to the demography of past societies.

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