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The Under-Appreciated Rodent: Harbingers of Plague From the Middle Ages to the Twenty-First Century

The social and interdisciplinary history of morbidity and mortality, of death and disease, is a relatively recent phenomenon, emerging in the 1970s with the *Bulletin of the Social History of Medicine* (1970)—reborn as *Social History of Medicine* in 1987—roughly coeval with the *Journal of Interdisciplinary History*. Shrewsbury's magisterial *History of Bubonic Plague in the British Isles* was also published in 1970, and Lebrun's *Les hommes et la mort en Anjou aux 17ième et 18ième siècles*, which appeared in 1971, arguably set the study of death and disease on a new track. In the years following, the historiography of the Black Death has flourished, and the history of morbidity and mortality has become an important area of historical expertise in its own right.[1]

In this literature, the agents of disease themselves, rather than their involvement with, and impact on, human societies, have been conspicuously absent. Zinsser's classic *Rats, Lice and History* (Boston, 1935), for example, centered on *Rickettsia prowazeki*, the causal organism of typhus, not on the rat itself. Among the rich and varied scholarly contributions to the pages of the *JIH*, four articles concern the medieval Black Death, and three treat plague in other centuries. In the first group, the ones by Davis and McCormick downplay the importance of rats. Davis doubted the role of the black rat, arguing

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1 I am grateful to Robert Rotberg for coining the phrase "the under-appreciated rodent." John F. D. Shrewsbury, *History of Bubonic Plague in the British Isles* (New York, 1970); François Lebrun, *Les hommes et la mort en Anjou aux 17ieme et 18ieme siècles: essai en demographie et psychologie historique* (Paris, 1971).

that it is a shy, ship-dependent, and diurnal rodent that existed in small numbers in the fourteenth century, and McCormick, working with improved archaeological techniques after the revolution in modern technologies, challenged the view that ship-borne rats distributed the disease through Europe, arguing instead for land-based travel via grain wagons.[2]

Dean et al. recently argued, based on a study of demographic data from nine European cities, that a human parasite model is a much better fit for the pattern of the fourteenth-century outbreak. However, Stenseth, director of the Centre for Ecological and Evolutionary Synthesis at the University of Oslo, who contributed to the study of Dean et al., also maintained that gerbils, not rats, are to blame for the Black Death, although gerbils, which are native to Africa, Asia, and India, did not arrive in Europe until the nineteenth century. The first identification of rats as the agents of plague transmission came after the 1894 Hong Kong outbreak, which prompted the British public-health authorities to monitor plague cases on ships. In the United States, San Francisco's Board of Health recommended the rat-proofing of buildings as a precaution against plague after the determination that ship rats had infected the local rodent population with *Yersinia pestis* c. 1900. Taking Davis' and McCormick's Black Death contributions as a starting point, this article stands in opposition to the recent historiography and focuses instead on the rat as an under-appreciated contributor to human history.[3]

2 The articles concerned with the Black Death in the *JIH* are David E. Davis, "The Scarcity of Rats and the Black Death: An Ecological History," XVI (1986), 455–470; Michael McCormick, "Rats, Communications, and Plague: Toward an Ecological History," XXXIV (2003), 1–25; John Theilmann and Frances Cate, "A Plague of Plagues: The Problem of Plague Diagnosis in Medieval England," XXXVII (2007), 371–393; Sharon DeWitte and Philip Slavin, "Between Famine and Death—England on the Eve of the Black Death—Evidence from Paleopathology and Manorial Accounts," XLIV (2013), 37–60.

3 Katharine R. Dean et al., "Human Ectoparasites and the Spread of Plague in Europe during the Second Pandemic," *Proceedings of the National Academy of Sciences*, available at www.pnas.org/content/early/2018/01/09/1715640115 (accessed April 1, 2019). For a counterargument, see San Woo Park et al, "Human Ectoparasite Transmission of the Plague during the Second Pandemic Is Only Weakly Supported by Proposed Mathematical Models," *ibid.*, available at www.pnas.org/content/115/34/7892. For a history of the view that rats did not play a causal role, see Monica Green, "On Learning How to Teach the Black Death," available at https://www.academia.edu/36171431/On_Learning_How_To_Teach_the_Black_Death_2018 (accessed April 1, 2019). For Nils Christian Stenseth et al., see https://www.history.com/news/scientists-blame-gerbils-not-rats-for-the-black-death (accessed July 10, 2019); Vernon B. Link and Theodore M. Bauer, *A History of Plague in the United States*, Public Health Monograph 26 (Washington, D.C., 1955), 10.

Plagues do not belong solely to the past; emerging and re-emerging infections have become an important strand of medical interest in the years since 1990. New infections either arose or were identified on several occasions following the recognition of the Marburg virus in 1967, but the general view remained that serious infectious diseases were a thing the past. The shock arrival of HIV/AIDS as a major epidemic in the 1980s marked an ominous step in a new progression that threatened to surpass the virulence of the largely controlled infections that predated it. In November 1993, Berkelsman and Hughes of the Centers for Disease Control published an editorial in *Annals of Internal Medicine* that threw into question the notion that infectious diseases were no longer a threat. Less than a year later, the sudden explosion of epidemic bubonic plague in the Indian states of Maharashtra and Gujarat in September 1994 underscored the point, seeming to mark the return of a globally legendary disease. Since India had not confirmed any human case of plague for decades, the event acted as a catalyst for concerns about existing vulnerabilities around the world. Since 1994, bubonic plague and its infamous perpetrator, the rat, have remained a constant presence in the consciousness of all those who study and treat infectious diseases.[4]

The Black Death of 1347 to 1353 stands out in history as the quintessential emergent infection, appearing almost out of nowhere and sweeping lethally across the European world to become the stuff of legend. Yet although Davis and McCormick sought effectively to dismiss the role of the rat in generating that plague, and scholars still question it, a trawl through the wider extant literature about rats and the history of bubonic/pneumonic plague suggests that these arguments are misguided. In the case of the British Isles, the long-established popular nomenclature for black rats as "ship" rats (as well as "house" rats) derives from their presence aboard ships, some of them carrying grain along with other cargo, on short coastal routes. Plague could have reached the country via infected fleas traveling on humans (see below) or in

4 Ruth L. Berkelsman and James M. Hughes, "The Conquest of Infectious Diseases: Who Are We Kidding?" *Annals of Internal Medicine*, XIX (1993), 426–427; David T. Dennis, "Plague in India," *British Medical Journal*, CCCIX (1994), 893–894. The journal *Emerging Infectious Diseases*, published from January 1995, bears witness to the existence and vigorous growth of a scholarly community concerned with infectious diseases. It began as a quarterly publication before becoming bi-monthly in 1999 and monthly in 2002.

goods, but black rats themselves could not have reached Britain without traveling by ship. Now largely displaced by the brown or Norway rat (also known as the "wander" rat), black rats had established a presence in Britain well before the Black Death (see below); they are still to be found in the ports and port towns around Britain, especially in the environs and hinterlands of London, Cardiff, and Liverpool.[5]

Recent archaeological evidence from London tends to support Davis' argument for a vector other than the black rat for plague in the fourteenth century. Although rats certainly inhabited London and elsewhere in England both before and after the Black Death, the mass rat deaths that are known to accompany modern bubonic plague are not in evidence there, least of all in the thirteenth- to fourteenth-century waterfront dumps where they are expected to be. Nonetheless, an animal that prefers built structures (mainly houses and ships, as its nicknames suggest) as a habitat is arguably more likely to die invisibly within them, leaving no trace when those constructions are demolished. Few buildings and ships survive from the thirteenth century, certainly not the timber-framed, wattle and daub–walled dwellings in which most of the human population lived. The house mice within the walls of the British houses that have survived from the sixteenth century onward, whether made of lath and plaster or brick, usually die

5 For the plague's entry into England through the small port of Weymouth on the south coast and its conveyance inland via infected goods, see Ole Benedictow, *The Black Death 1346–1353: A Complete History* (Woodbridge, 2004), 126–128. According to the British Wildlife Centre, black rats entered the country with the Romans: https://britishwildlifecentre.co.uk/planyourvisit/animals/blackrat.html. As a possible indication of their slow spread across the country, W. R. Boelter, *The Rat Problem* (London, 1909), 8, suggests that the Norman Conquest of 1066 marked their entry, noting that in the Wales of his day, the black rat was still known as *Llgyodun Ffancon*, "the French mouse." For the rats' whereabouts in the ports, see the National Biodiversity Network (NBN) maps, available at https://species.nbnatlas.org/species/NHMSYS0000080213 (accessed July 19, 2018); for the import and re-export of grain into London to and from Europe in medieval England, James A. Galloway, "One Market or Many? London and the Grain Trade of England," in *idem* (ed.), *Trade, Urban Hinterland and Market Integration c. 1300–1600* (London, 2000), 23–42, 33; for the names and habits of the black rat, https://en.wikipedia.org/wiki/Black_rat. The introduction of the brown rat into Britain is often dated as c. 1750, but indisputable evidence places it in Europe at least from the sixteenth century. L. Fabian Hirst, *The Conquest of Plague: A Study in the Evolution of Epidemiology* (London, 1953), 123–124. Hirst (1882–1964) was bacteriologist to the municipal government of Colombo, Ceylon (Sri Lanka), from 1911 to 1915 and again from 1918 to 1934, having joined the Royal Army Medical Corps during World War I, serving in Egypt and Salonica. For aspects of his career, see http://gmic.co.uk/topic/63382-serbian-re-cross-decoration-great-war/?page=2 (accessed July 26, 2018), and William MacArthur's foreword to *Conquest*, v.

inside the walls or under the floors of these homes, not in the open. The same pattern could hold for the house/ship rat.[6]

Evidence from the British government's Indian Plague Commission (1905–1907) tends to confirm these observations. Both the black rat and the grey (brown) rat were "far and away" the commonest rodents in early twentieth-century Bombay. The black rat, represented in large numbers throughout the city, was described as "essentially a house rat; it may almost be called a domesticated animal, living and breeding as it does in the house where people live." Although "typically a climbing rat," it also burrowed into earthen floors and walls, and its nests were often found in "little-disturbed accumulations," such as cotton waste, stacks of firewood, etc., "and in recesses such as cupboards." Furthermore, the type of building that black rats favored typically had earthen floors and "country tiled roofs," were in disrepair, and contained "accumulations" of rubbish and food, stores of grain, etc. In contrast, grey (brown) rats lived mostly outside houses, "in sewers, storm water drains, stables etc," and nested in burrows, "even" forming extensive burrows in the walls and floors of buildings. They never ventured above the third floor of a house, preferring house compounds, stables, godowns (warehouses), and food and tea shops. The two species had a common meeting ground in gullies, the lower floors of houses, and warehouses.[7]

Housing conditions in 1900s Bombay must have closely resembled those of medieval settlements, with earthen floors on the bottom and wooden ones above and permeable walls in which black rats could establish themselves. Bombay authorities collected both live and dead rats, performing postmortems on more than 5,000 of the dead ones during this operation. The results were inconclusive. In a group of affected villages outside the city, the number of plague rats was "very small" in proportion to the severity of the epidemic, "notwithstanding the very thorough and extensive search made." This experience, as Lamb noted, "points to the danger of concluding that plague-rats are absent from an infected locality unless a very thorough search is carried out." Given these Indian observations, and the nature of fourteenth-century

6 Barney Sloane, *The Black Death in London* (Stroud, 2011), 183–184.

7 George Lamb, *The Etiology and Epidemiology of Plague: A Summary of the Work of the Plague Commission* (Calcutta, 1908), 9, 10.

house construction, the lack of evidence regarding mass rat deaths, even from the city of London, is hardly surprising.[8]

Recent historical scholarship indicates that London's inordinately high death rates from 1348 to 1353 were due to the pneumonic rather than the bubonic form of the disease. Advanced bubonic plague can spread to the lungs, causing pneumonic plague, and aerosolized droplets from persons with either form of plague can infect others. Pneumonic plague has a rapid incubation period: Death can occur within four days; untreated, it is usually fatal. The dramatic death rates in the City of London receive confirmation in the wills of wealthy citizens who died at this time, indicating a mortality rate of 55 to 60 percent. Material taken from London's East Smithfield burial ground in 2011 allowed researchers to sequence the *Yersinia pestis* genome, thus confirming the identity of plague as the cause of this epidemic and indicating that the strain that caused the Black Death was the ancestor of most modern strains of the disease. Crossrail excavations in 2013 London enabled a further archaeological investigation in Charterhouse Square, which revealed a plague cemetery containing a large number of skeletons, neatly buried in layers. Dental pulp examined with the latest ancient DNA methods again revealed *Yersinia pestis* as cause of death and testified to the pre-existing poor health status of the victims, which would have rendered them highly vulnerable to severe infection.[9]

Although this evidence lends substance to the role of human-to-human infection, it diminishes, though it does not totally undermine, the traditional role of the rat. Sources from the early twentieth century, when plague was still a serious concern for British colonial administrators, show that black rats were present

8 *Ibid.*, 15, 18.

9 For information about plague from the World Health Organization (WHO), see www.who.int/csr/disease/plague/en/ (accessed April 1, 2019); for the London wills, Sloane, *Black Death*, 103–110; for information about pneumonic plague, https://www.sciencedirect.com/topics/pharmacology-toxicology-and-pharmaceutical-science/pneumonic-plague; "New Findings Rewrite the Story of the Back Death," 30 March 2014, available at http://www.channel4.com/info/press/news/new-findings-rewrite-the-story-of-the-Black-Death (accessed July 19, 2018). Kirsten I. Boc et al, "A Draft Genome of Yersinia Pestis from Victims of the Black Death," *Nature*, 478 (October 27, 2011), 506–510. These findings confirm the conclusions reached by DeWitte and Slavin in "Between Famine and Death," using earlier findings from London material. The study of ancient DNA, pioneered in 1984, has advanced remarkably during the last decade.

in medieval Britain around the time of the Black Death, that they had been present in Europe since prehistoric times, and that human individuals can act as plague transmitters independently of black rats. Among other things, the Indian Plague Commission found that plague was "usually conveyed from place to place by imported rat fleas, which are carried by people on their persons or in their baggage. *The human agent himself not infrequently escapes infection*" (my italics). The upshot is that the Black Death may have reached Britain without the agency of rats in yet another way.[10]

Hirst—whose first-hand studies of plague as a microbiologist in Ceylon (modern Sri Lanka) between 1912 and 1934 gave him an eclectic knowledge of the history of his subject—contended, "The view that rats were scarce in the British Isles during the fourteenth century is untenable." Evidence produced in support of this statement included a quotation from Geoffrey Chaucer's fourteenth-century "Pardoner's Tale," in which a young rioter bought poison from an apothecary "that he might his ratouns quell." It also contains the observation that the Old High and Low German languages distinguished rats from mice, whereas "the Aryan group of languages [used] the same word ... for both." Hirst further noted that Ælfric (c. 955–c. 1010), first Abbot of the Benedictine monastery at Eynsham near Oxford, used the word "*raturus*," and a fifteenth-century Irish bishop is on record as having had his library destroyed by "*majores mures* more vulgarly called *rati*" ("large mice more vulgarly called rats").[11]

Hirst also found more concrete evidence of rats. He noted that "the record of the rocks" (fossil specimens) suggested that "a species of rodent closely resembling *Rattus rattus*" had existed in Europe since prehistoric times. He referred specifically to specimens found "near Geneva, in Lombardy, Bohemia and in Crete," as well as the "half-digested remains" of *R. rattus alexandrinianus* among the mummified remains of sacred birds in Egypt. Also to the point is Hirst's observation that "the free-wandering species of flea" common to the black rat is "far more likely to attack man when it deserts the cooling body of a plague rat" than is the nest-loving species generally found on the brown rat.[12]

10 Lamb, *Etiology of Plague*, 93.
11 Hirst, *Conquest of Plague*, 122.
12 *Ibid.*, 126, 124.

Sources from the late twentieth and twenty-first centuries can also provide clues to what might have happened in past bubonic plague outbreaks. An example from modern Madagascar, where plague is now endemic in the local rodent population, illustrates the ease with which transmission from human to human occurs, as well as the role that small rodents other than rats play in maintaining reservoirs of infection. In Madagascar, the rural shrew population, which still carries the infection without being affected by it, lives alongside black rats in the highlands and shares their flea species. Rats may also develop resistance to the plague bacillus, adding a further layer of complexity to the processes of infection and making plague impossible to eradicate. Until recently, plague infection was endemic in the island only on land over 800 meters above sea-level. In 2017, an individual infected with bubonic plague traveling by bus from the highlands to Antananarivo, the island capital, and then to the coastal city of Tamatave transmitted pneumonic plague to thirty-one of his fellow travelers, four of whom died, despite modern antibiotic treatment.[13]

As the Madagascar case demonstrates, and early twentieth-century observers confirm, rats are not needed for an outbreak of pneumonic plague; human travelers will do. What made the Indian epidemic of 1994 so "unexpected and dramatic" was not so much the outbreak itself as the form that it took. Both bubonic and pneumonic plague had already caused outbreaks in Myanmar, Vietnam, Tanzania, Zaire, Peru, and Madagascar in the 1990s, but none of them had aroused much international attention. The 1994 Indian epidemic, however, was different. Large numbers of dead rats and new cases of bubonic plague emerged in the Seed district of Maharashtra state, 300 miles east of Bombay, in September. By September 26, fifteen villages had suspect cases. Four days earlier, Surat, a port city in Gujarat state 300 miles north of Bombay—home to many migrant workers among its population of 1 million people—had reported pneumonic plague but no bubonic plague and no unusual rat deaths. This sequence was thought to result from epizootic plague in wild rodents spilling into the commensal

13 Pascal Boisier et al., "Epidemiologic Features of Four Successive Annual Outbreaks of Bubonic Plague in Mahajanga, Madagascar," *Emerging Infectious Diseases*, VIII (2007), 311–315; Suzanne Chauteau et al., "Plague, a Re-Emerging Disease in Madagascar," *ibid.*, IV (1998), 102. For plague in 2017 Madagascar, see https://www.livescience.com/60715-plague-outbreak-madagascar.html (accessed July 10, 2019).

rodent population in Maharashtra, resulting in primary bubonic cases in humans with secondary pneumonic cases in workers returning to Surat. It is, again, suggestive of what might have happened in British ports in 1348 if uninfected plague-flea carriers, or incubating pneumonic cases, or even bubonic cases, had arrived on ship at the quaysides.[14]

Pneumonic plague normally requires close contact with a person already ill, but it also spreads through close contact with, or the eating of, sick animals, not necessarily rats. In the last, spasmodic, outbreak of plague in Britain, which occurred in Suffolk between 1906 and 1918, two initial cases derived from rabbits, one pneumonic (1906) and one bubonic (1911). Infected animal species identified around the affected parish of Freston in 1906 were rat, rabbit, hare, cat, and ferret. In the 1906 outbreak, the affected family had eaten a rabbit brought home by the householder for dinner shortly before the index case began; the 1911 victim had cut up a rabbit, slightly injuring himself in the process, before his illness developed.[15]

Herbert Bulstrode, the senior investigating officer for the 1910 outbreak, thought that this infection had most likely arrived with rats from the grain ships that brought cargo into the ports on the River Orwell from San Francisco, San Nicolas, Valparaiso, Rosario, and Alexandria. Van Zwanenberg, a twentieth-century medical commentator, however, thought it more likely to be sylvatic plague, noting that the disease had spread from China and Hong Kong in 1894 to many parts of the world, including the Scottish city of Glasgow in 1900 (where it killed sixteen people). In his view, it could have been an enzootic in the Suffolk area, only accidentally infecting individuals. Citing Hirst, he noted that sylvatic plague tended to be pneumonic, not bubonic. Reports of an "undue" mortality among rats at the time of the 1910 outbreak in humans, supported by subsequent local and bacteriological investigations, suggested that sylvatic plague had indeed established itself in the two rural districts of Samford and Woodbridge, which lay on either side of the Orwell River in Suffolk, and close to the Suffolk coast and the ports of Harwich and Felixstowe. These

14 Lamb, *Etiology of Plague*, 93; Dennis, "Plague in India," 893–894.

15 For how pneumonic plague spreads, see https://www.livescience.com/60715-plague-outbreak-madagascar.html (accessed July 10, 2019). David van Zwanenberg, "The Last Epidemic of Plague in England? Suffolk 1906–1918," *Medical History,* XIV (1970), 62–74.

cases, which demonstrated that plague infection was "fairly widespread" among rats and other rodents locally, triggered a vigorous campaign that killed more than 6,000 rats in the affected areas.[16]

The two histories from modern-day Madagascar and early twentieth-century Britain witness not just to the extreme infectiousness and fatality of pneumonic plague but also to the potential role of a wider range of animal carriers than the black rat. In crowded fourteenth-century ports, the number of rats sufficient to start a train of pneumonic infection can be small. Van Zwanenberg suggested that the Suffolk outbreaks might constitute the model for the behavior of plague in rural England, explaining the persisting infection in the country between 1350 and the late seventeenth century, which can be traced in burial registers and bills of mortality. The infection would have been impossible to detect if it had run its course as it did in Suffolk from 1906 to 1918; not until the opening of a bacteriological laboratory at Ipswich Hospital in 1910 were researchers able to diagnose this twentieth-century manifestation. Van Zwanenberg noted that conditions in early twentieth-century Suffolk did not differ much from those of the seventeenth century and that the Suffolk cases proved brown rats to be as capable of carrying the infection as black rats.[17]

The ability of plague to become established as an endemic infection in rodents and animals other than rats re-opens the question of endemic plague reservoirs, which has been in play since Twigg applied biological science to the role of the black rat in 1984. A recent scientific analysis that gives evidence of climate-driven re-introductions of the bacillus providing the dynamic of fresh epidemics does not find support for the existence of permanent plague reservoirs in medieval Europe. Yet, Carmichael demonstrated the presence of a rodent reservoir of plague among Alpine marmots in the sixteenth century. Furthermore, the evidence from

16 Zwanenberg, "Last Epidemic," 71,102. Useful details of the local circumstances are found in H. P. Sleigh, "Four Cases of Pneumonic Plague," *British Medical Journal*, 12 Nov. 1910, 1489–1490; Herbert H. Brown, "The Recent Cases of Plague in Suffolk," *ibid.*, 1490. Anon, "Plague in Glasgow," *The Lancet*, 22 Sept. 1900, 897–999. For the spread of plague in the 1890s, see Myron Echenberg, *Plague Ports: The Global Urban Impact of Bubonic Plague, 1894–1901* (New York, 2007). Hirst, *Conquest of Plague*, 192, 195–196; Sleigh, "Four Cases of Pneumonic Plague," 1489; Chief Medical Officer's Annual Report, *British Parliamentary Papers*, XXXII (1911), 14–55.

17 Zwanenberg, "Last Epidemic," 71–72.

early twentieth-century Suffolk—together with that of the modern United States; Hirst's descriptions of plague reservoirs among Russian marmots and ground squirrels, South African gerbils, and Argentinian cavies; and the endemic infection in shrews in present-day Madagascar—suggest that sylvatic reservoirs persisted in Europe as elsewhere for as long as climate and ecological conditions permitted. If plague entered medieval and later settlements by human agency from sylvatic reservoirs, it would have left no trace of mass rat deaths, as the modern case of Madagascar illustrates. Neither Pepys nor Defoe, both acute observers, mention rat die-offs in their respective accounts of the epidemics of 1665/6.[18]

The modern-day histories above witness not only to the extreme infectiousness and fatality of pneumonic plague but also to the potential role of a wider range of animal carriers than the black rat. The indications that the rat was not widely present in fourteenth-century English towns are not just archaeological. Although the legend of the pied piper of Hamelin in Lower Saxony dates back to c. 1300 and evidence attests to the presence of a rat catcher there at that time, the *Oxford English Dictionary* traces the first use of the English word *rat* to 1592. If this dating is accurate, urban rats did not exist in sufficient numbers to constitute a serious nuisance for many years, perhaps adequately controlled by ordinary citizens using poison, as the reference to Chaucer above suggests. Other creatures, such as rabbits, could also have been involved in the diffusion of plague, as in Suffolk. The Romans introduced rabbits into Britain as a food source, which they were to remain as a staple in English towns and cities well into the twentieth century. By the twelfth century, domesticated rabbits had also become popular among the well-to-do for their fur.[19]

18 Graham Twigg, *The Black Death: A Biological Reappraisal* (London, 1984); Boris V. Schmid et al., "Climate-Driven Introduction of the Black Death and Successive Plague Reintroductions in Europe," *Proceedings of the National Academy of Sciences of the United States of America*, CXII (2015), 3020–3025; Ann G. Carmichael, "Plague Persistence in Western Europe: A Hypothesis," in Green (ed.), *The Medieval Globe* (2014), I, 157–191; Hirst, *Conquest*, 189–204; Robert Latham and William Matthews (eds.), *The Diary of Samuel Pepys* (London, 1983), XI, 227–228; Daniel Defoe, *A Journal of the Plague Year* (London, 1966). Defoe, however, notes the killing of cats, dogs, and rats in London, in the belief that their fur carried the poison of plague. Defoe also records that the disease entered London from the west and north, not from the river (137, 146). I am grateful to Mary Dobson for these observations.

19 According to the Concordance of Shakespeare's Works (primarily, 1589–1613) (http://www.opensourceshakespeare.org/concordance/), the word *rat* occurs ten times therein, "*rats*" eight times, *ratsbane* (arsenic) three times, and *rat-catcher* once. For domesticated rabbits, see

The United States offers a modern example of the establishment of a wildlife reservoir of plague—one that has survived for at least a century, involving several species of rodent. Plague was first introduced into America via the Chinese population of San Francisco on March 6, 1900. That same year, quarantine stations in Port Townsend and New York diagnosed several cases, though the disease did not progress further into those cities. By 1910, the United States had three areas of known plague infestation, two on the California seaboard and one in Washington state, as well as a small patch on the shoreline border between Oregon and Washington. By 1935, the California infection had considerably extended its range, reaching, in a broken line, from the southeastern corner to the northwestern border just into Oregon. Plague also reached an area in northeastern Idaho, along the border with Montana. By 1939, the disease had marched solidly into Montana, Wyoming, Utah, Nevada, Arizona, and New Mexico in a patchwork pattern. Although rats appeared to be the principal agents, California discovered infected ground squirrels in 1924/5.[20]

In 1950, plague was identified in cottontail rabbits in Lea County, New Mexico. A wildlife survey detected numerous dead cottontail rabbits and pack rats; two specimens of each rodent had plague bacteria in their tissue and fleas. Fleas from other pack rats, as well as from pack-rat nests and grasshopper mice were also found to be infected. Since cottontail rabbits had never been implicated in an epizootic before, health officers in counties with known active plague foci warned hunters of the danger involved in handling and cleaning rabbits. By the year 2000, rodent reservoirs of bubonic plague in the western United States were present in marmots, rabbits, kangaroo rats, deer mice, and ground squirrels, each carrying a different flea species, none of which were *Xenopsylla cheopsis*, the classic plague flea, or *Pulex irritans*, the

https://www.justrabbits.com/rabbit-history (accessed July 20, 2018); Gilda O'Neill, *My East End: Memories of Life in Cockney London* (London, 2000), 209. For earlier evidence, see *Medical Officer of Health Annual Report* (Birmingham, 1880), 21; *ibid.* (1887), 47; for cellar-kept rabbits in eighteenth-century London, Tobias Smollett, *Humphrey Clinker* (New York, 1967; orig. pub. London, 1771), 153.

20 The outbreak in San Francisco has been well studied. See, for example, Susan Craddock, *City of Plagues: Disease, Poverty and Deviance in San Francisco* (Minneapolis, 2000); Guenter B. Risse, *Plague, Fear, and Politics in San Francisco's Chinatown* (Baltimore, 2012). Brock C. Hampton, "Plague in the United States," *Public Health Reports,* LV (1940), 1145–1149, including Figure 1 (1147).

human flea. Human plague cases still occur in the western states, although the infection has, for presumed ecological or climactic reasons, progressed no further east. As an indicator of the ongoing danger of infection, the Centers for Disease Control offers several information packages on its website, including fact sheets in English and Spanish.[21]

The ability of rats to travel the globe by ship acquired confirmation from at least two important sources. Following the outbreak of plague in India c. 1894, Sir Richard Thorne Thorne, Britain's chief medical officer, introduced an annual review of foreign manifestations of plague and of its occasional appearances onboard British ships and in British ports. On the other side of the Atlantic, where plague was a newly established epizootic, matters were even more serious. Link, Senior Surgeon for the Communicable Disease Center in San Francisco, published "Plague on the High Seas," a special study of the connexions between plague, rats, and shipping, in 1951. His report expressed surprise that the importance of the rat and its flea had "not been noticed until the twentieth century," citing several literary references connecting rats and plague—from the Bible through the works of Poseidonius (c. 135 B.C.E–c. 51 B.C.E.), the eighteenth-century Chinese poet Shih Taonan, and the Chinese official who offered a "10-cash piece" for every dead rat brought to him during the 1894 Hong Kong epidemic. For the current (Third) pandemic, Link observed that the first recorded cases of ship-borne plague had occurred in June 1894 on two vessels traveling from Hong Kong to Japan and Singapore. No ship-borne cases were reported in 1895, but from 1896 to 1938, plague was reported aboard ships every year—332 cases in which "human, rodent, or both types of plague were confirmed by clinical or laboratory determinations." These cases "involved many ports of departure and arrival in 55 countries in all continents."[22]

21 Link, "Plague Epizootic in Cottontail Rabbits," *Public Health Reports*, XCV (1950), 696; Alfonso Ruiz, "Plague in the Americas," *Emerging Infectious Diseases*, VII (2001), 539–540. For a recent update, see Kiersten J. Kugler et al., "Epidemiology of Human Plague in the United States, 1900–2012," *ibid.*, XXI (2015), 16–22. For information about plague from the Centers for Disease Control, see https://www.cdc.gov/plague/index.html (accessed April 1, 2019). See also Arnold F. Kaufmann, John M. Boyce, and William J. Martone, "Trends in Human Plagues in the United States," *Journal of Infectious Diseases*, CXLI (1980), 522–524; Mary Danforth et al., "Investigation of and Responses to 2 Plague Cases: Yosemite National Park, California. USA, 2015," *ibid.*, XXII (2016), 2045–2053.

22 See, for example, Medical Officer's Annual Report to the Local Government Board, *British Parliamentary Papers*, XXXII (1911), 46, 123–173; Bruce C. Lowe, "The Progress and

Link further described the international agreements (1903–1944), fumigation methods, and techniques of investigation that had attempted to end these plague-export routes, noting that only after the development of practicable methods for rat-proofing ships in 1924/5, based on those already used in the land-based building industry, was success finally achieved. The proof of this success was the complete absence of any reports of plague aboard any ship in the world since 1938. Link's survey provides solid evidence of the frequent, if not routine, presence of rats on ships before 1925; it is difficult to imagine that rats were not regular travelers on medieval and later vessels.[23]

This brief *longue durée* perspective on the involvement of rats and other rodents in plague history reflects the interdisciplinary nature of bubonic-plague studies. On the scientific side, Hirst's attention to the historical traces of black rats and current rodent plague reservoirs in the mid-twentieth century continued in Van Zwanenberg's account of bubonic plague in Suffolk from 1906 to 1918 and in Stenseth and his colleagues' turn to modern biology and mathematical modeling to suggest historical patterns of bubonic-plague movements. The Stenseth group's publications demonstrate how far modern science has come in its ability to make sophisticated contributions to our understanding of the past. Archaeologists' discoveries of plague burial grounds in London and their use of modern genome sequencing to unlock the secrets of ancient DNA and determine the microbial cause of the Black Death have proved invaluable in resolving alternative suggestions regarding causality, as well as lending a stark immediacy to the human consequences. The assiduousness with which past generations of public-health physicians recorded their work to advance medical understandings and achievements—as evidenced by the Indian Plague Commissioners, the early twentieth-century general practitioners in Suffolk and their colleagues at the Local Government Board, and Link—is not to be underestimated.

Historians have also made vast contributions to this interdisciplinary recovery of the rat and bubonic plague: Witness the

Diffusions of Plague through the World during 1910," *ibid.*, 205–255; Link, "Plague on the High Seas," *Public Health Reports*, LCVI (1951), 1467, 1468. The figures, which derive from the *Public Health Reports*, IX–LCIII (1894–1938), apply to American shipping only.

23 Link, "Plague on the High Seas," 1469–1470, 1471.

works of Hirst and Link, who were both scientists and amateur historians. Sloane's use of the documentary evidence, particularly wills, to evaluate the shockingly high death rates from London's plague of 1347 brings that epidemic crisis into sharp focus. Carmichael's uncovering of the marmot reservoir of bubonic plague in the Alps provides a clear-cut testimonial to Hirst's account of reservoirs among marmots and other rodents in various parts of the world.

This short history of the rat and the wider rodent family in relation to bubonic plague suggests multiple ways in which different research disciplines can contribute to the understanding of mortality, morbidity, and epidemics in the past. Demographic approaches to the history of such phenomena can clarify long-term trends in, and disruptions to, patterns of mortality, especially in tandem with expertise in the epidemiology and symptoms of specific disease entities. The study of recent and current disease behaviors since 1850—using period and contemporary materials combined with modern scientific and epidemiological methods whenever possible—can lend insights into past disease behaviors. Psychology, as Lebrun's *Les hommes et la mort* clearly shows, is also pertinent to aspects of this history. Archaeological discoveries and the still-developing technology of ancient DNA analysis can be extremely helpful; the most recent studies of London's burial pits are a case in point. Moreover, primary historical research involving, say, the study of wills and other documentation, are essential to creating an accurate picture of historical circumstances. Without the collaboration of interdisciplinary methods, as the example of the black rat and bubonic plague shows, our understanding would surely suffer. The history of plague and the Black Death encompasses far more than the involvement of rats, but the more or less enduring sylvatic reservoirs of plague infection that the rats and their many rodent cousins constituted in the past, and still do in the present, should not be blithely discounted.