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Rats, Communications, and Plague: Toward an Ecological History

Until recently, there were no Roman rats. As disease, ecological change, and their economic implications push their way to the top of the historian's agenda, ancient rodents have triggered controversy and new research, some of it in the pages of this journal. Rats are crucial to epidemics of bubonic plague, a disease that has been linked to the massive demographic changes that ushered medieval Europe into the modern age. Some historians implicate rodent-borne plague in the end of the ancient world. Today archaeology and zoology draw a picture of rats and their history that differs from even a decade ago. Tiny bones and DNA are yielding glimpses of the rat's migration from southeast Asia into the Roman empire and medieval Europe. The diffusion of the rat across Europe looks increasingly like an integral part of the Roman conquest. Its movements illuminate patterns of economic organization, communications, and urbanism, and carry significant implications for the history of disease and the ecology. The history of rats is tightly interwoven with the economic rise and fall of the ancient world, as well as the expansion of the medieval economy.¹

Historians' interest in rats stems from *Yersinia pestis*, the bubonic plague. Plague is a rodent disease; in humans, it is overwhelmingly a by-product of rodent infection, transmitted by an insect bite. Human-to-human infection, however, occurs mainly in the pneumonic expression of *Y. pestis*, which, despite its deadliness, does not spread as easily as historians have imagined. In the Roman and medieval world, various rodents, such as the Egyptian or African grass rat (*arvicanthis niloticus*), might have played a role in sustaining or transmitting plague.²

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1 David E. Davis, "The Scarcity of Rats and the Black Death: An Ecological History," *Journal of Interdisciplinary History*, XVI (1986), 455–470.

2 David T. Dennis et al., *Plague Manual* (Geneva, 1999), available from <http://www.who>.

Nevertheless, the black or ship rat, *rattus rattus*, is the prime suspect in the two premodern pandemics usually identified as bubonic. The Justinianic plague began in 541 and hammered the late Roman and early medieval world until the middle of the eighth century. In Europe, the second cycle of epidemics started with the Black Death of 1347, and continued until the eighteenth century. Rats were particularly dangerous “amplifying” hosts because of their proclivity to associate with humans and the ability of their blood to withstand enormous concentrations of the plague bacillus. When rats die from the plague, their fleas are forced to seek the blood of other hosts, including humans, and the fleas regurgitate the rats’ bacteria-loaded blood into their new hosts.³

int/emc-documents/plague/whocdscsredc992c.html, 11–12, 63. Emmanuel Le Roy Ladurie, “Un concept: L’unification microbienne du monde (XIV^e–XVII^e siècles),” *Schweizerische Zeitschrift für Geschichte*, XXIII (1973), 650–682, championed the demographic impact of the pneumonic plague. See Ole J. Benedictow, *Plague in the Late Medieval Nordic Countries* (Oslo, 1992), 214–227, for a critique of the Scandinavian historians who followed him. Its 100% mortality is indeed terrifying. Clinical data for the modern strains of *Y. pestis* confirm the contagiousness and lethality of the primary pneumonic form of the disease, but also qualifies the impression of it as a uniquely devastating form. See Benedictow, *Plague*, 25–37; Dennis et al., *Plague Manual*, 45–46, with further references. The 1997 outbreak confirms the clinical data. See Mahery Ratsitorahina et al., “Epidemiological and Diagnostic Aspects of the Outbreak of Pneumonic Plague in Madagascar,” *Lancet*, 355 (2000), 111–113, who estimate the infection rate in the contact population at 8.4%. Jean-Claude Beaucourmu, “Diversité des puces vectrices en fonction des foyers pesteux,” *Bulletin de la Société de pathologie exotique*, XCII (1999), 420. Today the grass rat inhabits central Africa and the Nile river; it shares many insect parasites with the black rat, including the oriental rat flea, *Xenopsylla Cheopis*, the most efficient vector of *Y. pestis* from rodents to man. Grass rats collected in the Fayum ranked ahead of the black rat in flea counts: Mohamed L. M. Khalid, Tossou A. Morsy et al., “Studies on Flea Fauna in El Fayoum Governorate, Egypt,” *Journal of the Egyptian Society of Parasitology*, XXII (1992), 783–799, 791 (Table 4), 796. African shrew mice (*Suncus murinus*) also harbor the plague. Although they do not seem to transmit the disease to humans, their enzootic infection could explain how plague reservoirs sometimes outlive the temporary extinction of rat colonies. Outbreaks in Madagascar from 1991 to 1996 suggest that the plague survives in another rodent species that transmits it to new rat colonies when they spring up again: S. Laventure et al., “Épidémies de peste urbaine à Majunga, côte ouest de Madagascar,” *Bulletin de la Société de pathologie exotique*, XCI (1998), 85–86. In the United States, squirrels and prairie dogs have become reservoirs of plague; they transmit it to domestic cats, which infect their handlers. See, for example, Centers for Disease Control, “Pneumonic plague—Arizona, 1992,” *Journal of the American Medical Association*, CCLXVIII (1992), 2146–2147. See also M. J. Keeling and C. A. Gilligan, “Bubonic Plague: A Metapopulation model of a Zoonosis,” *Proceedings of the Royal Society of London. Biological Sciences*, 267 (2000), 2219–2230.

3 The gray rat (*rattus norvegicus*) seems to have entered early modern Europe from the east, through the Baltic. Four or five apparently earlier remains have been assigned to this species but are still controversial—for one, on the basis of its size, the fragment of a rat femur from a fourth-century Roman well, found together with unambiguous remains of a black rat. See Gabrielle Sorge, “Ratten aus dem spätantiken Kastell Krefeld-Gellep,” *Provinzialrömische*

Western and central Europe had no reservoirs of sylvatic (that is, wild, or natural) rodent plague; according to the classic epidemiological model for *Y. pestis*, plague infection has always come to Europe from outside. Hence, the population dynamics, geography, and migration of rodents are indispensable to understanding plague epidemics. Rats also play a less spectacular, but more constant, economic role by destroying human food supplies. Data from modern Turkey suggest commensal rodents consume or damage 5 to 15 percent of grain and legumes in storage. Another way of looking at the problem is that twenty-five Norwegian or gray rats eat as much as one human being does, and they foul much more food than they eat. In societies pushing against Malthusian limits of food production and population, rats and mice constituted a heavy economic burden. A surging mouse population posed such a threat to medieval grain harvests that thwarting it was proof positive of a saint's power to protect his people and their food.⁴

Forschungen. Festschrift für Günter Ulbert zum 65. Geburtstag (Espelkamp, 1995), 387–395 (with further possible cases), who hypothesizes that this gray rat, perhaps already dead, arrived with materials accompanying troops from the Roman east. Today the two kinds of rat do not normally share the same habitat. Moreover, the size of modern black rats might be a misleading criterion, since substantially larger ones are documented in medieval Corsica. See Jean-Dominique Vigne et al., “Évolution ostéométrique de *Rattus rattus* et de *Mus musculus domesticus* sur de petites îles,” *Mammalia*, LVII (1993), 85–98. Serious work on the Justinianic pandemic began with Jean-Noël Biraben and Jacques Le Goff, “The Plague in the Early Middle Ages,” in Robert Forster and Orest Ranum (eds.) (trans. Elborg Forster and Patricia M. Ranum), *Biology of Man in History* (Baltimore, 1975), 48–80; Lawrence I. Conrad, “The Plague in the Early Medieval Near East,” unpub. Ph.D. diss. (Princeton University, 1981). Two new volumes are currently in press, Dionysios Stathakopoulos, *Famine and Pestilence in the Late Roman and Early Byzantine Empire*, and the acts of the international conference on the Justinianic plague, Rome, 2001, edited by Lester K. Little. Among studies of the medieval pandemic, three deserve special mention: Biraben, *Les hommes et la peste* (Paris, 1975); Benedictow, *Plague; La Peste Nera* (Spoleto, 1994). On amplifying vs. reservoir hosts, see, for example, J. D. Poland and A. M. Barnes, “Plague,” in James H. Steele (ed.), *CRC Handbook Series in Zoonoses: Section A. Bacterial, Rickettsial, and Mycotic Diseases* (Boca Raton, 1979), I, 534–537. For human blood's lower bacillus concentrations that militate against human-to-human infection through blood transferred by insect vectors, see Benedictow, *Plague*, 242–264; Thomas Butler et al., “Yersinia Pestis Infection in Vietnam. II,” *Journal of Infectious Diseases*, CXXXIII (1976), 493–499. On fleas, see, for example, Norman Gratz, in Dennis et al., *Plague Manual*, 65–66; Poland and Barnes, “Plague,” 532, 538.

4 See Keeling and Gilligan, “Bubonic Plague,” 2219–2230, for a new mathematical model, which introduces some nuance into the idea that new infections originated outside Western and Central Europe. In modern Egypt, an optimistic sounding 1% of all stored grain is reported lost. For Egypt and Turkey, see M. Lund, “Commensal Rodents,” in Alan P. Buckle and Robert H. Smith (eds.), *Rodent Pests and Their Control* (Wallingford, U.K., 1994), 23–43.

Opinions that medieval rat populations were insufficient to sustain outbreaks of plague have played no small part in challenges to the bubonic nature of the Black Death, and absent rats, no major human epidemic of bubonic plague would have occurred. Among other reasons, these dissenting studies cite the silence of ancient and medieval sources about the kind of rat die-off that would accompany modern outbreaks of plague. This apparent absence of rats from ancient and medieval texts may be due, in part, to literary disinterest in pests. But the problem is also conceptual. The ancients did not have use of the Linnaean conceptual apparatus to name and describe their animals. Even though the black rat is irrefutably documented in the ancient world, classical Latin and Greek lacked a word for “rat” that would distinguish it from what we call “mouse.” Latin *mus* (pl. *mures*) and Greek *mys* (pl. *myes*) may designate *either* rats *or* mice. Only rarely does context show that an ancient author was writing about a rat, when, for instance, persecutors tortured a Christian martyr by sealing him in a pit filled with big starving “*myes*.” The term *rat* is itself a medieval coinage, shared by the Romance, Germanic, and Celtic languages, and shunned by the classicists of the Renaissance. Although its origins remain unclear, its earliest, securely dated, attestations come from Old English and Old High German glosses of the eleventh century. Future studies will have to take into account that the written evidence for rats speaks almost indeterminately of “rodents.” Once this lack of distinction is understood, however, the written sources can be read as evidence that late Roman eyewitness were indeed struck by the *rodent* mortality that accompanied the Justinianic plague.⁵

25 (Table 2.2); A. N. Meyer, “Rodent Control in Practice: Food Stores,” *ibid.*, 276. I have not found a similar eating statistic for the slightly smaller black rat, which is a fussier eater and reportedly disappears from areas lacking its preferred foods of cereals and fruits: Lund, “Commensal Rodents,” 34–35. On saints’ power, see the tenth- or eleventh-century *Vita S. Urbani episcopi Lingonensis, XIV. Acta sanctorum Jan. III* (Paris, 1863), 106, which calls the rodents both *mures* and *sorices* (cf. Fr. *souris*); for the date, see *HAGIOGRAPHIES: Sociologie et histoire de la littérature hagiographique en Occident des origines à 1550*, Guy Philippart’s database of Latin hagiography (http://www.fundp.ac.be/philo_lettres/histoire/h221.htm). The Bollandists assign Paris, B.N., lat. 9376, the earliest ms., to the eleventh century: *Bibliotheca hagiographica latina manuscripta: Index analytique des Catalogues de manuscrits hagiographiques latins publiés par les Bollandistes* (<http://bhlms.fltr.ucl.ac.be>).

⁵ Graham Twigg, *The Black Death: A Biological Reappraisal* (London, 1984), 75–112 (insufficient rats); Davis, “Scarcity of Rats” (“scarce or absent”). Susan Scott and Christopher J. Duncan, *Biology of Plagues. Evidence from Historical Populations* (Cambridge, 2001), 56–58,

Lately, the terms of the argument about the early plagues have shifted dramatically. First, the debate about the presence of *Yersinia pestis* during the Black Death is approaching closure. Archaeomolecular investigation has begun to diagnose diseases beyond those that leave lesions on bones, vastly expanding the scope of palaeopathological research. French researchers have discovered the DNA of the plague bacillus in the dental core of victims even centuries after their burial. Indeed, the first three medieval and early modern plague pits that they investigated have all produced DNA sequences that are unique to *Y. pestis*, proving that plague infected at least the victims in question. Efforts are currently underway to extend the technique to human remains from the Justinianic pandemic. Second, the archaeology of Roman and medieval rats has expanded enormously, even as laboratory techniques begin to throw light on the distant history of modern rodents.⁶

Aside from isolated, and therefore controversial, finds, solid archaeological evidence for rats in the Roman world has accumulated only during the last two decades. It comes in different forms: gnawing marks on bones; owl or other predator pellets; and rat re-

108–109, accept much of the reasoning of Davis and Twigg. David Herlihy, *The Black Death and the Transformation of the West* (Cambridge, Mass., 1997), 26–27; Scott and Duncan, *Biology of Plagues*, 359–360; Twigg, *Black Death*, 111–112 (including a reference to the Justinianic plague). Theodoretus (ed. L. Parmentier and F. Scheidweiler), *Historia ecclesiastica*, 5. 39, 9–10, *Die griechischen christlichen Schriftsteller* (Berlin, 1954; 2d ed.), XLIV, 344.4–10. *Oxford English Dictionary Online*, s.v., suspects that *rat* entered European vocabulary through the Germanic languages, citing an Anglo-Saxon gloss of c. 1000; cf. Antonette di Paolo Healey (ed.), *Dictionary of Old English: Old English Corpus* [online] (Ann Arbor, 1998), s.v. *Raturus ræt*, in a list of animal names, between beaver and otter. These glosses' script dates from the first half of the eleventh century: Neil R. Ker, *Catalogue of Manuscripts Containing Anglo-Saxon* (Oxford, 1990; 2d ed.), 1–3. An eleventh-century hand glosses *glis*, *gliris* (*dormouse*) as *ratia* in a ninth-century ms.: Hartwig Mayer, *Althochdeutsche Glossen: Nachträge* (Toronto, 1974), 116. Further research into the glosses reported by Taylor Starck and J. C. Wells, *Althochdeutsches Glossenwörterbuch* (Heidelberg, 1990), 2.474, might turn up an earlier occurrence. For French, see Alain Rey (ed.), *Dictionnaire historique de la langue française* (Paris, 1998; 2d ed.), 3094. First attested c. 1175, the word often means *mouse* in dialects. Ernst Gamillscheg, *Etymologisches Wörterbuch der französischen Sprache* (Heidelberg, 1969; 2d ed.), 750, notes the Celtic languages. W. J. Van Douwen and J. P. N. Land (trans.), "Joannis episcopi Ephesi Syri Monophysitae Commentarii de beatis orientalibus et Historiae ecclesiasticae fragmenta," *Verhandelingen der koninklijke akademie der wetenschappen, Afdeling Letterkunde*, XVIII (1889), Frag. G, 234.20–25.

6 Didier Raoult et al., "Molecular Identification by 'Suicide PCR' of *Yersinia Pestis* as the Agent of Medieval Black Death," *Proceedings of the National Academy of Sciences of the U.S.A.*, XCVII (2000), 12880–12883; Michel Drancourt et al., "Detection of 400-Year-Old *Yersinia Pestis* DNA in Human Dental Pulp," *ibid.*, XCV (1998), 12637–12640.

mains preserved in situ. Why it was so scarce before that point is simple: Archaeologists were not looking for it, and the tiny rat bones easily escape the troweler's naked eye. Only exceptionally laborious procedures can detect them. Sieving excavated material through meshes of 1 and 2 mm (or smaller) produces a residue that must be inspected under a stereomicroscope to observe rat bones reliably. Such methods are drawing an increasingly dense map of early rat remains. The most complete inventory to date appeared in 1994, and much new evidence has followed.⁷

7 On the early finds, see, for example, Kurt Becker, "Rattus Rattus," in Jürgen Niethammer and Franz Krapp (eds.), *Handbuch der Säugetiere Europas* (Wiesbaden, 1978), I, 382–400. For further bibliographic material, see Frédérique Audoin-Rouzeau and Vigne, "La colonisation de l'Europe par le rat noir," *Revue de paléobiologie*, XIII (1994), 124–145. Günther E. Thüry, "Zur Infektkette der Pest in hellenistisch-römischer Zeit," *75. Jahre Anthropologische Staatssammlung München, 1902–1977. Festschrift* (Munich, 1977), which I obtained only as this article went to press, also presents valuable Talmudic evidence, some of it about *rattus norvegicus* in Mesopotamia. Terry O'Connor, *The Archaeology of Animal Bones* (Stroud, 2000), 48, 50 (Figure 5.7) for the gnawing patterns of *rattus rattus*, and 2–3, 123–125 for owls' regurgitation of undigested bones and fur in the form of pellets. Apparently sterile sieve residue from Corsica produced remains of "small mammals on the order of five to ten individuals per ten liters of sediment" (Audoin-Rouzeau and Vigne, "La colonisation," 145, n. 3; O'Connor, *Archaeology*, 28–35). Sorge, "Ratten," adds a few more sites. Since 1994, more than thirty new finds from about twenty ancient and medieval sites have come to light. For the first-century A.D. Roman rats near Amsterdam and in Burgundy, see Neli Gordijn-Vons, "Een voorbericht over dierbotvondsten van Romeins-Velsen uit de eerste helft van de eerste eeuw," *Westerheem*, XXVI (1977), 125 (Table 5); Sébastien Lepetz et al., "Nouvelles observations du rat noir (*Rattus rattus*) dans la moitié nord de la France à la période gallo-romaine," *Revue archéologique de Picardie* (1993), 173–174. For second-century and medieval rats from England, see Alison Locker, "The Mammal, Bird and Fish Bones," in David S. Neal et al. (eds.), *Excavation of the Iron Age, Roman, and Medieval Settlement at Gorhambury, St. Albans* (London, 1990) 211 (Table 23). For late Roman rats in southern Belgium, see Jan De Coninck et al., "L'abri de la Sigillée. VI," *Anthropologie et Préhistoire*, CI (1990), 39–45; in a Roman Rhine fort, Sorge, "Ratten"; in southern Italy, Salvatore Scali, "Observations on the Faunal Remains from the Territory of Metaponto," *The Territory of Metaponto 1981–1982* (Austin, 1983) (unpaginated); in central Italy, Michael M[a]cKinnon, "Animal Bone Remains," in David Soren and Noelle Soren (eds.), *A Roman Villa and a Late Roman Infant Cemetery: Excavation at Poggio Gramignano Lugnano in Teverina* (Rome, 1999), 539 (Table 1), 537, 555–556. For seventh- and eighth-century Syria, see Achille Gautier, "La faune de quelques maisons d'Apamée," in Janine Balty (ed.), *Apamée de Syrie. Bilan des recherches archéologiques, 1973–1979* (Brussels, 1984), 305–360. For late Roman and medieval rats at a papal farm north of Rome, see Anthony King, "Mammal, Reptile and Animal Bones," in T. W. Potter and A. C. King (eds.), *Excavations at the Mola di Monte Gelato* (London, 1997), 383–403. For many medieval sites, see Antonio Tagliacozzo, "I reperti faunistici," in Carlo Pavolini (ed.), *Caput Africae* (Rome, 1993), 258; Philip L. Armitage, "Unwelcome Companions: Ancient Rats Re-viewed," *Antiquity*, LVIII (1994), 234, which discusses the "Byzantine" rat remains reported by M. Stanzel from the excavations of the Artemis-Apollo temple at Kalopedi, in Boeotia; Hans Reichstein, "Über Kleinsäuger aus Burg Bodenteich," *Bonner zoologischer Beiträge*, XLVI (1990), 359–366; *idem*, "Die wildlebenden Säugetiere von Haithabu," *Berichte über die*

Two issues define the ancient and medieval history of rats today—the extension of rat colonies to new places and the expansion or contraction of those colonies. Extension is a slightly less elusive phenomenon than fluctuation. The ancestors of the modern black rat and, presumably, of the Roman one, stemmed from southeast Asia, perhaps Malaysia. When, how, and by what route ancient rats traveled from southeast Asia to the Mediterranean awaits definitive clarification. Unlike their southeast Asian forebears with their forty-two chromosomes, Mediterranean black rats have thirty-eight chromosomes. That Mediterranean karyotype appears to have arisen in southwestern India, the site of ancient Mediterranean trading colonies and the main source of black pepper for the Roman empire. If the black rat relies as much on passive transport as researchers tend to think (see further below), the Indian migrants must have piggybacked on early Indian Ocean, Red Sea, or Mesopotamian shipping and transport.⁸

But how did they cross overland to the Mediterranean? An obvious possibility is the famous canal linking the Nile communications corridor and the Red Sea, completed under Darius I (521–

Ausgrabungen in Haithabu, XXX (1991), 31–33, at least ten “early medieval” rats, with no stratigraphy; Bengt Wigh, *Animal Husbandry in the Viking Age Town of Birka and Its Hinterland* (Stockholm, 2001), 54 (Table 10), 125–126, from five different strata dating between c. 810–830 to c. 950. For thirteenth-century Muslim Portugal, see A. Morales and J. Rodriguez, “Black Rats (*Rattus rattus*) from Medieval Mertola,” *Journal of Zoology* (London), 241 (1997), 623–642, with valuable methodological reflections. For twelfth-century Namur, see W. Van Neer and A. Lentacker, “Restes fauniques provenant de trois fosses d’aisances du Grognon à Namur,” in J. Plumier and M. H. Corbiau (eds.), *Quatrième journée d’archéologie namuroise* (Namur, 1996), 89–104, Tableau 3; c. 1300 and the fourteenth–fifteenth century, B. De Cupere and I. Boone, “Le matériel faunique du château des comtes à Namur. Résultats préliminaires,” in J. and S. Plumier-Torfs and C. Duhaut (eds.), *Huitième journée d’archéologie namuroise* (Rochefort, 2000), 11–16. For late medieval Brabant, see Anton Ervynck et al., “Dierlijke resten,” in *idem*, *De “burcht” te Londerzeel* (Zellik, 1994), 155, cf. 181, 186, 211 (Tabel J), 213 (Tabel L). For the other ancient and medieval rat finds, see nn. 10 and 12 below. As this article went to press, John Clark kindly put me in touch with Kevin Rielly (both from the Museum of London), who generously alerted me to three unpublished eleventh-century rat finds, from the City of London (Bull Wharf, No. 1 Poultry and Guildhall sites), as well as another one of Saxon date from a pit excavated at the National Gallery Basement site (NGA87). These four finds are not included in my totals.

⁸ Audoin-Rouzeau and Vigne, “La colonisation,” 126. For Malaysia, see Ronald M. Nowak (ed.), *Walker’s Mammals of the World Online* (Baltimore, 1997; 5th ed.), s.v. *rattus*. For karyotypes and diffusion, see Jürgen Niethammer, “Zur Taxonomie und Ausbreitungsgeschichte der Hausratte (*Rattus rattus*),” *Zoologischer Anzeiger*, 194 (1975), 405–415, confirmed by R. Libois et al., “Les populations de rats noirs insulaires de l’ouest de l’Europe,” *Vie et milieu*, XLVI (1996), 213–218. On ancient trade with the region and the ports called Muziris and Nelkynda, see Lionel Casson, *The Periplus Maris Erythraei* (Princeton, 1989), 21–25.

486 B.C.) and refurbished by the first two Ptolemies (323–246 B.C.) and Trajan (98–117 A.D.). Although Ptolemaic structures have not yet been found, the Tamil texts discovered at the Roman port of Quseir el-Qadim, farther down the Red Sea coast underscore Egypt's vigorous India trade. The excavators have identified rats there in contexts of the first or second centuries A.D. If, as seems likely, this port was the Ptolemaic and Roman emporium of Myos Hormos, the obvious translation of the Greek name seems to be "Port of the Rat" (or "Mouse") rather than the conventional "Port of the Mussel." The ancient canal linking the Red Sea and the Mediterranean may have funneled more than commerce between the two shipping zones.⁹

Although isolated finds claim to go as far back as the fourth millennium B.C., so far the best evidence for the rat's Mediterranean debut comes from the western basin in the days of the Roman republic. On Corsica, the continuously trackable diet of barn owls, a rat predator, indicates that rats were absent until some point between the fourth and second centuries B.C., when they appeared and began driving out native small mammals. That this period marks the black rat's colonization of the northwestern Mediterranean gains support from rat finds on Minorca and in Pompeii dated to the second century B.C. In the east, as mummies prove, Egyptian birds were preying on rats under the Romans and, probably, the Ptolemies (323–331 B.C.), if not a century or two earlier. Although the evidence is not yet of the same caliber as in Corsica, it is tempting to regard Egypt as the source of the Mediterranean rats. An Egyptian starting place would fit well with the potential role of the Red Sea canal.¹⁰

9 See, for example, E. Bresciani, "Persia," *Oxford Encyclopedia of Ancient Egypt* (Oxford, 2001), III, 37; J. S. Holladay, Jr., "Pithom," *ibid.*, 50–53; *idem*, "Wadi Tumilat," in Kathryn A. Bard and Steven B. Shubert (eds.), *Encyclopedia of the Archaeology of Ancient Egypt* (London, 1999), 878–881; P. J. Sijpesteijn, "Der Potamos Traianos," *Aegyptus*, XLIII (1963), 70–83. The alternative translation of "Myos Hormos" as "Port of the Mussel" is widely accepted, but "mussel" is a secondary meaning of the word *mys*. For the site, see D. Whitcomb, "Quseir el-Qadim," *Encyclopedia of the Archaeology of Ancient Egypt*, 658–660; for the Roman rats, Angela von den Driesch and Joachim Boessneck, "A Roman Cat Skeleton from Quseir on the Red Sea Coast," *Journal of Archaeological Science*, X (1983), 210–211.

10 From the rich cave deposits on Monte di Tuda, c. 10 km from the sea, see Vigne and H. Valladas, "Small Mammal Fossil Assemblages as Indicators of Environmental Change in Northern Corsica during the last 2500 Years," *Journal of Archaeological Science*, XXIII (1996), 199–215. For the early but isolated claims, see Audoin-Rouzeau and Vigne, "La colonisation," 129 (Tableau 1, nos. 0–5), 132. For the single fragment tentatively assigned to the seventh–sixth century B.C. from an Adriatic site, see Tassos Kotsakis and Elena Ruschioni, "I microvertebrati di un insediamento dell'Età del Ferro presso Tortoreto," *Rendiconti della*

The mitochondrial DNA of modern rats in the western Mediterranean indicates they got there via two different routes—one “via Africa” and the other unclear. The limited geography of the European sample (Corsica, Sardinia, Elba, Sicily, two sites on the Spanish coast, and an island off Marseilles) cautions against over-emphasizing those pathways at this stage of research. Nonetheless, in their favor, recall that the Romans drove the Carthaginians, the great African seafarers, from both Corsica and Sardinia in the second century B.C., and that Phoenician amphoras are well attested on the Red Sea canal.¹¹

However the black rat reached Mediterranean shores, Roman rat colonies are archaeologically certain. The number of finds is still small for the time span—sixty-five to the eighth century A.D. Many are dated only broadly, and a few deposits may be intrusive, given that, in the warm Mediterranean ecology, black rats are known to burrow. Geographically, the finds are also unevenly distributed, in the usual way. Western Europe is better documented because it has been more intensively excavated than the rest of the ancient world. Only seven of the rat contexts come from outside Europe—Roman Africa (2), Syria (2), and Egypt (3). Within Europe, rats have been detected in many areas of heavy Roman presence: Italy, central and northern Gaul, Britain, the Rhine and Danube frontier, and Portugal. Although these early results give a good sense of the far-reaching presence of rats across the empire, nonetheless, they show only “islands” of rats at this juncture.¹²

Accademia nazionale dei Lincei. Classe di scienze fisiche, matematiche e naturali, LXXVI (1984), 295–304. Audoin-Rouzeau and Vigne, “La colonisation,” nos. 20, 24. L. Lortet and C. Gaillard, “La faune momifiée de l’ancienne Égypte,” *Archives du Muséum d’histoire naturelle de Lyon*, VIII (1903), 39–40, discovered a number of partially digested black rats in mummified birds of prey supplied by the Egyptologist Gaston Maspero (1846–1916). Lortet does not explicitly date them but states that they came from Giza and Kom Ombo in Upper Egypt. That he dates his bird mummies from Giza as Ptolemaic and, “maybe, XXVI dynasty,” that is, 663–525 B.C. (113–114), suggests that some of the Giza mummies might have been earlier, but that most, if not all, were Ptolemaic. Those from Kom Ombo were Roman.

11 Libois et al., “Les populations”; G. Cheylan et al., “Distribution of Genetic Diversity within and between Western Mediterranean Island Populations of the Black Rat *Rattus rattus*,” *Biological Journal of the Linnean Society*, LXIII (1998), 393–408. For amphoras at Tell el-Maskhuta, see Holladay, “Pithom,” 53.

12 Excluded from my sixty-five contexts are the seven northern finds for which Audoin-Rouzeau raises the possibility of an intrusive deposit: nos. 12 and 32, Ersigen-Murain and Vendeuil-Caply (both first century); 16, Lorch-Lauriacum (fifth century); 19, Magdalensberg, (first century B.C.–first century A.D.), 21; Muensterberg Breisach and 29, Sponeck (both

How did rats spread through the western provinces of the Roman empire? The answer entails two further historical and zoological problems—black rats' sedentary nature (and, therefore, their limited range of active movement) and their differences in behavior due to the ecological gradient. With respect to the first, the consensus is that black rats normally do not range much beyond 200 m. However, some evidence suggests that rats routinely move farther in the Mediterranean area than in the north. Accepting 200 m as the normal maximal dispersal range of a wild black rat during its estimated life span of two years or so means that a black rat population would need approximately five generations to move a kilometer—roughly, five years, depending on the ecological circumstances. Hence, absent human assistance, overland rat colonization would proceed at a rate of about 20 km per century (judging by a modern Atlantic ecology, however, this figure may be on the high side; ship rats in the United Kingdom migrate from ports only a few km inland). If this rate of self-powered locomotion is even remotely accurate, rats clearly did not traverse under their own power the more than 800 km from the Mediterranean coast to a first-century archaeological site at Baron, near Senlis, in only two to four centuries.¹³

fourth century); and 58, the poorly dated Unterregenbach (seventh–eleventh century). Ten finds are dated to a range that extends beyond the eighth century, including one that might also come from the ninth century; six might be as late as the tenth century (including the new data from Haithabu) (see n. 7 above); and one context each is dated eighth to thirteenth and seventh to sixteenth century. Audoin-Rouzeau and Vigne, "La colonisation," 129 (Tableau 1): nos. 11, Carthage (first to fifth century A.D.); 35, Zembra (seventh century); 26, Quseir el-Qadim (first or second century, six rats); the Apamaea finds (sixth to seventh and seventh to eighth century); the mummified birds in nn. 7 and 10.

13 On rats' limited range, see, for example, Biraben, *Les hommes et la peste*, I, 17, relying essentially on J. F. D. Shrewsbury, *A History of the Bubonic Plague in the British Isles* (Cambridge, 1970), 7–16, which seems to draw on R. A. Donaldson, *The Rat* (Philadelphia, 1924); M. A. C. Hinton, *Rats and Mice as Enemies of Mankind* (London, 1918). I have not found much empirical study of black rat movements in the wild. Radio tracking of three rats in a temperate wooded area near Sydney, Australia, indicated a home range of 0.76 to 0.3 ha (100 × 100 m sq) over a two- or three-day period. See Michelle P. G. Cox et al., "Use of Habitat by the Black Rat (*Rattus rattus*) at North Head, New South Wales," *Austral Ecology*, XXV (2000), 380; cf., for example, J. G. Innes and J. P. Skipworth, "Home Ranges of Ship Rats in a Small New Zealand Forest," *New Zealand Journal of Zoology*, X (1983), 99–110. Trapping and release experiments point to restricted home ranges. Over two months, G. F. Petrie et al., "A Report on Plague Investigations in Egypt," *Reports and Notes of the Public Health Laboratories, Cairo*, V (1923), 1–114, noted only one rat moving beyond a restricted (but ill-defined) home range in a block of houses in El Motiya, Egypt. That rat traveled 250 m. As the authors note, because this experiment coincided with a food shortage, breeding, and plague, movements may well have been maximal. However 159 of the 305 marked rats were not captured again, so we

Rattus rattus' affinity for ships is well known. Most (forty-seven, or 72 percent) Roman rat finds occur within 10 km of sea coasts or river banks. In many, if not all, of these cases, the rat colonies could have been established and reinforced via passive transport on sea or river vessels. These rodents testify to the power of ancient shipping networks, and to their capillary penetration up inland streams, since nearly half (twenty-eight, or 43 percent) have been found by the banks of inland waterways. Nonetheless, an unbroken chain of vessel movements seems unlikely to have carried the rodents to more than one-quarter of the sites. How did rats reach those places?

The ecological gradient, human population densities, and land transport systems have much to do with the answer. True to their warm origins, rats live unprotected in the Mediterranean wild; in the north, they tend to rely on human dwellings and food storage to thrive. Hence, spontaneous rat colonization may have extended more broadly around the Mediterranean, whereas passive transport from "island" to "island" of human settlement may have been more important in the north. Conceivably, the spread of the Romans' centrally heated buildings and baths contributed to rat colonization of the colder parts of the empire.¹⁴

know nothing about their movements (77). The thorough observations of Hans Joachim Telle, "Beitrag zur Kenntnis der Verhaltensweise von Ratten," *Zeitschrift für angewandte Zoologie*, LIII (1966), 144-145, indicate that 181 of 212 German black rat packs remained within a territory that included their food source; the only territory for which a size is given was a 12 × 4 m roof (150, Abb. 4). Warren F. Pippin's year-long study on a tropical island, "The Distribution and Movement of Roof Rats on Mona Island, West Indies," *Journal of Mammology*, XLII (1961), 344-348, does not fundamentally contradict the picture; rats released where they were captured were never recaptured more than 50 yds (45.5 m) away. Most rats released at various distances from the point of capture made their way back, suggesting a strong sense of territoriality. Some of those "homing" rats, however, traveled well over 1,000 yards (914 m) in a day or two; one covered 8,700 yds (7.95 km) in 48 hours. Four rats seem to have chosen to travel elsewhere, at distances of 950, 900, 600 (one to two days) and 350 yds (thirteen days). Finally, Telle, "Beitrag," 145, observed that unlike northern rats, Mediterranean rats made burrows, did not shun wet environments, and nested as far as 300 to 400 m from food sources; an ecological gradient may also be in play at Mona Island. According to my assumptions, estimated life span of rats in the wild is 2 to 2.5 years. Rats begin bearing after c. 100 days of life, and are pregnant for about twenty-two days. They may average four or five pregnancies during their lifetime. See Becker, "Rattus rattus," 394-395. Conditions may vary according to the ecological circumstances. E. W. Bentley, "The Distribution and Status of Rattus rattus L. in the United Kingdom in 1951 and 1956," *Journal of Animal Ecology*, XXVIII (1959), 302-303; Colin Matheson, "A Survey of the Status of Rattus Rattus and Its Subspecies in the Seaports of Great Britain and Ireland," *ibid.*, VIII (1939), 86-89. 14 Telle, "Beitrag," 144-145. Armitage, "Unwelcome Companions," 234, mentions a rat discovered in the Roman bath at Mirebeau. Lepetz et al., "Nouvelles observations," 173-174.

The “social mass model” sheds more light on patterns of rat colonization. It maintains that the frequency of communications reflects the spatial distribution of human beings: A huge concentration of people, such as in the ancient city of Rome, generates commensurate flows of communications of all sorts. From the rat’s perspective, more human movements mean more opportunities for transport, just as denser human populations imply an increased supply of food, both under way and stored or dumped. As archaeologists deduce the intensity of ancient cities’ communications with their rural hinterlands, they should uncover corridors of rat colonization outward from Rome and other major urban centers connected to the sea. That inland rat finds have been linked broadly with Roman road systems fits the modern observation that rats disperse better along natural corridors with roads than along roadless corridors. But not all roads are created equal; it is not enough simply to observe the presence of a Roman road to suppose that rats traveled it.¹⁵

Ancient land transport is now coming under healthy review. Ongoing work challenges the traditional view that downplayed its economic significance, given its greater cost relative to water transport. That type and frequency of traffic varied over time and by route also affected the passive transport of rats. For instance, patterns of plague contagion suggest that riverboat traffic up the Rhone from the Mediterranean coast during the late sixth century may have been interrupted eight miles south of Lyons; a shift there to land transport could well explain why plague was not transmitted from local rats to colonies further upstream.¹⁶

The *type* of land transport habitually used on a particular road also made a difference. It is hard to imagine many rats riding

15 J. C. Lowe and S. Moryadas, *The Geography of Movement* (Boston, 1975), 150–157. For comments on pottery circulation between Monte Gelato and Rome, see Helen Patterson, “The Early Medieval and Medieval Pottery,” in Potter and King (eds.), *Excavations*, 374, and, in general, Peregrine Horden and Nicholas Purcell, *The Corrupting Sea* (Oxford, 2000), 110–112. Audoin-Rouzeau and Vigne, “La colonisation,” 135; Sharon J. Downes et al., “Variation in the Use of Corridors by Introduced and Native Rodents in South-Eastern Australia,” *Biological Conservation*, LXXXII (1997), 379–383.

16 See, in general, McCormick, *Origins of the European Economy: Communications and Commerce, A.D. 300–900* (New York, 2001), 67–77. For a stimulating, positive appraisal of the economics of road transport, see Ray Laurence, “Land Transport in Roman Italy,” in Helen Parkins and Christopher Smith (eds.), *Trade, Traders and the Ancient City* (London, 1998), 129–148. McCormick, “Bateaux de vie, bateaux de mort,” *Morfologie sociali e culturali in Europa fra tarda antichità e alto medioevo* (Settimane di studi del Centro italiano di studi sull’alto medioevo, 45) (Spoleto, 1998), 58–61.

on the backs of horses, donkeys, mules, camels, or men: cart routes must have been more propitious to moving rats. By the later seventh century, for example, wagon trains seem to have carried what Rhone traffic there was all the way to Picardy from the Mediterranean port of Fos. Some passes through the Alps could accommodate Roman carts; the grade or paving of others seem suited only for pack animals and human bearers. Inland transport of goods unsuitable for pack animals, such as Merovingian limestone sarcophagi, offers another promising archaeological indicator of (evolving?) carting and its use of road systems. In each case, it would be useful to compare the detailed geography of cart transport and rats. For instance, two finds of rats from the first century A.D. occur at Annecy-le-Vieux, which is not directly connected to Roman river networks. However, Augustus built a road linking Annecy with the Little St. Bernard, one of the very passes from Italy serviced by Roman carts. Annecy's location on a proven cart route suggests that patterns of rat colonization may prove to be sensitive indicators of the changing geography of cart hauling. The study of rat migration can make a significant contribution to the debate about the competition between the camel (or the donkey) and the wheel and about shifts in the relative frequency of types of land transport and their economic implications at the end of antiquity. But what would have incited shy and sedentary black rats to hop on a cart in the first place?¹⁷

One of the rare ways of moving modern rat colonies recognized by zoologists offers an answer. Although famously omnivo-

17 For references to Rhone and Alps transports, see McCormick, *Origins*, 77–80. Walter Janssen, "Reiten und Fahren in der Merowingerzeit," in H. Jankuhn et al. (eds.), *Der Verkehr* (Abhandlungen der Akademie der Wissenschaften in Göttingen, Philologisch-historische Klasse, 3rd series, 180) (Göttingen, 1989), 198–202. For Augustus' road to the Little St. Bernard, see Raymond Chevallier, *Les voies romaines* (Paris, 1997), 213; M. Hudry, "Trace et trafic d'une voie romaine transalpine: section Petit-Saint-Bernard-Albertville," *Actes du colloque international sur les cols des Alpes* (Bourg en Bresse, 1969), 109. Most authors believe that the Great St. Bernard, however, was suited only for mule trains. See R. Fellmann, "Le strade romane attraverso il Massiccio Alpino della Svizzera," in M. Pavan and G. Rosada (eds.), *La 'Venetia' nell'area padano-danubiana* (Padua, 1990), 370–371. Dissenting is P. Hunt, "Summus Peninus on the Grand St Bernard Pass," *Journal of Roman Archaeology*, XI (1998), 265–274. Richard Bulliet, *The Camel and the Wheel* (Cambridge, Mass., 1975); Roger S. Bagnall, "The Camel, the Wagon and the Donkey in Later Roman Egypt," *Bulletin of the American Society of Papyrologists*, XXII (1985), 1–6. In Senegal, the distribution of rat colonies has changed since trains supplanted riverboats as the main line of communications with Mali. See J. M. Duplantier et al., "Répartition actuelle du rat noir (*Rattus rattus*) au Sénégal: Facteurs historiques et écologiques," in Michel Le Berre and Louis Le Guelte (eds.), *Le rongeur et l'espace* (Saint-Etienne, 1991), 345.

rous, black rats prefer grain. The grain fleets that carried the late empire's state-subsidized food shipments from Africa and Alexandria to the capitals of Rome and Constantinople probably played a role in the recurring transmission of plague. The sailings of those great fleets surely reinforced the long-term process of rat colonization, even as they built the maritime transmission of the pathogen into the very structure of imperial power. In carts, grain was also shipped around the empire as taxes or military supplies via the state post (the *cursus publicus*); as a commercial ware, it was carted under private auspices. Further investigation of this overland movement of grain is likely to uncover paths by which rats colonized landlocked sites in the empire. By the same token, the early medieval decline of those patterns of transport, and the triumph of pack animals over the wheel, must have impeded the reinforcement of established colonies.¹⁸

Rat colonies extending across the Roman empire are only the first half of the bubonic equation. The second half is their expansion. Big, dense commensal rat populations offer optimal conditions for spreading the disease to human neighbors. A sharply increasing rat population threatens ecological equilibrium and disposes the rodents to disease. Recent mathematical modeling estimates the critical density for that disposition at 3,000 rats per 0.5 sq km. New archaeological data challenge the opinion that late medieval Europe had too few rats to have sustained bubonic plague during the Black Death. Judging from 143 rat contexts of the ninth to the fifteenth centuries, medieval Europe's rat colonies were extensive and abundant. In sixty-six cases, excavators estimated the minimum number of individual rats attested. Those contexts yielded a total of 601 rats—that is, they averaged 9.1 rats each (range, 1–167 rats; mode, 1). One-fifth (thirteen) of those contexts displayed ten or more rats, and twelve of those most-infested sites are certainly thirteenth century or later.¹⁹

Overall, the raw rat counts hint at hugely expanding rat populations around the fourteenth-century plague. In favored cases, which preserve good samples of a rat colony, it may prove possible

18 Becker, "Rattus rattus," 393–394; McCormick, "Bateaux de vie, bateaux de mort"; Michael F. Hendy, *Studies in the Byzantine Monetary Economy* (Cambridge, 1985), 294–296, 603–608.

19 See Poland and Barnes, "Plague," 532. Keeling and Gilligan, "Metapopulation dynamics of bubonic plague," *Nature*, CDVII (2000), 905. The point about medieval Europe's rat colonies is based on Audoin-Rouzeau and Vigne, "La colonisation," 128–131 (Table 1), and the relevant material in n. 7.

to refine the raw data of numbers of rats and move toward the question of the colony's population trend. Archaeologists now routinely subject the human populations recovered from ancient and medieval cemeteries to palaeodemographic analysis: They classify the remains by age at death and sex and use various formulas to compensate for underreporting of immature individuals, in order to deduce the size, sex ratio, and age pyramid of the source population. The procedure illuminates the demographic trend—whether the population in question was stagnant, declining, or growing. At least one attempt has been made to assess a medieval rat colony's numbers by age cohort and mortality pattern. If such efforts are headed in the right direction, archaeozoologists may be able to apply an appropriately adapted analysis to clarify the dynamics and trend of such rat populations. They could thereby test and check the deductions made about rat population patterns from raw counts of the minimum numbers of individuals and mathematical simulations.²⁰

For now, the zodemographic trend of late antique rats remains more obscure. Whether this lack of hard data is due to insufficient investigation, to greater deterioration of fine rat bones after an additional millennium in the soil, or to lesser expansion of rat populations is unclear. Nevertheless, more than twenty-four of the ancient finds yielded an estimated total of 148 rats, an average of 6.1 rats per context (range, 1–126; mode, 1; one-quarter [6] of the sites had 10 or more rats). The data unearthed so far do not allow anything stronger than a surmise that the extending colonies of rats were also expanding in size, though one carefully scrutinized urban site at Naples yielded successive strata of four, eleven, and fifteen rats.²¹

20 Thus, Morales and Rodriguez, "Black Rats (*Rattus rattus*) from Medieval Mertola," 624–632, cautiously formulate the age distribution for a group of thirteenth-century rats, arguing that it shows an attritional (rather than catastrophic) age structure. See Keeling and Gilligan, "Bubonic Plague," and *idem*, "Metapopulation Dynamics." Although now dated, the classic statement of the cemetery method is Peter Donat and Herbert Ullrich, "Einwohnerzahl und Siedlungsgrösse der Merowingerzeit," *Zeitschrift für Archäologie*, V (1971), 234–265. For a recent application, see, for example, Klaus Georg Kokkotidis, "Belegungsablauf und Bevölkerungsstruktur auf dem alamannischen Gräberfeld von Fridingen an der Donau in Südwestdeutschland," *Fundberichte aus Baden-Württemberg. Aufsätze*, XX (1995), 737–801. For a far-reaching critique of similar methods for the Roman empire, see Walter Scheidel, "Roman Age Structure: Evidence and Models," *Journal of Roman Studies*, XCI (2001), 1–26.

21 The strata were dated c. 450–475, c. 475–525, and c. 525–699, respectively. See A. C. King, "Mammiferi," in Paul Arthur (ed.), *Il complesso archeologico di Carminiello ai Mannesi, Napoli* (Galatina, 1994), 376 (Tabella 39), 387–388, 405. Arthur, *ibid.*, discusses the dating, al-

Extension and expansion of rat colonies need not have been linear processes. Since both have fluctuated substantially in recent centuries, they probably did so in antiquity as well. Black-rat and human populations are linked in demographic terms: Dense human populations foster similar conditions among rats. Even today, despite sophisticated rat-control programs, many large cities are still “literally, rat paradises.” The varying demographic trends that are now emerging for different regions of the late Roman empire necessarily have implications for regional rat populations. That the number of humans in the empire’s northwest quadrant started to dwindle around the third century should have led to contracting rat populations there, even as seemingly uninterrupted demographic growth ought to have fostered more rats in the southern and eastern Mediterranean regions.²²

Left to themselves in a conducive ecological setting with unlimited food, rats proliferate famously. The great late Roman cities required massive cereal imports, and rats cannot have been far behind. Given that the Romans transported grain in bulk, and unloaded it by hand, it is fair to assume a substantial loss when Egyptian grain was transferred from Nile boats into state granaries in Alexandria, then put aboard seagoing vessels for shipment to the capitals, and finally loaded onto lighters for the trip up the Tiber or carried up the hill to the great granaries of Constantinople. Similar conditions undoubtedly obtained for shipments to military forces deployed around the empire. That the army relied on inter-regional grain transport seems to follow from the wide spectrum of ancient grains recovered from Roman military depots. Moving mountains of grain inevitably implies loss, which translated into exceptional resource availability for rats. More food means more rats.²³

Other factors may have expanded late Roman rat populations, starting with waste treatment. Archaeology shows that gar-

though the differing precision needs to be taken into account, in the introduction (“Sintesi delle principali attività per fasi,” 73–75) and the conclusion (“Conclusioni,” 433–435).

²² Becker, “*Rattus rattus*,” 387–390; *Grzimek’s Encyclopedia of Mammals* (New York, 1990), 3.167. For the broad late Roman demographic trends, see, for example, McCormick, *Origins*, 30–41.

²³ Becker, “*Rattus rattus*,” 394–396; McCormick, “Bateaux de vie, bateaux de mort,” 37–43, with further references; Jean-Pierre Devroey, “La céréaliculture dans le monde franc,” *L’ambiente vegetale nell’alto medioevo* (Settimane di studio del Centro italiano di studi sull’alto medioevo, 37) (Spoleto, 1990), 231–232.

bage often stayed in the towns that generated it but not yet where and how it was treated; according to Roman law, owners or renters were responsible for keeping the street clear in front of their properties. The unsavory sanitation arrangements of the high Roman empire may have worsened in late antiquity. Excavators have observed that, c. 450, some rooms of an apartment block (*insula*), as well as the contiguous city street, began to serve as garbage dumps in downtown Naples. In the very next stratigraphic sequence, c. 500, black rats appear. As the western empire descended into chaos, could dwindling urban administrations, changing social ethos, or simply the failure to enforce the old legal provisions have eroded such sanitation practices as had existed earlier?²⁴

Deepening exploration of late antique cityscapes may discern subtle spatial patterns in urban rat colonies that correlate with economic and architectural features. Some will have attracted rat concentrations, others will have discouraged them. In 1950s London, black rats reached beyond the banks of the Thames only in zones characterized by “multi-storied, centrally-heated . . . non-residential buildings interspersed with restaurants, cantines, and other sources of food.” As Alexandre Yersin, the discoverer of the plague bacillus, observed, the 1894 outbreak at Hong Kong spared resident Europeans almost entirely, even as it devastated the Chinese quarters of the city. Differing building and sanitary conditions appear to foster specific densities of rat infestation and, hence, human infection.²⁵

During the plague season in early twentieth-century Egypt, rats avoided crossing broad paved spaces; recent research confirms that wide streets impede rat colonies. Thus, the colonnaded avenues of late antique Constantinople or Ephesus may have discouraged rats from some zones within the city. As street patterns

24 On sanitation in Roman cities, see A. Scobie, “Slums, Sanitation and Mortality in the Roman World,” *Klio*, LXVIII (1986), 399–433. On Roman waste and the implications for rats, see Thüry, *Die Wurzeln unserer Umweltkrise und die griechisch-römische Antike* (Salzburg, 1995), 23–26, 77, n. 61; *idem*, *Müll und Marmorsäulen* (Mainz, 2001). For Roman trash law, see, in particular, *Digesta*, 43, 10, in Theodor Mommsen and Paul Krueger (eds.), *Corpus iuris civilis* (Berlin, 1922), I, 733; cf. *Digesta*, 9, 3, 1–7, *ibid.*, 163–164; *Digesta*, 44, 7, 5, *ibid.*, 765, on injuries caused by refuse thrown out of windows onto passersby. Arthur, “Sintesi,” 73.

25 Bentley, “Distribution,” 303–304. Yersin quoted in Thomas Butler, *Plague and Other Yersinia Infections* (New York, 1983), 17.

changed in the sixth and seventh centuries, souk-like warrens of shops and squatter structures encroached on those open corridors, foreshadowing the medieval Islamic urban fabric. The new, denser urbanism may have extended rat populations more widely within towns. Roman rats surely flourished along the routes by which the public grain moved from transport ships to granaries and, ultimately, to the public bakeries.²⁶

Slaughterhouses also foster abundant rat populations. Witness, for example, modern Alexandria. The waste associated with slaughterhouses excited complaint in medieval London; Elizabethans connected it with outbreaks of plague. The problem of trash removal is crucial to this story. As the analysis of butchered bones clarifies the changing patterns of meat production in Rome and other towns, the mapping of supply networks, meat markets, and slaughterhouses should provide another focus for identifying ancient rat populations.²⁷

Finally, block-by-block investigation of the epidemiology of plague in an early modern German town revealed curious islands of resistance among smiths and coopers. The nocturnal habits of the rat go hand in hand with exceptionally sensitive hearing; if the German evidence has been completely understood, rats avoided places where they would have been subjected to the frequent—but irregular—noise of hammering. Roman rats may have behaved similarly.²⁸

26 Petrie et al., "Report," 16. For broad streets, rats, and Japanese cities, see the abstract of Tatsuo Yabe, "Changes in Species Composition of the Norway Rat (*Rattus norvegicus*) and the Roof Rat (*R. rattus*) in Urban Area [in Japanese]," *Medical Entomology and Zoology*, XLVIII (1997), 285–294, according to BIOSIS Previews online. James Russell, "Transformations in Early Byzantine Urban Life," *17th International Byzantine Congress: Major Papers* (New Rochelle, 1986), 144; Jean Durliat, "L'approvisionnement de Constantinople," in Cyril Mango and Gilbert Dagron (eds.), *Constantinople and Its Hinterland* (Aldershot, 1995), 30–32.

27 For Alexandria, see Naguiba F. Loutfy et al., "Study on Rodents Infestation in Alexandria and Prevalence of *Trichinella Spiralis* Infection among Them," *Journal of the Egyptian Society of Parasitology*, XXIX (1999), 897–909, according to BIOSIS Previews online. For London (without explicit mention of rats), see Twigg, *Black Death*, 110–111. For recent plague epidemics near a city market and its garbage, see Pascal Boisier et al., "Epidemiologic Features of Four Successive Annual Outbreaks of Bubonic Plague in Mahajanga, Madagascar," *Emerging Infectious Diseases*, VIII (2002), 314. MacKinnon, "High on the Hog: Linking Zooarchaeological, Literary, and Artistic Data for Pig Breeds in Roman Italy," *American Journal of Archaeology*, CV (2001), 649–673.

28 According to Erich Woehlkens, *Pest und Ruhr im 16. und 17. Jahrhundert* (Hanover, 1954), 72–74, only one-quarter of smith or cooper enterprises were hit by plague in 1597, whereas 84% of other shops were affected. Although rodent hearing is highly sensitive, ultrasound devices seem fairly ineffective against them, in part because their initial aversion is overcome by

On a broader scale, warfare brings wide fluctuations in rat populations. Rat numbers jumped repeatedly in the wake of the wars fought on German soil between 1813 and 1945. They would remain high for about two decades before declining. Such surges stem from disrupted supply networks, individuals' makeshift food hoarding, and degraded housing stock. All of these causes sound plausible in a sixth century that saw the Frankish conquest of southern Gaul; persistent banditry on the Egyptian and African borders; Justinian's reconquest of Africa, Italy, and part of Spain; the wars with Persia; and the appearance of central Asian and Slavic marauders in the Balkans.²⁹

Another circumstance implicated in a recent plague episode may have also affected late antiquity. The earthquake that hit India in 1993 disrupted food storage and gave rats access to "unlimited energy inputs," that is, food. Rodent populations mounted during the next eight to ten months until they upset population equilibrium. An outbreak of plague ensued in the following year. Severe earthquakes struck the Middle East in the sixth century, and again in 740, on the eve of the final outbreak of the Justinianic pandemic. Constantinople suffered them in 525, 533, 548, 554, 557, and 740; the first and last two seisms were the most destructive. The timing of the earthquake that is known to have struck in December 557 is particularly noteworthy, since it anticipated the plague that is first reported at Constantinople eight months later, in July 558. Granaries must have been damaged, implying temporary but substantial surges in the food supply available to rodent colonies.³⁰

habit. If the German case is valid, the factors of rat deterrence there may have been more complex, involving the availability of alternative habitats in the vicinity. On rodent hearing, see D. W. Macdonald and M. G. P. Fenn, "The Natural History of Rodents: Preadaptations to Pestilence," in Buckle and Smith (eds.), *Rodent Pests*, 6. On their habituation to noise, see Smith, "Rodent Control Methods: Non-chemical and Non-lethal Chemical," in *ibid.*, 113–114 (with Table 5.1).

29 Becker, "Rattus rattus," 388.

30 Vijay K. Saxena and T. Verghese, "Ecology of Flea-Transmitted Zoonotic Infection in Village Mamla, District Beed," *Current Science (Bangalore)*, LXXI (1996), 800–802, from the abstract in BIOSIS Previews online. See also S. Shivaji et al., "Identification of *Yersinia Pestis* as the Causative Organism of Plague in India as Determined by 16S rDNA Sequencing and RAPD-based Genomic Fingerprinting," *FEMS Microbiology Letters*, 189 (2000), 247–252, confirming the *Y. Pestis* diagnosis. Glanville Downey, "Earthquakes at Constantinople and Vicinity, A.D. 342–1454," *Speculum*, XXX (1955), 598–599. For the 558 plague, see Stathakopoulos, "Crime and Punishment: The Plague in the Byzantine Empire," forthcoming in the volume to be edited by Little, cited in n. 3.

Two further factors drove rodent populations up or down by influencing the overall ecological system. Modern environmental change has been connected with fluctuating vector populations. The long-suspected link between increased precipitation and plague has now been confirmed by a study of the American southwest. At a local level, above-normal precipitation produces increased plague outbreaks; conversely, above-normal dryness diminishes plague. In an arid or semi-arid ecology, precipitation that increases two to six months before rodent breeding peaks launches a "trophic cascade." An explosion of plant and insect growth bolsters the food chain and fosters a surge in the rodent population. In this kind of ecology, increased precipitation succeeded by drought may well be the sequence most favorable to plague transmission: Drought decreases the food supply for the newly swollen rodent colonies, which then disperse in search of food.³¹

The history of the late Roman climate is in its infancy. So far the evidence on Mediterranean precipitation in the 530s and 540s comes from texts, and it is anecdotal: A dry spell and water shortage befell Constantinople in 530; a drought hit Persia in 536; and heavy snow fell in Syria in 540. To these three items, we might add a slackened and then restored flow of the River Po in the course of 539/40. Dendrochronology ought soon to add tree-ring data that could illuminate local precipitation patterns.³²

Reliable late Roman observers also record a truly major climatic disruption. In 536 and 537, the sunlight faded for twelve to eighteen months, probably because of a dust veil, perhaps follow-

31 On environment and vectors, see Duane J. Gubler et al., "Climate Variability and Change in the United States: Potential Impacts on Vector and Rodent-Borne Diseases," *Environmental Health Perspectives*, CIX, Supplement 2 (2001), 223–233 (228–229 on plague in particular). Robert R. Parmenter et al., "Incidence of Plague Associated with Increased Winter-Spring Precipitation in New Mexico," *American Journal of Tropical Medicine and Hygiene*, LXI (1999), 814–821. Unless precipitation is equal throughout an entire region, the correlation between increased precipitation and plague holds better at the local than the regional level. Observations from Africa suggest that the precipitation–rodent link extends beyond New Mexico's arid conditions. See Rhodes H. Makundi, "Annual Changes of Reproduction in Rodents in the Western Usambara Mountains, North-East Tanzania," *Journal of African Zoology*, CIX (1995), 15–21; cf. Afework Bekele and Herwig Leirs, "Population Ecology of Rodents of Maize Fields and Grasslands in Central Ethiopia," *Belgian Journal of Zoology*, CXXVII (1997), 39–48, although there were few black rats in this last sample.

32 For Constantinople and Persia, see Johannes Koder, "Climatic Change in the Fifth and Sixth Centuries?" in Pauline Allen and Elizabeth M. Jeffreys (eds.), *The Sixth Century: End or Beginning?* (Brisbane, 1996), 275–276. For the Po, see Procopius, *Bella*, 6, 28, 3–6, in J. Haury and G. Wirth (eds.), *Opera omnia* (Leipzig, 1963), II, 275.16–276.12.

ing on low solar emissions, which appears to have set off a global cooling of the northern hemisphere in the years before the plague. Tree rings from northern Europe document poor growth in 536, and again in 540, the same year as that exceptionally heavy winter precipitation in Syria. The cooling may have been foreshadowed by low solar emissions. The direct cause of the "536 event" is still unclear; a gigantic volcanic eruption or an oceanic asteroid or comet impact are the predominant explanations. As more evidence comes to light about the ecological consequences of the great climatic disturbance, our understanding of rodent populations in the months and years leading up to the outbreak of the Justinianic plague may improve.³³

Predators also affected rat populations. The Naples excavation that turned up so many rats also indicated that towns of late antiquity now hosted more cats; flea remains suggest that cats spread into Europe's countryside in the early Middle Ages. A heavy mortality (twenty) of mostly young cats coincided at Naples with that of rats, evoking the intimate connection of predator, prey, and bubonic infection.³⁴

Human impact on the environment certainly influenced nat-

33 For Rome's fading sunlight, see Procopius, *Bella*, 4, 14, 5-6, 1.482.19-483.5; Cassiodorus, *Variae*, 12, 25, in Å. J. Fridh (ed.), *Corpus christianorum, series latina*, XCVI (1973), 492-494, makes clear that the previous year had produced an exceptionally good harvest in Italy; drought accompanied the obscuring of the sun for eighteen months. See Amir Harrak (trans.), *The Chronicle of Zuqnin* (Toronto, 1999), 87. Koder, "Climatic Change?" For the Syrian snow, see, for example, *Chronicle of Zuqnin* n. 89. Joel D. Gunn, "A.D. 536 and Its 300-Year Aftermath," in *idem*, *The Years without Summer: Tracing A.D. 536 and Its Aftermath* (Oxford, 2000), 12. The Greenland ice cores appear to argue against a volcanic origin, according to Mike Baillie, *Exodus to Arthur: Catastrophic Encounters with Comets* (London, 2000; 2d ed.), 8, 65-68 (on the stress displayed by European trees in 536 and 540/1). For solar emissions, see Paul Farquharson, "Byzantium, Planet Earth, and the Solar System," in Allen and Jeffreys (eds.), *Sixth Century*, 263-268. David Keys, *Catastrophe: An Investigation into the Origins of the Modern World* (London, 1999), 18-19, argues that drought followed by precipitation most favors plague outbreak, citing unspecified research "monitored" by the Centers for Disease Control. Hence, for him, the Justinianic plague was caused by infected rodents migrating from their usual African habitat because of the event of 536. The chains of causality are likely more complex; it is not certain that *Y. pestis* originated in Africa. See McCormick, "Toward a Molecular History of the Justinianic Pandemic" (forthcoming).

34 King, "Mammiferi," 387-388 (Tabella 39). Although some say that rats are too big for cats, see P. D. Meek and B. Triggs, "The Food of Foxes, Dogs and Cats on two Peninsulas in Jervis Bay, New South Wales," *Proceedings of the Linnaean Society of New South Wales*, CXX (1998), 117-127, 124; von den Driesch and Boessneck, "Roman Cat Skeleton," 210-211, for the six rats discovered in a mummified Roman cat's digestive tract. For fleas and country cats, see J. H. Yvinec et al., "Premiers apports archéontomologiques de l'étude des Pucés," *Bulletin de la Société entomologique de France*, CV (2000), 422.

ural predators. The strong evidence of the arrival of rats in the western Mediterranean comes from the remains of owls' prey in a Corsican cave. It underscores how sensitive the microfaunal population was to ancient human activity. The clearing of fields at the expense of forest or wooded cover to feed the growing human population of antiquity, as of the later Middle Ages, ought to have caused a decline in the number of certain types of owl and other birds of prey, as well as rat-eating foxes and weasels. This removal of the natural checks on rodents occurred as burgeoning settlements multiplied their commensal opportunities, and spreading cereal fields increased their food of choice. Conversely, advancing woodland and its predators may have reduced rat populations in the early Middle Ages.³⁵

Some scholars have wondered whether the centuries-long disappearance of plague after the eighth century might not have been due to the extinction of infected rats. Perhaps rats did in fact disappear from some places. Roman housing may well have been conducive to the spread of rats accustomed to the mild Mediterranean weather, whereas the northern medieval housing and climate *may* have been less attractive for the once-subtropical animal. But the claim that conditions in the north would have discouraged, or even precluded, significant rat populations is overstated. Although black rats in Germany and England today stay close to human habitations, to assume that only human support can sustain rat populations outside a Mediterranean ecology is to underestimate rats' adaptability. Thriving colonies have recently been observed in the cool Atlantic climate of the Hebrides, and, even more surprising, in the subantarctic ecology of Macquarie Island (54° 30'S, 158° 57'E) under conditions that defy the conventional wisdom about their requirements. Besides, the belief that medieval housing and climate were unsuitable for rats is summarily contradicted by their presence on northern sites of the ninth, tenth, and eleventh centuries.³⁶

35 Vigne and Valladas, "Small Mammal Fossil." Modern Italian owl diets conform to Roman and medieval owl droppings in Corsica, showing that *rattus rattus* is a favorite food for certain owls. See, for example, Dario Capizzi et al., "Feeding Habits of Sympatric Long-Eared Owl *Asio Otus*, Tawny Owl *Strix Aluco* and Barn Owl *Tyto Alba* in a Mediterranean Coastal Woodland," *Acta Ornithologica* [Warsaw], XXXIII (1998), 85–92. New Zealand foxes (*Vulpes vulpes*) feed opportunistically and abundantly on black rats. See Meek and Triggs, "Food," esp. 120 (Table 1). Weasels are famous rat hunters.

36 Armitage, "Unwelcome Companions," 233–234; Davis, "Scarcity of Rats," 456–457; Twigg, *Black Death*, 99–100, 124; G. Key et al., "Ship Rats *Rattus rattus* on the Shiant Islands,

Even so, plague, increasing predators, decreasing human host populations, and dwindling cities all could have triggered geographically circumscribed extinctions, just as slackening communications hindered replenishment of decimated rat colonies. Precisely dated rat remains are scarce for the eighth and ninth centuries; the only ones in northwestern Europe so far dated strictly to the eighth century come from far-away Ireland. That the scattered northern sea and river ports where rats would be expected to collect during late antiquity and the early Middle Ages show nothing is especially odd when other small rodents have turned up there (showing that the collection methods were effective). Rats may have repopulated northern Europe via the "Northern Arc," the Viking-age trade route linking the North Sea with Byzantium and the Caspian Sea via the great Russian rivers and Scandinavia. The absence of rats from the eighth- and early ninth-century strata at Birka until 810 to 830 and their reappearance at York only in the late ninth-century Viking deposits seems to point in this direction. Nevertheless, fifteen other European contexts dated, with varying precision, between the eighth and twelfth centuries may yet tell against extinction, or circumscribe its geography. In any event, rats had returned in big numbers by the later Middle Ages. Future research will have to decide whether these new rats derived from a secondary process of colonization spurred by the revival of medieval trade, whether they were survivors from Roman rat colonies, or whether they were the outcome of a complex mixture of survival and repropagation.³⁷

Hebrides, Scotland," *Journal of Zoology* [London], CCXLV (1998), 228-233. The rats in the Macquarie Islands have found a niche at the base of grass plants. They have adapted to distinctly non-Mediterranean conditions; temperatures in their burrows ranged from lows of 4.8 °C (cool day) and 8.7 °C (warm day) to highs of 5.0 °C (cool day), and 9.2 °C (warm day). See T. Pye et al., "Distribution and Habitat Use of the Feral Black Rat (*Rattus rattus*) on Subantarctic Macquarie Island," *Journal of Zoology*, CCXLVII (1999), 435-436. For the most certain evidence of rats in the medieval north, see Audoin-Rouzeau and Vigne, "La colonisation," 129-130 (Table 1), nos. 41-42, 44-46, 48, 51, 56, 61, from France, Belgium, Germany, England, and Sweden. For the new finds in Viking-age Birka, see Wigh, *Animal Husbandry*, 54 (Table 10).

³⁷ For northwestern Europe, see Audoin-Rouzeau and Vigne, "La colonisation," 130 (Table 1), no. 53, where they qualify the find with a question mark. The authors also mention Boulogne, Portchester, York, Southampton, and Paris (137). At York, rats apparently were introduced c. 175-250 A.D. Unlike mice, they are absent from eighth-century deposits, reappearing under the Vikings in the late ninth century. See O'Connor, "Bones from 46-54 Fishergate," in *idem*, *The Animal Bones (The Archaeology of York, 15.4)* (Dorchester, 1991), 256-258. For the "Northern Arc," see *idem*, *Archaeology*, 157. For Birka, see Wigh, *Animal Husbandry*, 54 (Table 10), 125-126. For York, see O'Connor, "Bones." The Dorestad absence

A new twist comes from recent mathematical modeling of the patterns of persistence and recrudescence of plague among rats. In some cases, internal population dynamics of resistant and susceptible rats may have been more important than previously thought. If so, the classic model of bubonic infection—each outbreak requiring the arrival of a new source of infection from outside a rat population—would require modification. The classic model would still hold for smaller rat populations, but the new model suggests that large rat populations, such as those in large cities, could harbor low levels of plague infection for years without causing significant human outbreaks. Without new inputs of infection from outside, the internal rat infection might reach a threshold high enough to spill over into humans only occasionally, about once every ten years. The mathematical model appears to function for so long as a century. If it should prove well-founded, it will introduce unprecedented complexity into the patterns by which bubonic infection persisted and flared during the late Roman and late medieval pandemics, and lend even greater importance to the detailed history of rat populations. But it still leaves intact the enigma of the disappearance of plague from the Mediterranean world and its hinterlands between the eighth and the fourteenth centuries.³⁸

The history of rats has changed in important ways. Much remains to be learned about how rats reached the Mediterranean, and about their history in the inland sea's eastern basin. Northwestern Europe's local extinctions and early medieval repopulation, and their potential links with changing patterns of commerce and communications, await definitive clarification. Nevertheless, archaeologists have already transformed the presence of the black rat

is not significant; sieving came late there. The key mesh was large (4 mm), and only 6 g of wild small mammal remains were identified from 780 l of soil. See Wietske Prummel, *Excavations at Dorestad, 2. Early Medieval Dorestad: An Archaeozoological Study* (Amersfoort, 1983), Table 20, 245–246; 41–42 (collection methods). For the fifteen other contexts, see Audoin-Rouzeau and Vigne, “La colonisation,” nos. 41–42, 45–46, 49, 52, 55, 57, 60–63, 66, and Reichstein's report of the finds at Haithabu and in the castle of Bodenteich, n. 7. For the rats' return, see, for example, Wigh, *Animal Husbandry*, 125–126; O'Connor, “Pets and Pests in Roman and Medieval Britain,” *Mammal Review*, XXII (1992), 108.

38 Keeling and Gilligan, “Bubonic plague,” 2219–2230, show the model for a rat population of 60,000. *Idem*, “Metapopulation Dynamics”; Elizabeth Matisoo-Smith et al., “Patterns of Prehistoric Human Mobility in Polynesia Indicated by mtDNA from the Pacific Rat,” *Proceedings of the National Academy of Sciences of the United States of America*, XCV (1998), 15145–15150.

in Roman and medieval Europe from speculation to certainty, in the process provoking new questions for archaeology, zoology, and molecular biology, as well as for our written sources. The story of black rats is crucial to that of bubonic plague. If the same technique that has identified the DNA of *Y. pestis* in the teeth of human victims could be applied to the teeth of ancient and medieval rodents, and if the DNA displays sequences characteristic of *Y. pestis*, the results could open up a host of new insights about the transmission of *Y. pestis* during the two great pandemics.

But the rat has much more to teach us. As data accumulate and research deepens, insights into the environmental impact of man's transformations of the ancient and medieval landscape, into ancient urbanism, and into changing patterns of long-distance and local transport and communications will undoubtedly follow. Indeed, phylogenetic studies of mitochondrial DNA in Polynesian rats (*Rattus exulans*) are using the genetic history of commensal rodents to illuminate human migrations and movements, suggesting the black rat's potential in this regard, too. Final answers may not be imminent, but at least the questions are becoming clearer. The human and animal past is one. Historians will have to follow archaeologists, zoologists, and molecular biologists into new areas of reality. Every instrument in the historical, archaeological, and scientific toolkit is needed to understand the past in all of its ecological complexity.