beneath the Siwaliks Hills. However, the uplift profiles of the youngest Holocene terraces across the Bagmati/Ratu anticline (fig. S1) (*15*) do not exhibit the expected component of elastic deformation (discussion S3 and fig. S2) (*15*). Rather, terrace profiles suggest that the ruptures associated with blind M_w <8.2 events contribute by permanent postseismic deformation to the long-term folding of the most frontal Himalayan structures.

In the second hypothesis, the large slip value observed at Marha Khola would have been produced by a great earthquake that ruptured a large segment of the Himalayan arc. In contrast with the M_w = 8.1 1934-type events, its seismic energy would have been sufficient for the rupture to propagate up to the surface. In this hypothesis, the ~1100 A.D. earthquake may have nucleated below the High Himalayas, as is suspected for the 1934 event, and broken through to the surface trace of the Main Frontal Thrust fault, a cross-strike distance of about 100 km (Fig. 1). Its lateral extent could have therefore reached or overcome the 200- to 300-km length that has been ascribed to the 1934 M_w 8.1 earthquake (*14*). A trench across the Main Frontal Thrust fault in far east Nepal (*3*, *4*) exposed a rupture with >4 to 8 m of slip that occurred between 1050 and 1300 A.D. (Fig. 4). If this surface rupture is synchronous to the ~1100 A.D. event, its lateral extent would reach at minimum 240 km. The magnitude of this earthquake would range from M_w 8.4 up to M_w 8.8 (*20*), assuming that the respective slip values observed in far east Nepal and Marha Khola trenches are representative of the average slip on the fault plane.

Additional paleoseismic studies are required to test the above hypotheses and to ascribe a more precise rupture length, mean slip, and magnitude to the inferred great medieval earthquake. For the moment, according to the worst scenario and to magnitude distribution law for thrust earthquakes in Nepal (*21*), the return period for a ~M_w 8.8 and 17-m mean slip event would range between 1800 and 3000 years at Marha Khola (with large uncertainties, given that the magnitude distribution law can not easily be extrapolated to large earthquakes). Such very large events would thus accommodate 25 to 50% of the shortening across the Himalayas, and if generalized to the whole Himalayan arc, would help to bring the seismic moment summation to closure (*19*). Between two such great earthquakes, the Main Himalayan Thrust can generate, in addition, several 7.5 < M_w < 8.2 events, but in the absence of surface ruptures, estimating the recurrence and slip for this type of Himalayan thrust earthquake is not possible using conventional paleoseismic trench studies.

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How Science Survived: Medieval Manuscripts' "Demography" and Classic Texts' Extinction

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Determining what fraction of texts and manuscripts have survived from Antiquity and the Middle Ages has been highly problematic. Analyzing the transmission of texts as the "paleodemography" of their manuscripts yields definite and surprisingly high estimates. Parchment copies of the foremost medieval textbooks on arithmetical and calendrical calculation closely fit age distributions expected for populations with logistic growth and manuscripts with exponential survivorship. The estimated half-lives of copies agree with Bischoff's paleographically based suggestion that roughly one in seven manuscripts survive in some form from ninth-century Carolingian workshops. On this basis, many if not most of the leading technical titles circulating in Latin probably survived, even from late Antiquity.

Every student learns that the germ of his or her science barely made it through the Middle Ages. Just how likely were individual handwritten books to survive, or entire works to be lost? So far, the best evidence has come from the histories of individual manuscripts, libraries, and texts as reconstructed by paleographers, and it is overwhelmingly anecdotal.

Because manuscripts, unlike printed material, must be copied individually from antecedents, like organisms, their multiplication likewise should be inherently exponential. By treating the manuscripts of a

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text as if they were fossils from an extinct population (*1*, *2*), and by drawing on centuries of paleographic scholarship for demographic data, it becomes possible to roughly characterize the dynamics of the transmission process.

The Markov birth-and-death process is perhaps the simplest and most generally applicable stochastic model for any such statistical population's growth (*3*). Suppose that, in any given instant, each manuscript of a text has a certain probability λ of "giving birth" (being copied) and a certain probability μ of "death" (being destroyed). The population's expected per capita birthrate will be λ, and its expected per capita death rate will be μ. Individuals will die off exponentially with half-life (ln 2)/μ. If $\lambda > \mu$, a population of size M_t at time t will increase exponentially with doubling time $(\ln 2)/(\lambda - \mu)$ and will suffer chance extinction with probability $(\mu/\lambda)^{M_0}$ (*3*).

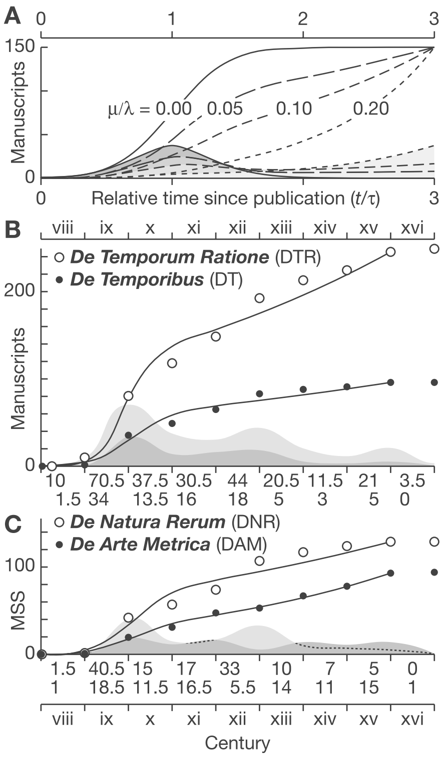

Fig. 1. Age distributions for manuscript populations. (**A**) Age distributions predicted from the model developed for populations with differing "birth" (λ) and "death" (μ) probabilities. Shown are cumulative curves for the number of manuscripts m_t surviving from time t out of a total $m_T = 150$ at a time $t_T = 3\tau$, and each of these curve's time derivatives dm_t/dt, which correspond to the manuscripts' age-frequency curves (*1*). The graph is scaled for comparison with the four cases in (B) and (C). (**B** and **C**) Age distributions for parchment manuscripts of the Venerable Bede's four technical works showing the numbers of manuscripts known from each century and the least-squares curves for m_t up to t_T = 1500 A.D. fitted according to the model in (A) (Table 1). The manuscripts themselves range from isolated pages to complete copies. Ages are given to the nearest century because that is how precisely most manuscripts have been dated. The endpoint t_T = 1500 A.D. represents the end of the last full century during which copies were produced entirely by hand. The number of copies surviving from each century is given below the age axis for each text and is plotted in the background, tone screens distinguishing the texts (*1*). To alleviate the problems of aliasing, a borderline case dated "ca. 800" or "saec. VIII/IX," for instance, is counted as half a manuscript in the eighth century and half in the ninth. MSS, manuscripts.

Of course, any real population's per capita growth rate will decrease as M_t increases toward some limit M_∞. Suppose that the per capita birth rate λ_M decreases linearly with the difference between the population's actual and limiting sizes: $\lambda_M = \lambda - (\lambda - \mu)(M_t/M_\infty)$. The rationale is that new copies, being very expensive, were produced individually to order, as librarians' book lists and correspondence suggest (*4*), not by the batch on speculation, like printed books. Suppose also that the actual per capita death rate μ is constant, the rationale being that manuscripts' destruction generally was unintentional and hence tended to proceed at a more or less constant per capita rate, barring proscription or obsolescence of the text.

What emerges is the Verhulst-Pearl logistic equation for population growth, which Price suggested might apply to growth of the scientific literature (*5*), and a somewhat different expression for the surviving number of manuscripts m_t (as opposed to the generally unknown M_t): $m_t/m_T = [e^{-\lambda(T-\tau)} + e^{-\mu(T-\tau)}]/[e^{-\lambda(t-\tau)} + e^{-\mu(t-\tau)}]$, where τ is the expected time for a population to grow from $M_0 = 1$ to $M_\tau = M_\infty/2$, and $T = t_T - t_0$ is a reference time interval (*1*) (Fig. 1A). The "fossil" population's age distribution (m_t) should be very sensitive to the probability ratio μ/λ (*1*). If $\mu/\lambda < 3 - 8^{1/2} \approx 0.17$, the cumulative age distribution (m_t) will have an inflection point, and the corresponding age-frequency curve (dm_t/dt) will preserve a distinct maximum corresponding to the maximum in the growth-rate curve (dM_t/dt). Otherwise, if $\mu/\lambda > 3 - 8^{1/2}$, both curves will be concave upward.

The Venerable Bede's *De Temporum Ratione* (725 A.D.) (*6*–*8*) is nearly ideal for studying the dissemination of technical information: It was the standard textbook on arithmetical and calendrical calculation from the eighth to sixteenth centuries (*9*, *10*): Its first chapter, on finger counting, was the standard instruction manual for the "pocket calculator" of the time, and so found a readership in commercial as well as learned circles (*11*); it was ideologically neutral; it is relatively common; and its manuscript tradition is well known (Fig. 1B). Much the same can be said of Bede's three other technical works (*1*), which are included for comparison (Fig. 1, B and C).

Despite many potential complications, the model evidently applies well to all four cases, the iteratively fitted least-squares curves in Fig. 1, B and C, accounting for 96 to 99% of the variance in m_t (R^2, Table 1) (*1*). Figures indicate that a title's manuscripts were about 15 to 30 times more likely to be copied as to be destroyed and had a half-life of four to nine centuries, and that population's doubling time was on the order of two to three decades (Table 1). Modest escalations (*5*) in M_∞ took place during the ninth-century Carolingian renaissance [when Bede's textbooks began to be mass produced as part of the program to promote and standardize education and administration throughout the nascent Holy Roman Empire (*11*, *12*)], during the 12th-century renaissance, and again during the Renaissance of the 15th century (Fig. 1, B and C)—correspondingly modest violations of the model's assumption of constant M_∞, but also evidence that manuscripts' age distribution reflects an ongoing balance between supply and demand, as assumed.

For manuscripts in general, the fraction that escaped destruction during social upheavals such as the Viking wars or French Revolution, or through simple neglect after printed editions appeared, has attracted widely varying guesses but hardly any reasoned estimates. The one most generally accepted for titles of Bede's vintage has been that of Bischoff, who suggested that about one in seven manuscripts have survived from ninth-century Carolingian workshops (*13*, *14*). If a roughly six-century half-life is typical of the Bede manuscripts, as Table 1 suggests, that number would be closer to two in seven—remarkably good agreement, considering the uncertainties (*1*).

Table 1. Estimated values and standard errors of population parameters for the Venerable Bede's four technical works (*1*). cent, centuries; DTR, *De Temporum Ratione*; DT, *De Temporibus*; DNR, *De Natura Rerum*, DAM, *De Arte Metrica*.

Text	λ (cent^{-1})	μ (cent^{-1})	μ/λ	τ (cent)	R^2
DTR	3.6 ± 0.2	0.11 ± 0.00	0.032 ± 0.002	~1.6	0.98
DT	2.4 ± 0.1	0.08 ± 0.01	0.033 ± 0.004	~2.0	0.98
DNR	2.5 ± 0.2	0.10 ± 0.01	0.040 ± 0.006	~2.0	0.96
DAM	2.6 ± 0.0	0.18 ± 0.00	0.070 ± 0.006	~1.9	0.99

The fraction of titles that have survived from Antiquity has been even more uncertain. Present results suggest that a substantial proportion of the more popular texts circulating in the early Middle Ages probably has survived. If a dozen parchment copies of any one of the four Bede texts existed in Carolingian times, and if each copy has had a one-in-seven chance of surviving to the present, the likelihood is greater than 80% that at least one of these would survive today, and thus that the text itself would survive. If a population of a potentially popular text such as those in Table 1 started with $M_0 = 1$, so that the unlimited birth-and-death process would apply as an approximation, the text would have roughly a $\mu/\lambda \leq 0.07$ chance of ultimate extinction (*3*). Thus, if all 35 of the mostly nontechnical works that Bede lists in his *Historia Ecclesiastica Gentis Anglorum* (731 A.D.) (*15*) likewise had an extinction probability of $\mu/\lambda \leq 0.07$, one might expect no more than two or three to be extinct. In fact, three are extinct (*16*), suggesting that present results apply as an approximation to Bede's nontechnical as well as technical works, and quite possibly to contemporary textbooks in general.

Taken together, present results suggest that many if not most scientific and technical works that circulated in Latin on parchment in the early Middle Ages or even in late Antiquity survive in some form. But why then have so few actually survived from Antiquity? For instance, only one of seven works by Pliny the Elder and only a small fraction of the approximately 2000 works on which he based his *Naturalis Historia* (77 A.D.) (*17*), the foremost scientific encyclopedia of the Middle Ages, have survived. The answer may lie in copyists' changeover from papyrus to parchment during the third and fourth centuries (*18*). Surviving texts may be mostly those similar to Pliny's (*19*), which happened to have been in demand during and soon after the transition to the new and more durable medium.

Only further research will tell how accurate or how representative present estimates are. The important point is the apparent feasibility of quantitatively investigating the dynamics of knowledge transmission in ancient and medieval times by demographically analyzing centuries' worth of accumulated paleographic data.

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The Restoration Potential of the Mesopotamian Marshes of Iraq

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Uncontrolled releases of Tigris and Euphrates River waters after the 2003 war have partially restored some former marsh areas in southern Iraq, but restoration is failing in others because of high soil and water salinities. Nearly 20% of the original 15,000-square-kilometer marsh area was reflooded by March 2004, but the extent of marsh restoration is unknown. High-quality water, nonsaline soils, and the densest native vegetation were found in the only remaining natural marsh, the Al-Hawizeh, located on the Iranian border. Although substantially reduced in area and under current threat of an Iranian dike, it has the potential to be a native repopulation center for the region. Rapid reestablishment, high productivity, and reproduction of native flora and fauna in reflooded former marsh areas indicate a high probability for successful restoration, provided the restored wetlands are hydraulically designed to allow sufficient flow of noncontaminated water and flushing of salts through the ecosystem.

The Mesopotamian marshes of southern Iraq (30° to 33°N, 45° to 48°E) are considered by many to be the "cradle of western civilization" and are often referred to as the Garden of Eden (*1*, *2*). Their ecological and cultural value derive from their large expanse of wetland habitat in southwest Asia, once covering nearly 15,000 km^2 (*3*, *4*) (Fig. 1A). Unique to the Mesopotamian marshes is the indigenous population of marsh dwellers, commonly called the Marsh Arabs, who already have a special place in the anthropological and cultural literature for their alluring way of life, living in harmony in relative isolation within the marsh environment for the past 5000 years on man-made reed islands and along the periphery of the marshes (*1*, *5*, *6*). Notably, the marshes were once the permanent habitat for millions of birds and a flyway for millions more migrating between Siberia and Africa (*7*, *8*).

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