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Counting Sheep: Potential Applications of DNA Analysis to the Study of Medieval Parchment Production

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Abstract

This chapter follows up on several preliminary tests that have shown that DNA survives in medieval parchment manuscript leaves and may be extracted and analyzed, and offers suggestions for defining and implementing future genetic studies of parchment. It articulates the need to consider genetic data in conjunction with other types of evidence—such as historical texts and archaeological data—both in planning tests of parchment and in interpreting the results of such tests. I consider the potential influences of diet, urbanization, market and trade specialization, and changes in agricultural practices and animal husbandry on parchment production, and discuss how genetic analysis can contribute to our knowledge of these topics as well as how historical and archaeological evidence will both complicate and contextualize data derived from genetic testing.

Zusammenfassung

Dieser Beitrag schließt sich an eine Reihe von ersten Tests an, die gezeigt haben, dass DNA in mittelalterlichen pergamentenen Handschriftenseiten nachweisbar ist und extrahiert und analysiert werden kann. Es werden daraus Anregungen für die Bestimmung und Umsetzung zukünftiger genetischer Pergamentuntersuchungen entwickelt. Genetische Daten, so wird argumentiert, werden dabei im Zusammenhang mit anderen Erkenntnissen, etwa aus historischen Texten oder archäologischen Befunden, sowohl bei der Planung kodikologischer Untersuchungen als auch bei der Interpretation ihrer Ergebnisse eine wichtige Rolle spielen. Der Beitrag diskutiert die möglichen Einflüsse von Nahrung, Urbanisierung, der Spezialisierung des Handels sowie von Wandlungen in bäuerlichen Praktiken und der Haustierhaltung auf die Pergamentproduktion. Besprochen wird auch, wie genetische Analysen zum Erkenntnisgewinn in diesen Fragen beitragen und ob und wie sie historische und archäologische Belege sowohl in Frage stellen als auch kontextualisieren.

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1. Introduction

In December of 2009, I published an article in *The Papers of the Bibliographical Society of America* (*PBSA*) detailing the successful outcome of a project designed to determine the feasibility of extracting the DNA contained in the parchment leaves of medieval manuscripts (Stinson). Working with C. Michael Stinson, a biologist with experience in phylogenetic research, I was able to confirm that DNA not only survives in medieval parchment, but also that it may be extracted and analyzed in order to reveal bibliographical information as well as information about the animals whose skins furnished the parchment. Through an analysis of the DNA contained in five disbound parchment leaves that had likely once belonged to a fifteenth-century Flemish book of hours, we were able to determine the genetic relatedness of calves that had been used in the manufacture of the book, showing that two leaves were derived from one maternal lineage and the other three from a second maternal lineage. Our project joins a small number of similar studies that seek to leverage the genetic information contained in parchment in order to gain a fuller understanding of medieval books and documents in their historical and physical contexts; Woodward et al. conducted a study of the parchment of the Dead Sea Scrolls, Burger et al. surveyed a wide variety of pre-historic hided materials, and Poulakakis et al. published a study of the parchment of Greek manuscripts written on goat skin.[1] All of these studies have been exploratory in nature, and each has demonstrated the survival of DNA in medieval parchment and the feasibility of extracting it in order to identify the species from which the parchment was made and to reveal the genetic relatedness (or lack thereof) of the animals used to make it. Our study is ongoing, with current work focusing on the development of techniques for testing parchment that are minimally destructive but provide reliable scientific results.[2]

In addition to detailing the techniques and results of our study, my article briefly suggested four potential benefits that the analysis of genetic information offers to the study of medieval books, which I repeat here in abbreviated form:

1. Localizing herds. Once a substantial number of manuscripts were tested and the results entered into databases, we would have the potential to localize both herds

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[1] See also Spencer and Howe (246–47), for a brief discussion of their experimentations "with methods for extracting DNA from parchment". To date there have been no further publications from their study.

[2] All studies thus far have used pieces of parchment or hide material larger than is permissible or desirable for the large-scale study of library and archival collections of manuscripts. Our own study used samples measuring 0.5×0.5 cm taken from the center of the lower margin of manuscript leaves, a sample size that is ample from scientific terms, but clearly not ideal from a preservation or curation point of view. A further goal of the current phase of our project is the analysis of nuclear as well as mitochondrial DNA, which will be necessary in order to achieve some of the possibilities mentioned in this essay. The distinction between these types of DNA is discussed in my *PBSA* article.

and manuscripts. Working from manuscripts with known dates and provenance,[3] we might be able to construct models showing the likely family descent and local origin of animals and parchment, thereby equipping scholars with a new tool for determining the origins of manuscripts.

2. Studying the parchment trade. Little is known about the medieval parchment trade, a deficit that this project could begin to remedy. It is generally assumed that early in the medieval era, monasteries that were engaged both in copying texts and in raising herd animals for meat, hide, and wool likely used their own herd animals to produce parchment, and that the earlier a manuscript is the more likely that this is the case. Commercial production of parchment in the later medieval era, meanwhile, likely involved trade routes and the mixing and redistribution of skins in both market towns and in workshops producing and selling parchment in large cities and university towns such as London, Paris, and Oxford. Such practices would complicate the study of both herd populations and the origins of individual skins, but conversely parchment from this era might provide data for tracking the movement of animals and the trade and distribution of skins.

3. Analyzing the construction of codices. Although parchment is quite durable, as are the books created from it, many manuscripts have of course deteriorated substantially due to poor handling, intentional disbinding for financial or other motives, fire, moisture, overzealous binding, and misguided conservation efforts. This has often resulted in the loss of codicological information necessary to understand how the manuscript was initially constructed. Because bifolia were originally one piece of skin, DNA identification to the level of the individual organism might allow scholars to deduce the original gatherings and how they were combined to create a codex.

4. Resolving debates concerning individual manuscripts. Scores of puzzles and debates surrounding single codices might be resolved (or at least one position in these debates substantiated) through such analysis. A good example of such, and one that has been previously raised by Christopher de Hamel ("DNA – Genetic Fingerprinting"), is the famous Bury Bible, one of the treasures of the Parker Library at Corpus Christi College, Cambridge that dates to the twelfth century. The *Gesta Sacristarum*, a late thirteenth-century history of the Bury St. Edmunds abbey where the Bury Bible was made, states that the parchment used for the Bible's illustrations was a special, expensive lot brought in "from regions of *Scotia*" because Master Hugo, the illuminator, could find no local parchment to suit him (*Memorials* ii, 290). This story is seemingly borne out by the fact that the illuminations are all rendered on individual leaves of parchment glued to ones beneath them that are sewn into the book, but scholars disagree on whether *Scotia* refers to modern-day Scotland or Ireland. An analysis of the origins of this

[3] A good starting point for such research would be standard reference works listing dated and datable manuscripts such as Robinson's *Catalogue of Dated and Datable Manuscripts c. 888–1600 in London Libraries* and Watson's *Catalogue of Dated and Datable Manuscripts c. 435–1600 in Oxford Libraries*.

book combined with comparisons to parchment from other codices could augment our understanding of a medieval historical text (the *Gesta*), add important context to our understanding of how a medieval Latin place name was used, and go far towards solving a modern scholarly debate about this important manuscript.

The third and fourth benefits listed above are reasonably self-evident; if we are able to identify the animals from which parchment leaves were derived as well as their potential relatedness to other animals in the same book, then it is clear that this information might provide direct information about how a disbound book was initially constructed and/or to contextualize the construction of a given book (e.g., all animals in the book are closely related and from a definable area, or the book is an admixture of more distantly related animals). My goal in this essay is to discuss the first two potential benefits in greater detail. I will consider how genetic studies of parchment might make the realization of these goals possible as well as how we will need to consider genetic data in conjunction with other types of evidence—such as historical texts and archaeological data—both in planning tests of parchment and in interpreting the results of such tests. Without doing so, we will be unable to reach the fullest possible understanding of the significance and meaning of genetic data found in medieval parchment.

2. Parchment as Archaeological Evidence

It is worth pausing first to consider several ways in which parchment provides particularly unusual and valuable evidence concerning human use of and interaction with animals. To date, parchment's historical value has primarily been understood to be its role as a substrate for written texts; its durability and ability to support and preserve texts and illustrations over many centuries have contributed enormously to the survival and transmission of much of our intellectual and cultural heritage from the medieval era. Viewed another way, we might see parchment leaves themselves as important artifacts that contain much information about human industry as well as the lives of the animals from which the substance was derived. It is not unusual for animal remains from the medieval era to be examined for evidence of what they can tell us about medieval life; for example, zooarchaeologists exhume bones, shells, and teeth in order to understand how animals were utilized, processed, and disposed of by humans, while museum curators and historians study decorative arts and practical everyday objects made from the same materials, from musical instruments to combs and knife handles. But parchment, which survives in tens of thousands of extant medieval books, many of which contains hundreds of pieces of parchment each, as well as in countless unbound documents held in libraries and repositories around the world, remains for the most part unexamined as archaeological evidence. There is, of course, a good reason for this, the very reason that so much parchment has survived—much of it in

excellent condition—while many other artifacts from the Middle Ages survive only in poor condition, if at all. This is the fact that the books containing the parchment are highly prized both for their aesthetic merits and for the information conveyed in the texts they comprise, and many have been considered worthy of curation and careful treatment from early in their histories (although many others have not, unfortunately). As Holsinger notes, "[w]hile a phylogenetic archaeologist will not hesitate to extract a nice chunk of ossified bone marrow from a thirteenth-century cow femur for laboratory analysis, the book is priceless; the book [. . .] has legal protection" (620).

We are fortunate indeed that books have been so prized, for animal bone and hide were used to manufacture many common items in the medieval era, including clothing, footwear, bags, drinking vessels, and bone tools of many varieties, but these items range from being relatively rare to virtually impossible to find today. Parchment books survive in very large numbers, however, and the development of techniques for extracting and analyzing DNA means that the parchment leaves that these books contain now have many stories to tell other than those written upon them, and the survival of so many samples in good condition offers a wealth of possibilities for scientists to explore once sufficiently non-invasive testing procedures have been developed.[4] Medieval parchment books are especially important sites of archaeological and historical evidence because of their nonpareil combination of physical and textual information. A cow femur dug from an archaeological site will not have written upon it the name of someone who processed or consumed the cow, nor will a comb made from bone usually have written upon it the date and place of its origin, but similar information is routinely found in certain types of texts such as legal documents and chronicles. We cannot assume that parchment was derived from the same area where texts were copied onto it, as discussed below, but the combination of local historical information such as names, dates, place names, and regional dialects with the very large-scale survival of well-preserved artifacts containing DNA is without parallel, and we stand to gain much from analyzing this information in tandem.

DNA evidence is particularly promising due to its potential to be combined with other types of evidence, including not only historical and legal texts, but also other faunal remains, to develop much more specific and complete understandings of how medieval humans interacted with and used animals during the medieval era. In order to understand how such studies of genetic information might usefully be conceived and carried out, it is first necessary to acknowledge the ever-shifting nature of the conditions of humans and domestic animals across the medieval era. Population growth,

[4] Developing such techniques is the focus of the next phase of our ongoing research into the genetic analysis of parchment. Possible techniques include taking very small core samples from parchment leaves and swabbing the surface of the parchment or rubbing it gently with a metal implement in order to get useable cells. Techniques for taking tiny core samples have not yet been perfected, and swabbing or rubbing the surface increases the likelihood of contaminated samples.

changes in economic structures, shifts in the types of food consumed, climate change, deforestation, increasing numbers of roads and opportunities for trade, new agricultural techniques and practices, and the hunting of animals such as bears and wolves to near extinction all had profound impacts on humans as well as the animals on which they depended, whether wild or domestic (Resl Introduction 3). Furthermore, such changes happened at different times in different areas of Europe, and were subject to other local conditions, including regional climate, natural disasters, war, and disease. The production of parchment for books was impacted by all of these forces (and the demand for parchment may have in turn influenced at least some of them, such as agricultural practices and trade), and as such we should be hesitant to accept blanket assertions about its production, value, and use across the whole of medieval Europe.

3. Genetics and the Parchment Trade

The two topics that I have identified for this study—the genetics of local herds and the parchment trade—are necessarily intertwined; in order to trace how parchment moved from place to place, we will first need to be able to identify local and regional groups of animals, which seems feasible due to the fact that in Europe parchment was almost always produced from domesticated herd animals. As a case study, I will consider here one question regarding parchment that has been frequently posed—how expensive was it to produce a single book?—and focus primarily on one animal and nation—the sheep in England—although I will draw upon evidence of other animals and countries for purposes of comparison. This will demonstrate not only how genetic information might be used to answer such a question, but also how other disciplines and types of evidence that inform us of herd populations and the parchment trade will be necessary to contextualize genetic information. My aim here is to think through some of the preliminary conditions for designing a study of medieval parchment and book production that incorporates genetic evidence, including what other disciplines are already able to tell us regarding these topics at any given time and place in history, for without doing so we are unlikely to arrive at meaningful results simply by taking decontextualized samples of genetic materials from medieval books.

In order to answer the question of how expensive it was to produce a book copied on sheepskin parchment in medieval England, we must consider how many skins such a book would require as well the relative value of those skins if used in other ways (e.g., leather) or the value of the animal if left alive (e.g., wool, milk). As Febvre and Martin noted some decades ago, a number of written accounts of the number of animal skins used in the production of parchment books provide exaggerated claims that do not square with basic mathematical calculations:

> A simple calculation will be sufficient to demolish the stories so often told about the fabulous numbers of sheep and calves required to make a single book. Even modern works of scholarship continue to repeat these old errors. Thompson, for example, quotes an order by the Countess of Clare in England in 1324 for a copy of the *Vitae Patrum*, for which no fewer than 1,000 skins were allegedly required. At the current price of 2 pennies per skin, the vellum alone would have cost the fabulous sum of £6. In fact an examination of the *Vitae Patrum*, whether in Latin or in one of the contemporary French versions, quickly shows that when written in two columns the text generally fills about 150–160 leaves of 25 cm × 16 cm, a total area amounting to no more than 6 square metres—a dozen skins at the most. (17)[5]

Even if such clearly inaccurate calculations are too common, they may at least easily be shown to be in error. A more complicated matter is the commonly repeated and potentially misleading claim that a single book might comprise the skins of an entire herd or flock; for example, Jean Leclercq notes that "a flock of sheep was needed to provide the parchment necessary for copying a book by Seneca or Cicero" (123). Such claims tend to obscure the truth as much as they relate it, for they simply convey into the reader's mind whatever size they imagine a medieval flock of sheep to be, whereas the reality varied from a few sheep owned by a private farmer to herds comprising tens of thousands of animals owned by noblemen or industrious monastic orders. For example, "[t]he Benedictines of Ely were already feeding 13,000 sheep at the time of the Domesday Book (1086)," and the Benedictines at Winchester Cathedral Priory are recorded as owning a flock of 20,000 sheep in 1320 (although of course these may have been dispersed into numerous smaller flocks), which could provide enough parchment for many books year after year (Butler and Given-Wilson 85–6). This is not to say that very large volumes did not utilize the skins of many animals; the largest volumes utilized one calfskin per bifolium, as these were of course larger than the skins of young sheep. Bruce-Mitford calculated that the Codex Amiatinus—which measures 505 × 780 mm, has more than 1,000 folios, and weighs approximately 75 pounds—contains 515 calfskins (2). The Book of Kells, meanwhile, measures 330 × 240 mm and contains 340 folios and was made from as many as 150 calves, and even so it is incomplete; approximately 40 folios are missing and a binder has trimmed the leaves down from an estimated original size of 370 × 260 mm (Henry 152). Thus claims that one flock (or herd) of animals went into one book must be considered carefully, as a small flock might number a dozen sheep—and a small book be produced from that dozen—while even the largest books do not approach the sizes of the largest flocks of many thousands of domesticated animals.

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[5] Febvre and Martin here cite J. W. Thompson, *The Medieval Library* (645).

Since books and herds vary greatly in size in medieval England, it may be more useful to consider the value of a single animal skin at any given time, and to extrapolate from that the value of the parchment in one book. One way to do this, of course, is to consult records for sales of unfinished skins and/or finished parchment, as Febvre and Martin do in the passage quoted above; they argue that in both England and France the price of parchment remained "reasonably stable from the second half of the 14th to the first half of the 15th century, when book production was increasing rapidly, and this seems to prove that it was not such a rare commodity" (18). The authors are here interested in the impact of printing, and the subsequent increase in the number of books being created, on the price of parchment, and researchers should follow their lead in consulting records of the price and sale of parchment for the time periods and local regions that interest them and match their research agenda. But such records are not always available, and determining the relative value of a skin in their absence is a complex matter, for its value must be considered in relation to other uses for either it or the animal that had to be killed in order to provide it:

> Looked at another way, what was the economic cost to the community to produce (i) the raw material, and (ii) the secondary product? Was the cost very high in relation to alternative uses for the skins, or in terms of the decision to slaughter an animal before it had reached full maturity and therefore maximum meat weight? Or did parchment-making, with its demand for young animal skins, fit easily into a system where many young male animals were slaughtered annually in order to conserve winter fodder for the breeding and milk-yielding females? (Ryan 125)

As Ryan notes, determining the relative value of a skin involves imagining two other possible scenarios. The first is that the raw skin is put to alternative uses, such as the production of leather. The second is the economic benefit of letting an animal reach adulthood. Because the skins of young animals not old enough to reproduce were used for parchment production, such benefits may be numerous, including the ability of these animals to reproduce (thus providing offspring with their own economic benefits), the increased meat that might be provided by adult animals, larger hides for leather (although these would be too thick for parchment), wool, manure for fertilizer, horn (which was used for a variety of manufactured goods), and milk. These economic benefits of letting animals reach an adult age were potentially offset by other factors, including a market for veal or lamb, the economic benefit of having fresh meat to sell throughout the year, sufficient grazing space, the fact that adult hides were more likely to be damaged by disease or insects, and the cost of providing fodder for adult animals during the winter in colder climates.

Genetic analysis has the potential to answer clearly and definitively the number of different animals whose skins were used to produce the parchment in a given book,

such as our hypothetical English book with sheepskin leaves, for tests can be conducted in such a way that they distinguish one organism from another. It is possible, of course, that one skin would have been made into parchment sheets that ended up in different volumes—indeed it must have happened frequently—but calculations that estimate the surface area of one skin combined with genetic evidence of how many different animals are found in one volume should provide a very close estimate of the number of individual animals used in any given volume, as well as how likely it is that part of these skins were used in other volumes or for other purposes. Determining the relative value of these skins, however, as well as the economic tradeoffs that would have been made in culling young animals for parchment instead of letting them reach maturity, cannot be achieved from genetic analysis alone, and it is here that combining research into DNA with extant scholarship will be crucial.

4. Uses of Historical and Archaeological Evidence

In his introduction to *Breaking and Shaping Beastly Bodies: Animals as Material Culture in the Middle Ages*, an anthology of essays on zooarchaeological topics, Terry O'Connor notes that archaeologists "need all of the other disciplines that study the medieval world" in order to understand and contextualize their data (6). Similarly, in the course of reporting his study of domestic animal remains from the medieval era found near Dudley Castle, Richard Thomas notes that "[z]ooarchaeologists have tended to use historical facts as 'interesting anecdotes' rather than as an integral part of research", while "the majority of historical expositions regarding the exploitation of animals in the medieval and post-medieval periods are considered almost to the complete exclusion of archaeological evidence" (17–18). In order to realize the full potential of genetic analysis of parchment, and to avoid producing reports of isolated facts about the genetic makeup of medieval sheep, cattle, and goats, we need to heed such advice by considering the extant archaeological and historical data both before and after conducting genetic tests of parchment. I would thus like to turn now to examples of the types of historical and archaeological evidence that might help to answer questions regarding the relative value of parchment (as well as many other questions), evidence that genetic analysis of parchment might serve to contextualize and that in turn might serve to clarify and make meaningful the results found through DNA testing.

A particularly important body of such evidence lies in our knowledge of medieval practices of animal husbandry. I have already noted that herd sizes differed significantly in the medieval era, which would of course have implications for the genetic variety of any given herd population. As is still the case today, many domesticated male animals were castrated, which made them more docile and their meat more tender. A few adult males were of course needed for breeding, but then as now one bull or ram would be

sufficient for a large numbers of cows or ewes. As the size of the herd increases, we should of course expect to find more genetic diversity, as a small herd might descend from one adult male for a number of consecutive years, whereas a large herd numbering thousands of animals would be more likely to result in a breeding female mating with different males in consecutive years, and would necessitate more than one breeding male for the herd each year. In addition to varieties in the size of herds, there are general trends in animal husbandry across the time period that also must have affected the genetic composition of those herds. In early medieval England, for example, sheep and other domesticated animals were "semiwild" and lived outdoors "between the farm and forest", requiring protection from forest predators, but "[t]he general trend between the eleventh and fifteenth centuries brought animals from the forest to the farm and from the farm to the urban market and slaughterhouse" (Pascua 82–3). This process culminated at the end of the Middle Ages with the policy of enclosure, which maximized the income of wealthy landowners, but famously led to depopulation of villages, unemployment, and other social ills, as well as to a sheep population that "had multiplied so rapidly that it produced a major crisis in the use of land" (Lander 38). The story of sheep populations in England is not one of uninterrupted expansion, however, as changes in climate and outbreaks of disease periodically decimated populations:

> The best-known early epidemics occurred during the period 1315–1319. However, the problems began in the decade of 1270–1280. From England to Castile, chroniclers mention declining crop yields and monasteries, particularly Cistercian, unable to produce the amount of wool contracted with merchants. Large manors went bankrupt, a sign of an economy in collapse. The flocks of the Bishop of Winchester, which exceeded 27,000 sheep in 1272, numbered fewer than 9,000 in 1278 and yet fewer in 1280. (Pascua 96)

Selective breeding was also practiced and developed during the Middle Ages in England; the Cistercians, for example, were "pioneers in grading their wools, which the Benedictines had preferred to sell mixed and in bulk" and "studied feeding and breeding, and the possibility of grappling with the deadly disease of sheep-rot" (Butler and Given-Wilson 85). The potential of genetic studies of parchment to contribute to our knowledge of animal husbandry practices is clear. It may be possible, for example, to articulate genetic differences between free-roaming sheep that were kept by shepherds—and perhaps mated with other herds found "between the farm and forest"—and those sheep kept in enclosures at the end of the medieval era. Or perhaps we may be able one day to chart the influence of Cistercian practices on breeds of sheep. But this information also serves as a caution to us, for it shows that we cannot assume that something true of ninth-century animals will also be true of late fifteenth-century animals, and thus we must proceed carefully both in designing our genetic studies of parchment and in drawing conclusions from those studies. The variety of situations outlined here also

shows how the relative value of parchment might have shifted over time. The amount of labor required to shepherd sheep versus keeping them in enclosures, the waxing or waning market demand for wool over the centuries, and the overpopulation (or underpopulation) of sheep might all impact the relative value of letting lambs reach adulthood versus the value of culling them for parchment.

Another factor that likely had an effect on the value of parchment is dietary practice and the relative abundance or scarcity of food, which, as with other things we have seen, differed throughout time and from place to place. The impact of culling young animals from species also used for meat and dairy is obvious: they provide less meat than if they had grown to their full weight, and females culled at a young age do not produce milk and do not have offspring that may also be used for meat and dairy products. The direct impact of diet on parchment production, or vice versa, however, is difficult and perhaps impossible to discern, barring the discovery of parchment and bones from butchered animals that share an ancestry.[6] But since skinning animals and butchering them necessarily go hand in hand, and since the respective needs for meat and skins must have had impact on one another, it is worth reviewing relevant historical and archaeological evidence of using herd animals as meat sources in medieval Europe in order to acquire a fuller understanding of how culling these animals for skins must have been integrated into annual agricultural cycles and practices that also produced sufficient food for medieval people. I will consider three relevant topics: who ate meat and what sort they ate, annual cycles of butchering and preserving meat, and regional varieties in such practices.

As with many things in medieval society, access to meat was strongly affected by social class and status:

> Food was also class specific in the Middle Ages. The ability to access and afford foodstuffs and clothing materials of different types was generally regulated by economic constraints. The diet of peasants continued largely to be based on cereals and tended to feature meat only if they could hunt it down, whereas

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[6] In certain research situations, such a discovery may be less fortuitous than it sounds. Woodward and his colleagues working on the Dead Sea Scrolls were able to analyze samples from ibex and goat hides and also "to isolate and amplify DNA from archaeological bones of ibex and goats found at Masada", thereby demonstrating their ability "to recover the necessary genetic information from ancient animal remains that will enable [. . .] comparisons between the scroll fragments and the animals from which they were derived" (Woodward 228). Many excavations of the remains of butchered domestic herd animals in Europe involve very large numbers of bones; see, e.g., Maltby and Buglione, whose excavations each yielded data from thousands of bones and/or horn cores. Buglione, meanwhile, differentiates between the bones of mature animals and those killed at twelve months or younger in Apulia, a distinction that could be very useful to genetic studies of parchment. She notes that in late antiquity 3.5% of cattle were killed under 12 months of age, and in the early Middle Ages the number was 17.30%, whereas with sheep the numbers are 38.8% and 32.7% respectively (194–95).

> the aristocracy consumed meat on a regular basis, with special treats reserved for feast days. (Resl Introduction 5)

It should be remembered that peasants would not have been owners of large herds of domestic animals, and thus that decisions regarding how much meat a herd should produce would likely reflect the dietary needs and habits of a smaller elite minority than that of an entire local population; not only veal and lamb, but also beef and mutton would have been rare treats for many peasants throughout medieval England. Members of monastic orders that raised herd animals would have had their own supply of meat, but they had dietary regulations that, if followed, would have reduced their consumption of this meat. In a study of monks in late medieval Westminster, for example, Barbara Harvey notes that their diets were subject to special restrictions during periods of fast, and that "[o]utside the fast season of Advent and Lent, an average week in the monastery comprised four meat days and three fish days, and in principle every monk ate flesh-meat on two of the meats days and meaty dishes on the other two" (63). Moreover some monastic orders abstained from eating meat because it "was clearly identified as being the penchant of a certain echelon of society" from which they wished to distance themselves (Seetah 25, Bond 77).

Records from monastic houses and manorial kitchens sometimes offer information useful in determining the types and quantities of meat consumed. Harvey documents a wide variety of fish and meat sources used at the monastery in Westminster, including thirteen types of fish, chickens, ducks, geese, connies, and mature and young sheep, cattle, and pigs (tables A and B, 226–28). Historical information concerning who had access to meat as a food source and how much those individuals consumed helps to contextualize parchment production because it shows that only a limited portion of the population had rights to or created demand for meat from these animals, that this population had access to a wide variety of other animal food sources, and, in the case of monastic orders, that consumption of meat was itself limited due to the periods of fasting tied to the liturgical calendar as well as weekly dietary guidelines (and of course some of these fasts and dietary guidelines would have applied to observant laymen as well). Records kept by managers of manorial and monastic kitchens also permit scholars to estimate the number and size of animals butchered for food, thereby providing further context for understanding how the use of animals for meat might have related to the parchment trade. For example, Harvey provides estimates that a mature cow carcass weighed 308 pounds, whereas a calf weighed fifty-seven pounds; an adult sheep, meanwhile, weighed thirty-one pounds whereas a lamb weighed eleven and a half. Such evidence not only suggests how large—and thus how old—young sheep and cattle were when culled, perhaps for parchment, but also provides a basis for calculating how large their skins would have been.

Medieval consumption of meat also varied seasonally, as the only alternatives to fresh meat were salted and smoked meats. Pork, which cured better than beef or mutton, was subject to a "seasonal chronology of butchery", with chines ("the backbone and immediately adjoining area") being consumed as early as October through December, preserved meat being eaten through the spring, and fresh meat available thereafter (Woolgar 116–17). A similar chronology is found in the consumption of other mammals. Throughout much of medieval Europe, a large slaughter of animals in the autumn, often on Martinmas (November 11), not only provided a source for salted meat, but reduced the number of animals that would need to consume fodder over the course of the winter:

> The Martinmas slaughter of animals, salting down carcasses, continued as a method of ensuring a supply of preserved meat through the winter. It was practised at Frampton in 1343, at Hunstanton in 1349 and in many other places. Throughout the period, fresh meat was available in winter, but it was more expensive and its consumption was restricted to those of the highest status. By the mid-fifteenth century, a higher proportion of cattle may have been available as a consequence of the driving trade, bringing cattle from the north and west—and the availability of fresh meat increased. (Woolgar 112–13)

The large-scale slaughter of sheep and cattle at Martinmas suggests the expense, and perhaps impossibility, of keeping many adult herd animals alive over the winter, especially in colder climates. This, in turn, suggests that the culling of animals earlier in the year—at a time when their skins would be suitable for producing parchment—would have fit into this annual cycle in a way that would not necessarily mean that culling these young animals was an enormous financial sacrifice. For many of the animals, the only options seem to have been culling them for fresh meat and skin suitable for parchment production or killing them only a few months later and salting the meat (and indeed some of the animals slaughtered at Martinmas would still have been young enough for their skins to be suitable for parchment production).

It should be noted that dietary preferences, the availability of meat as a food source (whether fresh or preserved), and both the ability to preserve food as well as the pressures to do so due to impending winter weather varied from place to place and from time to another across medieval Europe. For example, Pascua notes both an overall increase in meat consumption in Europe among the lower classes during the fourteenth and fifteenth centuries and regional differences in what meats were available and/or preferred:

> The diet of thirteenth-century peasants consisted mainly of bread and dairy produce, that is, cheese and milk, which together accounted for four-fifths of the calorific value of all food consumed. Fowl was the main source of meat

> in France, and pork was the main source of meat in Britain and Germany. In the fourteenth and fifteenth centuries, animal protein accounted for 40 percent of total food. The common diet was based on mutton and goat in the Mediterranean region, Italy, and Spain; fresh beef in Hungary, the Low Countries, and Sweden, and pork in France and Germany. Beef and mutton remained paramount in Britain, where ovine livestock predominated, though less so than in the south of Europe. (98)

The reasons for these changes in diet have implications for studies of parchment, for Pascua notes that they occurred because the "key developments set in motion by the economic growth of the central centuries of the Middle Ages persisted: urbanization, market integration, and regional specialization" (98). Urban markets demanded that agricultural products, including meats and hides, be brought in from the countryside, and large towns and cities had regions that specialized in working animal products. The first stop for animals in specialized market systems would have been the butcher.[7] After butchering, parts of the animals were frequently distributed to a number of specialist workers, including furriers, tanners, parchmenters, pinners, glovemakers, and others, many of which were organized into guilds. As such, evidence for the local origins of these animal parts may be obscured due to these manufacturing activities, which would have mixed together and redistributed very large numbers of animal carcasses. Transhumance, meanwhile, meant that many animals traveled significant distances before they were slaughtered. For example, cattle drovers regularly brought cattle from Scotland and Wales into England (Pascua 98).

In addition to the transhumance of livestock to meet market demands for meat, there was also significant trade of finished animal products along established trading networks throughout medieval Europe. According to Veale, "[t]he anonymous author of the political poem, *The Libelle of Englyshe Polycye*, writing between 1436 and 1438, commented on Ireland's great wealth in skins, referring to the good martens, deer, otter, squirrel, hare, sheep, lamb, fox, kid, and rabbit skins with which she traded", while Scotland, meanwhile, had a "flourishing trade in fox, squirrel, marten, cat, beaver, and otter skins" (60). England was (and still is) famous for its wool, which found a ready market not only in market towns within England, but in continental centers specializing in cloth production, such as those in Flanders and Florence (Butler and Given-Wilson 85). Transhumance was also practiced for the purposes of maintaining flocks of sheep kept for their wool; in Spain, over three million Merino sheep were involved in an "unceasing flow from north to south" along "complex networks of routes that peppered the landscapes" of the Iberian Peninsula (Pascua 94). It is likely that parchment moved along some of these same trade routes for furs and wool. A very promising possibility is that genetic analysis of skins might help to trace the movement of parchment from

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[7] See Seetah for an overview of the importance and development of the butcher's trade in the medieval era.

one region to another, but this evidence of robust international trade must also give us pause, since it suggests that we cannot simply assume that parchment dated through textual evidence to a particular locality was manufactured there, or that the animals from which it was made originated there.

Finally, it is worth considering that the broad trends that I have outlined here concerning sizes of herds and flocks, animal husbandry, diet, the movement of animals and goods manufactured from them, urbanization and the development of market economies, and regional differences in diet and the animals preferred as either livestock or food were all subject to disruption at any time from forces such as war, epidemic disease of either humans or livestock, drought, flood, and other factors. For example, Ryan reports that salt, which was not locally available in Ireland, was periodically scarce: "In A.D. 1338, a rise in the price of salt was recorded in Clyn's Annals, and in 1486, the chronicler of the Annals of Ulster recorded a severe shortage" (137). This, of course, would have implications for salting beef to preserve it over the winter, and might result in more animals being eaten at a younger age and their hides made available for the production of parchment or leather. Bad weather in "1315–1317 laid the foundation for endemic murrains that affected bovines and sheep from Ireland to Germany", and a few years later "[r]eference to catastrophic animal mortality and ruined crops in every monastic cartulary suggests rates of mortality in oxen of between 25 and 50 percent and between 50 and 70 percent in sheep" (Pascua 96–7). And of course wars and catastrophic losses from plague affected the human populations of much of Europe during this century as well. Any of these events could have drastic and perhaps long-lasting impact on the value of animals and their skins, and on the relative merits of culling animals early enough to produce parchment.

5. Conclusion

The experiment that I described in the *PBSA* article and the experiments by Woodward, Burger, and Poulakakis have shown conclusively that DNA survives in medieval parchment and that it may be extracted and analyzed. We are faced now with the many millions of extant surviving parchment pages and how we might approach unlocking their secrets through genetic analysis. Such broad-scale analysis is predicated upon developing minimally destructive techniques, but this is a matter of when and not if; one only needs to consider the miracle that the possibilities of this technology would appear to be to medieval parchment makers—or even nineteenth-century parchment makers—to have confidence that the development of such techniques will come with time. The question, then, will become how best to deploy the technology, and what sorts of questions we might pose and answer with it. I have attempted to show here both the significant possibilities and the potential complications of genetic analysis of

parchment. On the one hand, we have the potential to leverage the genetic information of parchment to obtain unparalleled glimpses into the medieval past. Perhaps we will be able to trace parchment trade routes or document the effects of the enclosure system, or Cistercian breeding agenda, or salt shortages in Ireland, or epidemic murrains across Europe on the production of books and the lives of humans and animals from many centuries ago. But the conditions that I have outlined here also serve as a caution that we will not be able to discern the full meaning of the genetic information contained in parchment if we do not consider it alongside historical and archaeological information (much of which itself remains insufficiently examined). Isolated genetic information from single leaves, or even single books, will in most cases remain unclear, and may be misleading, without a historical understanding of trade and agricultural practices; although genetic data will likely greatly enrich such fields of study, it will also rely upon them, especially in the early stages. In designing studies of the genetic data contained in parchment and in interpreting the results of them, we must always be mindful of the ever-shifting landscape of parchment production in the medieval world.

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