International Journal of Osteoarchaeology
Int. J. Osteoarchaeol. **24**: 247–255 (2014)
Published online 18 December 2013 in Wiley Online Library
(wileyonlinelibrary.com) **DOI**: 10.1002/oa.2362

SPECIAL ISSUE PAPER

Walking on Eggshells: A Study of Egg Use in Anglo-Scandinavian York Based on Eggshell Identification Using ZooMS

JOHN R. M. STEWART,[a]* RICHARD B. ALLEN,[b] ANDREW K. G. JONES,[c] T. KENDALL,[c] K. E. H. PENKMAN,[d] B. DEMARCHI,[d] T. O'CONNOR[a] AND **M. J. COLLINS[a]**

[a] *BioArCh, Biology S-Block, University of York, Heslington, York, YO10 5DD, UK*
[b] *Department of Archaeology, Durham University, Stockton Road, Durham, DH1 3LE, UK*
[c] *York Archaeological Trust, 47 Aldwark, York, YO1 7BX, UK*
[d] *Department of Chemistry, University of York, Heslington, York, YO10 5DD, UK*

ABSTRACT Eggshell is a potentially common archaeological resource, but it tends to be ignored. The recent development of ZooMS (zooarchaeology by mass spectrometry) as a rapid and robust system for taxonomic identification of preserved eggshell fragments has facilitated new insights into patterns of egg use in the past. This paper presents a case study of egg use at two sites in Anglo-Scandinavian York (Hungate and Coppergate). The results described below suggest that the relative prevalence of goose eggshell may become a useful indicator of status, consistent with other characteristics of the two sites, and also demonstrate an apparent lack of exploitation of eggs of wild birds in York during the Anglo-Scandinavian period. These results highlight the interpretative potential of eggshell, which can now begin to be more fully explored.

Key words: eggshell; ZooMS; zooarchaeology; bioarchaeology

Introduction

Introduction and overview

Birds' eggs have formed a substantial component of the diets of many people, as well as serving a wide range of other functions such as raw material for artefacts (Kightly, 1984; Orton, 2008; Baldwin 2009, 2010; Serjeantson, 2009). Egg production is either an important focus or a highly beneficial by-product of keeping most domestic birds, while the eggs of wild birds (particularly seabirds) represent a major seasonal resource in many areas (e.g. Hunn *et al.*, 2003; McGovern *et al.*, 2006; Baldwin 2009, 2010; Serjeantson, 2009). The collecting season for wild birds is usually quite narrow, but eggs can be stored for a number of months even without modern technology, and domestic species may have a longer or repeated laying interval (Baldwin 2009, 2010; Serjeantson, 2009). Although domestic species (particularly chicken) provide all of the eggs consumed by most people today, documentary records describe the exploitation of a wide range of species by British coastal communities even into the latter part of the 20th century, and egg collecting remains an important activity in many traditional societies (Kightly, 1984; Hunn *et al.*, 2003; Baldwin 2009, 2010; Serjeantson, 2009).

Despite the long history of exploitation, substantial ethnographic and historical evidence of the importance of eggs, and the abundance of the material at many archaeological sites, surprisingly little is known of egg use in past societies from the archaeological record. For example, in the recent edition of *Cambridge Manuals in Archaeology on Birds* (Serjeantson, 2009), only 16 of 450 pages are devoted to eggs and eggshell. Previous work by Keepax (1981) and Sidell (1993a, 1993b), while significant, did not initiate a wider appreciation and investigation of excavated eggshell. This paper will exploit a recently published ZooMS (zooarchaeology by mass spectrometry) technique for identification of

* Correspondence to: John R.M. Stewart, BioArCh, Biology S-Block, University of York, Heslington, York, YO10 5DD, UK.
e-mail: js1063@york.ac.uk

Received 28 *October* 2013
Accepted 4 *November* 2013

archaeological eggshell fragments by analysis of their protein component (Stewart *et al.*, 2013). This is used here to conduct a case study on egg exploitation using the large eggshell collections excavated from two significant urban sites representing Anglo-Scandinavian York (Hungate and Coppergate). The aims of this case study are to begin to establish the range of bird species exploited for their eggs in York during this period, the relative prevalence of wild and domestic species, and to begin to shed some light on how the eggs of different species were perceived, including, e.g. the relative status of the eggs of different species.

Eggshell in the archaeological record

Avian eggshell is composed primarily of calcite. It also incorporates a substantial organic phase (3.5–4% by weight in chicken eggshell), which initiates and mediates deposition of the mineral phase (e.g. Hincke *et al.*, 2010). Calcite is the most stable crystalline form of calcium carbonate at normal temperatures and pressures, and so eggshell is extremely durable at the neutral to alkali pH ranges found at many archaeological sites. Despite the archaeological potential of eggshell, extensive studies of the material are rare. One reason for this is that eggshell is difficult to recover during excavation. It is usually highly fragmented, requires sieving of sediments using at least a 5 mm mesh (preferably 2 mm), and separating eggshell fragments out from other small fragments of bone and mollusc shell can be very time consuming. Second, the fragmented preservation state of eggshell renders it difficult to identify the material taxonomically based on morphology.

Despite efforts by a number of researchers (Keepax, 1981; Sidell 1993a, 1993b; Eastham & Gwynn 1997), until recently there has been no rapid and robust system for identification of these fragments capable of analysing the large assemblages often found at archaeological sites (Stewart *et al.*, 2013). Even where it has been recovered, eggshell is often archived and never taxonomically identified. The length of time and amount of labour required to identify eggshell fragments often preclude analysis of whole assemblages, which may comprise hundreds (even thousands) of fragments.

Although ZooMS was initially developed for analysis of bone fragments (Buckley *et al.*, 2009), the variant of the technique used in this study is able to yield accurate taxonomic information on thousands of eggshell fragments (Stewart *et al.*, 2013). It can therefore be used to analyse whole assemblages; this increases the archaeological value and interpretative power of eggshell. Previous research has demonstrated that ZooMS can taxonomically identify heavily fragmented bone (Buckley *et al.*, 2009, 2010; Richter *et al.*, 2011), as well as providing a means for high-throughput analysis of eggshell assemblages (Stewart *et al.*, 2013).

The sites

The two sites discussed in this study are described below. Over 2750 eggshell fragments were recovered from these sites and were analysed using the new technique. Analysing this volume of material would not be practicable using previously available techniques.

Hungate

Hungate is located near the centre of York, abutting the north bank of the River Foss (Figure 1). The site is a large multi phase site, and the Dig Hungate excavations conducted by York Archaeological Trust (YAT) began in late 2006 and will be completed in line with the Hungate (York) Regeneration Ltd. development schedule. The source of the material used in this study, Block H, was excavated between 2007 and 2011. Most of the contexts evaluated in this paper are provisionally assigned to Anglo-Scandinavian age activity (unless stated otherwise). Structural and artefact evidence, and topographic position, suggest that during the Anglo-Scandinavian period (late 9th – mid 11th centuries) the site was of relatively low status compared with the contemporaneous Coppergate site a few hundred metres to the south-west (see below). Over 2000 fragments of eggshell were recovered from the Hungate excavation by 5 mm and 1 mm sieving, which YAT excavators performed routinely on samples of most types of deposit.

Coppergate

Coppergate, which is located around 350 m to the south-west of Hungate (Figure 1), was excavated by YAT between 1976 and 1981. A site of activity during the Roman period, Coppergate was apparently deserted during the post-Roman period, and became active once more with the onset of the Anglo-Scandinavian period (mid-9th century) (O'Connor, 1989). During the early Anglo-Scandinavian period, there is evidence for glass working and possible structures; these were definitely established at the site by the mid-10th century. There is also evidence of iron working at the site during this period (Hall, 1989).The areas to the rear of these structures contained a large number of pits, in which organic preservation was often excellent (Kenward & Hall, 1995). Relative to Hungate, Coppergate is considered a high-status site on the basis of the type of industrial activities, finds, and structures excavated. Altogether, 758 fragments of eggshell were recovered

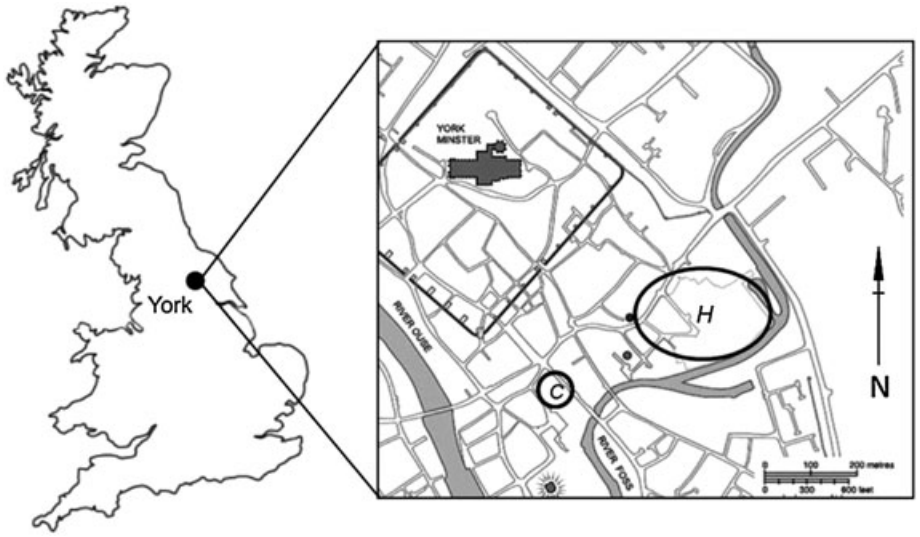

Figure 1. Location of Hungate (H) and Coppergate (C) sites. Reproduced courtesy of York Archaeological Trust. Based on the Ordnance Survey mapping © Crown copyright.

from the site by YAT excavators and were analysed using the technique described in section 2.

Methodology

Extraction procedure and analysis by MALDI-ToF mass spectrometry

The procedure used to extract the proteins follows that developed by Stewart *et al.* (2013). Fragments were cleaned by sonication in ultra-pure water. Residual dirt was then removed by hand, and samples were left to air-dry. A small piece of each fragment was then removed using fine tweezers, weighed into sterile 2 mL Eppendorf tubes, and exposed to strong bleach (sodium hypochlorite, 12% w/v) at a concentration of 50 µL/mg sample for 7 days in order to oxidise inter-crystalline proteins (Penkman *et al.*, 2008, 2011; Stewart *et al.*, 2013). This isolates an intra-crystalline protein fraction and is an established approach in studies of the protein fraction of biominerals (e.g. Berman *et al.*, 1988; Collins *et al.*, 1991; Sykes *et al.*, 1995; Collins & Riley, 2000; Penkman *et al.*, 2008, 2011). The fragments were then thoroughly rinsed in ultra-pure water, briefly suspended in HPLC-grade methanol, air-dried, and the calcite partially dissolved in dilute (0.6M) hydrochloric acid (HCl) at 4°C over seven days to extract a fraction of the intra-crystalline proteins. This approach left a non-dissolved eggshell core to buffer the solution at pH ≈ 7, yet still released a sufficient volume of proteins for mass spectrometry.

Internal disulphide bonds on cysteine residues were reduced using 0.01M dithiothreitol (DTT) at a concentration of 1 µL per 2 µL sample solution at 60°C for one hour and subsequently alkylated using 0.05M iodoacetamide (IAA) at a concentration of 1 µL per 3.3 µL sample solution at room temperature in dark conditions for 45 min. Proteins were digested with 4 µL of 0.4 µg/µL porcine trypsin in trypsin re-suspension buffer (Promega, Southampton, UK) at 37°C in order to produce peptides in the detection range of the mass spectrometer used in analysis. Digestion was stopped after 24 h by addition of trifluoroacetic acid (TFA) at a concentration of 0.5–1% of the total solution.

Solid phase extraction was performed on BioVyon C18 10mg 96 well plates (Porvair, Fareham, UK) conditioned (as per manufacturer's instructions) with 50% acetonitrile (ACN) in 0.1% TFA, and equilibrated with 0.1% TFA in aqueous solution. Samples were then loaded and the unbound fraction washed off in 0.1% TFA in ultra-pure water, before the peptides were eluted in 75 µL of 50% ACN in 0.1%TFA. One microlitre of this eluate was spotted in triplicate on an MTP384 Bruker ground steel target plate. On each spot, 1 µL of matrix (α-cyano-4-hydroxycinnamic acid; 10 g/L in 50% ACN in 0.1%TFA) was mixed with the sample. From start to finish, this process takes around two weeks; this is due to the need to leave samples to sit at various stages. The process is not labour intensive; a combined total of roughly 5–10 min per sample allows analysis of a large number of samples.

Samples were analysed in positive mode on the Bruker Ultraflex III MALDI-ToF (Matrix-Assisted Laser Desorption/Ionisation-Time of Flight) mass spectrometer

with the following parameter settings: ion source, 25 kV; ion source, 21.4 kV; lens voltage, 9 kV; laser intensity, 35–40%; and mass range, 800–4000 Da. Peptide masses below 650 Da were suppressed. Final mass spectra were externally calibrated against an adjacent spot containing six peptides (des-Arg^1-Bradykinin, m/z = 904.681; Angiotensin I, 1296.685; Glu^1-Fibrinopeptide B, 1750.677; ACTH (1–17 clip), 2093.086; ACTH (18–39 clip), 2465.198; ACTH (7–38 clip), 3657.929). FlexAnalysis software 3.3 (Bruker Daltonics) was used to baseline subtract, normalize spectra, and determine peak m/z values and intensities in the mass range of 800–4000 m/z (m/z is the mass-to-charge ratio of the targeted peptides; as only singly charged peptides are used, this is a direct function of peptide mass).

Taxonomic identification

Both approaches to identifying eggshell fragments described below rely upon comparison of mass spectra obtained from archaeological material with a reference database obtained on specimens of known species. This has been drawn mostly from museum material and currently comprises 56 species in 13 orders (Stewart *et al.*, 2013). One approach is based on identification of potentially diagnostic peptide masses. These were identified by screening peptide masses found in each species against the entire reference collection (Signal/Noise ratio (S/N) $\geq$6). This approach provided a reference list of peptide masses which were potentially useful as taxonomic indicators (Table S1), although the level of resolution achieved varies between markers; for example, it is not possible to separate different species of ducks, geese, or gulls using this technique (Table 1).

Rather than identifying specific markers, the second approach uses peptide mass fingerprinting (PMF); the whole list of peptide masses is compared with reference spectra in order to derive taxonomic information (e.g. Henzel *et al.*, 1993; James *et al.*, 1993; Pappin *et al.*, 1993; Hollemeyer *et al.*, 2007, 2008). For all archaeological samples, matching of mass spectra to species based on comparison with reference spectra was performed using an in-house Microsoft VB application (ChickenHawk) (Stewart *et al.*, 2013). This software searches a reference database constructed of known peptide masses and reports both the number of matches between observed peptide masses and data in the reference collection, and the percentage of peaks observed in each species which are observed in the sample. It also screens the data for the presence or absence of potentially diagnostic peptide markers. An example of output (Appendix S1) is provided in supplementary information.

The level of resolution of this approach varies between taxa due to (i) differences in the extent to which taxa are represented in the reference collection; and (ii) the degree to which the peptides observed in different members of the taxa differ (for example, there is no way of distinguishing confidently between different members of the closely related and highly speciated family Laridae). ChickenHawk will identify which species in the reference collection is the closest match, but cannot always extrapolate this into definite species identification, though identification to family or order is more realistic in some cases. The major advantages of this approach are that it is applicable to all species, is very fast, and can be very accurate if the relevant sections of the reference collection have good coverage.

Results

Success of technique

In total, over 2750 separate eggshell fragments were analysed. Successful taxonomic identifications were achieved for eggshell from 35 of 39 sampled contexts at Hungate (89.7%), and all 29 sampled contexts at Coppergate. At Coppergate, the success rate of the technique by fragment was 98.33% (12 of 758 fragments remain unidentified). This rate was lower at Hungate, but was not quantified. An exploration of possible reasons for this disparity is provided below (section 4.1). Where no identification was made, this was due to poor quality mass spectra rather than inability to match good spectra to the reference database.

Relative composition of eggshell assemblage at Coppergate and Hungate

The percentage representation of the species identified in an eggshell assemblage, whilst it gives some indication of the prevalence of use of that species, should not be taken as a proxy quantified measure of the absolute abundance of eggs of that species in the sampled deposit or original refuse. This analysis does not account for differential pathways of egg fragmentation, which are unknown and probably impossible to quantify with any degree of confidence. For example, if the relative abundance of shell fragments from Coppergate (Figure 2) were taken at face value, it might be deduced that goose eggs were barely used.

As it is not possible to relate the number of fragments recovered to the number of eggs originally present, assessing only the *presence* or *absence* of each species in each context is a more appropriate method of quantification. Three taxa were identified: chicken,

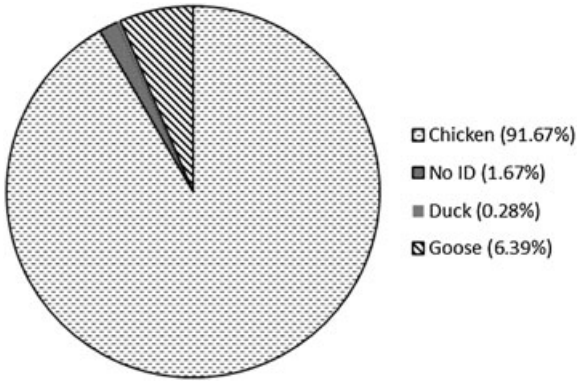

Figure 2. Taxonomic composition of Coppergate eggshell assemblage (n = 758).

goose, and duck. A cross-context comparison of the two sites shows that goose eggshell is present in a high proportion (41%) of contexts at Copperate (Figure 3). The breakdown of the data presented in Figure 3 by context is also given below (Table 2). Chicken is equally ubiquitous at both sites, but goose is far more prevalent at Coppergate (see section 4.2). The only occurrence of duck eggshell was also at Coppergate (context 34726). The percentage representation per context is calculated as the proportion of the contexts in which successful identification was achieved, which was in all 29 contexts from Coppergate, and all 35 from Hungate.

Table 1. Sample of peptide markers identified from the reference database. These represent a sample from Coppergate (context 34726) which contained both chicken and duck eggshell. Note that markers are capable of variable levels of taxonomic resolution, and also the examples of convergent peptide masses. The full list of peptide markers (n = 491) is given as supplementary information (Table S1)

Marker ID	Peptide *m/z*
Galliformes	1018.5
Galliformes	1024.5
Galliformes	1042.6
Galliformes	1047.5
Chicken	1150.6
Anseriformes	1290.6
Galliformes/Corvidae/Charadriiformes	1309.7
Chicken/Grouse/Magpie	1345.7
Chicken/Duck	1348.8
Duck	1366.6
Duck/Swan	1382.6
Chicken	1688.7
Duck/*L. fuscus*	1723.7
Chicken	1734.9
Duck/Swan	1739.8
Chicken	1774.8
Galliformes	1808.9
Chicken	1859.8
Anseriformes	2051.8
Duck	2362.2

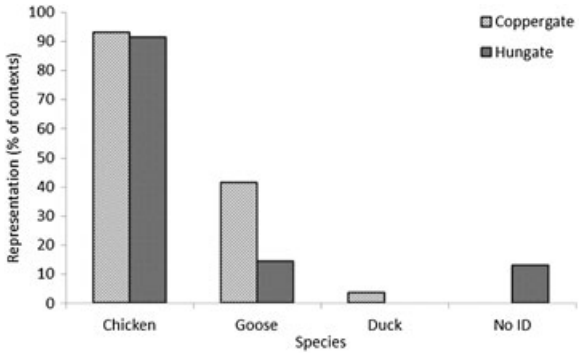

Figure 3. Cross-context comparison of eggshell assemblage composition at the two sites. The Hungate data represent all contexts, including those known to post-date the Anglo-Scandinavian period. Limiting the contexts represented to only those from this period does not affect the pattern observed.

Discussion

Success of the technique

There are several non-mutually-exclusive factors which may explain the disparity in successful identification rate between the sites. A simple age effect may seem a logical explanation, but some of the Hungate contexts from which no identification was made are among the youngest at the site. Other factors which may contribute to this disparity include better organic preservation in general at Coppergate; improvements in resolution and execution of the technique between the two analyses; possible burning of some shell fragments at Hungate; and misidentification of very small fragments of plaster or mollusc shell as avian eggshell at Hungate.

Is goose eggshell an indicator of high status?

Significant differences were observed in the prevalence of goose and duck eggshell at the two sites. It is possible that this results from the difference in status between the sites. Although direct data for the Anglo-Scandinavian period are unavailable, it has been estimated that chickens in England were producing 70–100 eggs per year by the late medieval period (late 13th – early 14th century), and that members of every social stratum would have had access to these (Slavin, 2009). In comparison, medieval domestic geese seem to have been, as now, seasonal layers, producing around 40 eggs per year, predominantly in the spring (Serjeantson, 2002). It seems reasonable to propose that hens' eggs would also have been an everyday food item during the Anglo-Scandinavian period, while goose eggs would have been only seasonally available.

Table 2. Composition of Hungate and Coppergate eggshell assemblages by context. Results presented in italics represent contexts known to post-date the Anglo-Scandinavian period

Hungate				Coppergate				
Context	Fragments	Chicken	Goose	Context	Fragments	Chicken	Goose	Duck
48310	*2*	*X*		1118	4	X		
48314	*12*	*X*		2562	2	X		
48709	5	X		3054	12	X		
48716	2	X		6437	3	X		
48780	7	N/A	N/A	6531	1	X		
49087	1	X		6536	1	X		
49223	2	X		6879	8	X		
49478	60–70	X		7696	2	X		
49480	2	X		7863	8	X		
49487	40–50		X	13577	10	X		
49494	4	X	X	14297	109	X	X	
49509	2	X		15311	23	X	X	
49599	>1000	X		16605	26	X		
49645	3	X		16877	43	X	X	
49646	50–60	X		18429	7	X	X	
49671	150	X		19271	8	X	X	
49720	4	X		21204	1		X	
49731	12	X		22154	72	X		
49810	6	X		22209	17	X		
49817	*1*	*X*		22452	18	X	X	
49827	2		X	22574	173	X	X	
49854	3	X		22746	69	X	X	
50551	10		X	22857	18	X		
50834	*6*	*N/A*	*N/A*	23437	61	X	X	
50839	2	X		24560	2	X		
51266	80	X		27017	8		X	
51435	1	X		28384	12	X		
52192	1	N/A	N/A	34290	22	X	X	
52300	13	N/A	N/A	34276	18	X		X
52438	60	X						
52444	60	X						
52852	70	X						
52960	50	X						
83328	*66*	*X*						
83350	*6*	*X*						
83460	*66*	*X*						
83461	*108*	*X*						
83471	*26*	*X*						
83548	*16*	*X*						

Albarella (2005) shows that goose husbandry was well established in England during Anglo-Saxon times, so it is likely that this husbandry persisted in the Danelaw regions. Comparing eggshell results with bird bones from the two York sites, only Coppergate has a fully quantified analysis (O'Connor, 1989). From all Anglo-Scandinavian deposits, 363 specimens could be attributed to *Anser anser*, compared to 1267 specimens of domestic fowl, a ratio of about 3.5 hens per goose, and much smaller numbers attributable to other *Anser* and *Branta* species. At Coppergate, the goose bones were predominantly of adult birds. Although immature bird bones are obviously more vulnerable to taphonomic loss than those of adults, taphonomic attrition of the Coppergate assemblage was minimal and even immature goose bones are relatively large and recoverable. It is a fair inference, therefore, that the geese at Coppergate were kept as much for feathers and eggs as for meat, and the eggshell results would seem to confirm that interpretation. Although the contemporary material from Hungate has yet to be fully quantified, first impressions are that the proportion of goose bones in 10th century contexts is close to that at Coppergate, falling off in later contexts (C. Rainsford, pers. comm.). If so, that might show that Hungate was a neighbourhood where geese were kept but the eggs were not eaten, unlike Coppergate.

The results of this study might begin to suggest that the eggs of ducks and geese were higher status or more expensive items in Anglo-Scandinavian society. Direct evidence to support the notion that goose eggs were a higher status food during the Anglo-Scandinavian period in England is lacking other than by interpretation

of associated structural and artefact assemblages. However, some support may be found in roughly contemporaneous accounts from Ireland. The probably 12th century Irish tale 'Fled Dúin na nGéd' suggests that goose eggs were considered higher status fare than chicken eggs (Mac Con Iomaire & Cully, 2007). Direct comparison between Anglo-Scandinavian northern England and Ireland is historically valid; major cultural links between the Vikings and Ireland were well established by this stage (e.g. Ó Corráin, 2001). Indeed, it has been argued that the Viking parties which dominated Dublin and York may have had a common origin in Scotland (e.g. Ó Corráin, 1998). It seems reasonable to expect a degree of cultural overlap between these regions during the Anglo-Scandinavian period. In Ireland, the perception of goose eggs as a luxury food seems to have persisted into the Modern era (Mac Con Iomaire & Cully, 2007).

Wild vs. domestic resource use in Anglo-Scandinavian York

There is a complete lack of demonstrably wild species in the eggshell assemblages (Figure 3, Table 2). Although the technique described above cannot presently distinguish between different species of duck and goose, or between domestic and wild types, these are known to have been kept domestically in the city during the Anglo-Scandinavian period (O'Connor, 1989, 2000). It is therefore parsimonious to cautiously propose that the duck and goose eggshell represents domestic species, while acknowledging that this cannot be stated conclusively. This is in contrast with the bird bone assemblages from the two sites, which exhibit a wide range of wild species, including water-fowl and seabirds (O'Connor, 1989, 2000).

It has been suggested that egg production was probably the main focus of chicken farming in Anglo-Scandinavian York (O'Connor, 2000), consistent with the predominance of adult birds in bone assemblages. Given the extensive nature of the surrounding agricultural economy, it would not be surprising if the inhabitants of Anglo-Scandinavian York were able to obtain all of their eggs from domestic species. It would perhaps be more surprising if there were no preference for certain types of wild egg. For example, razorbill eggs were highly prized for their taste among diverse British communities from the 17th century until the mid-20th century (Kightly 1984; Baldwin, 2009). While it is pure speculation to extrapolate this back to the Anglo-Scandinavian period, it is interesting that no evidence of preference for any wild eggs has been forthcoming from either site, particularly in the higher status Coppergate assemblage. Razorbill (*Alca torda*) and guillemot (*Uria aalge*) bones are found at Coppergate (O'Connor, 1989), showing that transport of goods from coastal regions was occurring.

The lack of demonstrably wild species in the eggshell assemblage is consistent with the idea that wild species may have been a focus of exploitation outside of their breeding season, probably during winter (O'Connor, 2000). Wild fowling may have provided additional food and/or income during the period when the time demands of normal economic activity may have been relaxed; according to this interpretation, during the fairly narrow window when wild eggs were available, people would have been occupied with normal economic activities (O'Connor, 2000). The eggshell results from Hungate and Coppergate begin to suggest that domestic species were the only source of eggs exploited in the city during this period. Although this is a preliminary interpretation, based upon analysis of only two sites, it is based on a large number of samples representing an occupation period of at least two centuries. The Coppergate contexts analysed here are confidently assigned to the Anglo-Scandinavian period; the Hungate contexts provisionally so, pending completion of post-excavation analysis. Future research will aim to further develop understanding of the use of bird eggs in Anglo-Scandinavian York, and beyond. Current research is analysing eggshell assemblages from contemporaneous coastal sites, which are expected to contain a higher proportion of wild bird eggshell.

Conclusions

For a long time, eggshell has presented a conundrum for archaeologists; it is a common archaeological resource, but the volume and/or value of information which can be gained by studying it have often been limited. This case study on eggshell fragments from Anglo-Scandinavian York has highlighted the archaeological potential of eggshell by demonstrating that taxonomic identification can be made on sufficient material to give useful results, and that contrasts between contemporary neighbourhoods within one town can be clearly seen, raising the possibility that the eggs of different species were of different cultural value during this period, and may therefore become useful as indicators of status. Expanding the evidence base for egg use in Anglo-Scandinavian Britain (and beyond) is the subject of on-going research; this will facilitate new interpretations of egg use in the past.

Acknowledgements

This research was funded by a Collaborative Doctoral Award (Grant ref: AH/I504958/1) between the AHRC and York Archaeological Trust, awarded to the University of York. Support for some of the analytical work came from NERC via NE/G004625/1. The work has been helped greatly by: Adam Dowle (University of York); Isla Gladstone (Yorkshire Museums Trust); Rachel Cubitt, Clare Rainsford, Emma Turner (York Archaeological Trust); Jane Sidell (English Heritage); Mike Buckley (University of Manchester); Enrico Cappellini (University of Copenhagen); and Jan Bolding Kristensen (Zoological Museum, University of Copenhagen).

References

Albarella U. 2005. Alternate fortunes? The role of domestic ducks and geese from Roman to medieval times in Britain. Documenta Archaeobiologiae 3. Feathers, grit and symbolism, G Grupe, J Peters (eds.) Verlag Marie Leidorf: Rahden, North Rhine-Westphalia; 249–258.

Baldwin J. 2009. Harvesting seabirds and their eggs on the Irish Sea islands (Part 1: the Welsh islands, Lundy and Scilly). *Folk Life: Journal of Ethnological Studies* **47**: 76–96.

Baldwin J. 2010. Harvesting seabirds and their eggs on the Irish Sea islands (Part 2: Mainland of Man). *Folk Life: Journal of Ethnological Studies* **48**(2): 144–169.

Berman A, Addadi L, Weiner S. 1988. Interactions of sea-urchin skeleton macromolecules with growing calcite crystals - a study of intracrystalline proteins. *Nature* **331**: 546–548.

Buckley M, Collins M, Thomas-Oates J, Wilson JC. 2009. Species identification by analysis of bone collagen using matrix-assisted laser desorption/ionisation time-of-flight mass spectrometry. *Rapid Communications in Mass Spectrometry* **23**: 3843–3854.

Buckley MW, Kansa S, Howard S, Campbell S, Thomas-Oates J, Collins M. 2010. Distinguishing between archaeological sheep and goat bones using a single collagen peptide. *Journal of Archaeological Science* **37**: 13–20.

Collins MJ, Riley MS. 2000. Amino acid racemization in biominerals: the impact of protein degradation and loss. In Perspectives in Amino Acid and Protein Geochemistry, GA Goodfriend, *et al*. (eds.). Oxford University Press: New York; 120–142.

Collins M, Muyzer G, Curry GB, Sandberg P, Westbroek P. 1991. Macromolecules in brachiopod shells: characterization and diagenesis. *Lethaia* **24**(4): 387–397.

Eastham A, Gwynn IA. 1997. Archaeology and the electron microscope: eggshell and neural network analysis of images in the Neolithic. *Anthropozoologica* **25**: 85–94.

Hall R. 1989. Archaeological Introduction. In Bones from Anglo-Scandinavian Levels at 16–22 Coppergate, T.O'Connor (ed.). Council for British Archaeology: London; 141–142.

Henzel WJ, Billeci TM, Stults JT, Wong SC, Grimley C, Watanabe C. 1993. Identifying proteins from two-dimensional gels by molecular mass searching of peptide fragments in protein sequence databases. *Proceedings of the National Academy of Sciences* **90**: 5011–5015.

Hincke MT, Nys Y, Gautron J. 2010. The role of matrix proteins in eggshell formation. *Journal of Poultry Science* **47**: 208–219.

Hollemeyer K, Altmeyer W, Heinzle E. 2007. Identification of furs of domestic dog, raccoon dog, rabbit and domestic cat by hair analysis using MALDI-ToF mass spectrometry. *Spectroscopy Europe* **19**(2): 8–15.

Hollemeyer K, *et al*. 2008. Species identification of Oetzi's clothing with matrix-assisted laser desorption/ionisation time-of-flight mass spectrometry based on peptide pattern similarities of hair digests. *Rapid Communications in Mass Spectrometry* **22**: 2751–2767.

Hunn ES, Johnson DR, Russell PN, Thornton TF. 2003. A study of traditional use of birds' eggs by the Huna Tlingit. National Park Service Technical Report NPS/CCSOUW/NRTR-2002-02; Seattle.

James P, Quadroni M, Carafoli E, Gonnet G. 1993. Protein identification by mass profile fingerprinting. *Biochemical and Biophysical Research Communications* **195** (1): 58–64.

Keepax CA. 1981. Avian egg-shell from archaeological sites. *Journal of Archaeological Science* **8**: 315–335.

Kenward HK, Hall AR. 1995. Biological Evidence from 16–22 Coppergate, York (Archaeology of York: The Environment 14/7). Council for British Archaeology: London.

Kightly C. 1984. Country voices: life and lore in farm and village. Thames and Hudson: London.

Mac Con Iomaire M, Cully A. 2007. The History of eggs in Irish cuisine and culture. In Eggs in Cookery: Proceedings of the Oxford Symposium on Food and Cookery, R Hosking (ed.). Prospect: Totnes; 137–149.

McGovern T, *et al*. 2006. Coastal connections, local fishing, and sustainable egg harvesting: patterns of Viking Age inland wild resource use in Myvatn district, Northern Iceland. *Environmental Archaeology* **11** (2): 187–205.

Ó Corráin D. 1998. Vikings in Ireland and Scotland in the Ninth Century. *Peritia* **12**: 296–339.

Ó Corráin D. 2001. The Vikings in Ireland. In The Vikings in Ireland, A-C Larsen (ed.). The Viking Ship Museum: Roskilde; 17–29.

O'Connor T. 1989. Bones from Anglo-Scandinavian Levels at 16–22 Coppergate. Council for British Archaeology.

O'Connor T. 2000. Bones as evidence of meat production and distribution in York. In Feeding a city: York: the provision of food from Roman times to the beginning of the twentieth century, E White (ed.). Prospect Books: Devon; 43–60.

Orton J. 2008. Later Stone Age ostrich eggshell bead manufacture in the Northern Cape, South Africa. *Journal of Archaeological Science* **36**(7): 1765–1775

Pappin DJC, Hojrup P, Bleasby AJ. 1993. Rapid identification of proteins by peptide-mass fingerprinting. *Current Biology* **3**: 327–332.
Penkman KEH, Kaufman DS, Maddy D, Collins MJ. 2008. Closed-system behaviour of the intra-crystalline fraction of amino acids in mollusc shells. *Quaternary Geochronology* **3**: 2–25.
Penkman K, Preece RC, Bridgland DR, Keen DR, Meijer T, Parfitt SA, White TS, Collins MJ. 2011. A chronological framework for the British Quaternary based on Bithynia opercula. *Nature* **476**: 446–449.
Richter K, Wilson J, Jones AKG, Buckley M, Doorna N, Collins MJ. 2011. Fish 'n chips: ZooMS peptide mass fingerprinting in a 96 well plate format to identify fish bone fragments. *Journal of Archaeological Science* **38**(7): 1502–1510.
Serjeantson D. 2002. Goose husbandry in Medieval England, and the problem of ageing goose bones. *Acta Zoologica Cracoviensia* **45** (Special issue).
Serjeantson D. 2009. Cambridge Manuals in Archaeology: Birds. Cambridge University Press: Cambridge.
Sidell EJ. 1993a. A methodology for the identification of avian eggshell from archaeological sites. *Archaeofauna. Archaeornithology: Birds and the Archaeological Record* **2**: 45–51.
Sidell EJ. 1993b. A methodology for the identification of archaeological eggshell. University of Pennsylvania: Philadelphia.
Slavin P. 2009. Chicken husbandry in Late-Medieval Eastern England: c. 1250–1400. *Anthropozoologica* **44**(2): 35–56.
Stewart J, *et al*. 2013. ZooMS: making eggshell visible in the archaeological record. *Journal of Archaeological Science* **40**: 1797–1804.
Sykes GA, Collins MJ, Walton DI. 1995. The significance of a geochemically isolated intracrystalline organic fraction within biominerals. *Organic Geochemistry* **23**(11/12): 1059–1065.

Supporting information

Additional supporting information may be found in the online version of this article at the publisher's web site.