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‘SmartFauna’: a microscale GIS-based multi-dimensional approach to faunal deposition at the Ness of Brodgar, Orkney

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Abstract

Recent technological advances in survey and computing are opening up new opportunities for the accurate spatial recovery and recording of archaeological materials during excavation. These have the potential to revolutionise understanding of depositional practices and (other such) taphonomic processes which create the deposits and sites that archaeologists explore. This article summarises a new methodological approach to the recovery and analysis of faunal remains which enables a highly accurate 3D spatial analysis of any patterning in bone deposited within archaeological layers using a combination of high resolution survey techniques for the recovery of animal bones, ‘bridging’ software and a high end GIS package. Application of this methodology to archaeological deposits from the Ness of Brodgar in Orkney has provided evidence for deliberate placement of selected cattle and red deer remains, suggesting that these species were of central importance in Late Neolithic society.

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1. Introduction

Taphonomy, the pathway of activities and behaviour that lead from once living animals to assemblages of bone recovered from an archaeological site, is a major focus for research within zooarchaeology, allowing insight into human attitudes to and utilisation of fauna in the past, as well as the pre- and post-depositional histories of a site (Lyman, 1994; Charles and Halstead, 2000; Orton, 2012; Madgwick and Mulville, 2012). A limitation for taphonomic studies, however, is the prevalence of bulk retrieval strategies for faunal material under which spatial co-ordinates of individual skeletal elements are not routinely recorded but are taken only in specific situations (e.g. animal burials and articulations, floors or working surfaces), often at the discretion of the on-site archaeologist. This has implications for the understanding of depositional processes involving faunal material and is particularly problematic where the aim is to address non-economic attitudes to animals though identification of the deliberate placement or ‘structuring’ of biological remains and material culture within archaeological features (e.g. Thomas, 1999; Pollard, 2001). Recognition of such practices requires an understanding of spatial variation within a bone deposit, which is impossible when animal bones are normally excavated in bulk; this limits analytical resolution and has engendered some scepticism regarding identification of ‘structured’ depositional events, particularly where incorporated in larger bone dumps (Wilson, 1992; Rowley-Conwy and Owen, 2011; Orton, 2012).

Recent technological advances in survey and computing are opening up new opportunities for the accurate spatial recovery and recording of archaeological materials, including bone, during excavation. High resolution metric survey (i.e. sub 2 cm accuracy) and the use of integrated GIS and database systems have been common place in archaeology for at least 10 years, pioneered by projects such as the work in advance of Heathrow T5 (Framework Archaeology, 2010), while the potential of GIS to address spatial variation of material remains is becoming increasingly evident (Arroyo, 2009; Katsianisa et al., 2008; Smith and Levy, 2012). More recently, application of laser scanning is facilitating rapid 3D recording of sites, structures and deposits (Lambers et al., 2007; McPherron et al., 2009). As part of a wider research project into Late Neolithic faunas at the Ness of Brodgar in Orkney, and in specific response to an unusual bone deposit recovered from this site, the Structure 10 ‘bone layer’, a methodology for the multi-dimensional recovery and analysis of faunal remains was developed. This combines high resolution survey techniques for the recovery of animal bones, ‘bridging’ software and a high end GIS...
package to enable a highly accurate 3D spatial analysis of any patterning in bone deposited within archaeological layers. This article presents the methodology and reviews the potential of this approach for identifying selectively in the deposition of particular categories of faunal remains (species, element, body-side, sex) within dense accumulations of bone, i.e. midden-type deposits.

1.1. The Ness of Brodgar

Excavation at the Ness of Brodgar in Orkney is revealing a remarkable multi-phase complex of late Neolithic structures contained within a large walled enclosure (Card, 2010, 2013) (Fig. 1). Radiocarbon dates imply that the site was the focus of activity for at least a millennium (circa 3300–2300 cal BC) and exclusively associated with Grooved Ware ceramics. In its later phases so far revealed, the site is dominated by several large buildings, whose scale, complexity, architectural details, decoration and associated finds assemblage indicate that their function is out with the domestic sphere, and is presently being interpreted as a communal ceremonial centre associated with the nearby stone circles at the Ring of Brodgar and the Stones of Stenness.

In the site’s penultimate phase earlier ‘stalled’ structures are superseded by an even larger building whose architecture is a departure from these earlier buildings: Structure 10 is monumental in scale with walls 4 m thick that initially defined a sub-square central chamber later modified into a cruciform plan (Fig. 1). Surrounding this building was a paved pathway defined by its external wall face and an external revetment. Apart from its scale (over 20 m long by 19 m wide) many aspects of Structure 10 sets it apart: the incorporation of several standing stones in its build, its alignment with Maeshowe, and the extensive use of dressed and decorated stone (Card and Thomas, 2012, 117).

At the end of Structure 10’s life, the building was ‘decommissioned’, with an elaborately pecked stone being placed next to an upturned cattle skull in the central hearth, whilst the surrounding pathway was backfilled. The upper most fill of the pathway was a thick deposit of animal bone C14 dated to c. 2300 cal BC. The interior of Structure 10 was then filled with a sequence of dumps of midden-enhanced soils and rubble, and the walls systematically robbed. This not only signifies the end of the use of this building but also marks the cessation of the Ness as a major Neolithic centre.

From when it was initially encountered, the unusual nature of the bone layer and its potential structured deposition was recognised. Occurring at a crucial stage in the history of the Ness, a closer examination and recording of the bone was considered essential to clarify the interpretation and meaning of the deposit. Rather than excavating it in its entirety a staged approach was taken, with a series of sondages through the deposit, initially with bone recovered in ‘bulk’ and subsequently, in 2011 and 2012, using the high resolution survey techniques outlined in this paper (Fig. 1). To date approximately 20% of the bone deposit has been excavated representing over 30% (n = 19,850) of the animal bone recovered from the Ness excavations.

2. Materials and methods

2.1. Developing a methodology for the 3D recording of faunal assemblages: X-bones and Crossbones

The methodology presented here for the 3D recording of faunal assemblages is an adaptation of ‘X-bones’, a survey and analytical software package developed for the 3D visualisation of mingled human remains in, e.g. mass graves (Isaksen et al., 2007). ‘X-bones’ comprises two elements: on-site protocols for the excavation and 3D recording of human remains (‘Crossbones’) and analytical software for manipulation of the resulting survey data to render accurate 3D visualisations (‘X-bones’). The X-Bones software is fully Open Source and is designed to work with GIS packages such as ArcGIS, gvSIG, GRASS/Paraview and qGIS. It takes a simple text file of survey data (Point ID, x, y, z) coded according to the X-bones schema, and generates a series of schematic 3D bone representations (polygons, darts, horizontal and vertical planes or darts) (Isaksen et al., 2007). The skeletal information inherent in the survey data is retained within the 3D polygons allowing them to be linked to more extensive analytical data, such as for example, an
osteological database containing information on body side, sex, and for aspects of this analytical data to then be displayed and queried spatially. It thus enables spatial understanding of relationships between elements, individuals and the intervening soil matrix, which can often be difficult to establish during excavation. It has been applied to the recovery of human remains, primarily within archaeological contexts (e.g. Simmonds et al., 2008) though it also has potential for forensic applications. It has not hitherto been used for the recovery or analysis of animal bones.

2.2. Excavation and recovery methods for the 3D recording of faunal assemblages

Three sondages, 0.5 m², were excavated into the St.10 bone spread in July 2011 (ctx 1403, SF Area 1, ctx 1237, SF Area 2) and July 2012 (Ctxs 4253, 4269, SF Area 3) (Fig. 1). In 2011, the surface was cleaned back to reveal the uppermost bone layer, before each bone was identified by the project zooarchaeologist (Mainland) and given a unique number (henceforth referred to as SmartFauna ID). Initially each fragment was given its own recording sheet and sketch plan (as for the Crossbones technique, Isaksen et al., 2007, 10) before it was realised that the amount of disarticulation and sheer volume of bone present made the use of full and partial excavation spits more practical.

For each spit, a rectified photograph was taken and a sketch plan made, showing all bones to be removed. The bones were surveyed in using a TST (Total Station Theodolite) according to a set of schema designed specifically for the recovery of animal bones; the resulting metric data for each bone fragment encountered during excavation thus comprises a pair of 3D co-ordinates (x, y, z) representing the proximal and distal extremities of each mammalian limb bone, or for the skull and vertebral elements, the mesial/cranial and distal/caudal extremities. Once this process was complete, the bones were removed and bagged individually with a record of their SmartFauna ID. While the aim was to recover the bone deposit in its entirety in this way, in practice fragments smaller than c. 5 cm in diameter were not surveyed in, unless they could be identified to anatomical element. In addition to metric survey, two bone spits were scanned using a Leica C10 Laser Scanner to assess whether the resultant point cloud could be integrated with the Crossbones software as an alternative to manual metric survey (Saunders et al., in prep). In 2012, a slightly different approach was followed to enable assessment of recovery protocols without an on-site zooarchaeologist. For each bone layer removed, bone fragments were tagged with the unique SmartFauna ID, photographed, sketched, surveyed in and then bagged and removed as above. The directionality of bone fragments (i.e. which bone end was proximal or distal, etc.) was determined subsequently by I. Mainland, where possible, using the photographic records, and the point data was then amended accordingly in the survey database.

2.3. Faunal analysis

All bone fragments were identified to species and element where possible and were recorded using UHI Faunal Remains Laboratory protocols which includes distinction of body part (prox/dist, etc.), body side, element completeness, fusion, eruption/wear and of burnt, butchered, eroded, gnawed and pathological bone (for full details see Mainland and Webster, 2013). To gain insight into pre- and post-depositional taphonomic processes, bone weathering was recorded using Beyensmeyer (1978) and breakage using Outram (2001, 2005), which distinguishes fresh (e.g. marrow-cracking) from dry breaks (i.e. post-depositional). Sex was assessed metrically using the distal tibia (the most numerous element present).

2.4. 3D visualisation and multi-dimensional analysis of faunal data

The raw point data generated during excavation of the Structure 10 bone deposit was converted into 3D entities (pyramids and lines, the lines then being visualised as tubes) using the Crossbones software (http://sourceforge.net/projects/openarchaeology/). The internal algorithm involved relies on the identification by the programme of point pairs (p, p', i.e. the survey points obtained from proximal and distal ends of the bone fragments) and uses basic geometry to create the form of the desired entity: for example, in the creation of a line, the programme stipulates that a vector, v, be drawn between the two points (p, p’) (see Isaksen et al., 2007 for a full explanation).

The vector lines generated by the X-bones software contain full orientation information but do not convey directionality, i.e. which end is proximal/cranial or distal/caudal; this is obvious in the pyramidal data, the wider end being designated as proximal/cranial (Fig. 2). Where certain fragments did not have readily definable proximal or distal ends (e.g. where precise identification has not
been possible or direction is difficult to assess due to fragmentation, as in long bone or skulls fragments, respectively), these are represented as tubes of equal thickness (see, e.g. Figs. 2 and 3). This is merely a more user friendly graphical representation of the existing line data.

The DXF file generated by this process was integrated with the faunal database by converting the 3D entities into shapefiles using ArchMap 10.0 (a GIS programme) and creating a join with the faunal database based on the SmartFauna ID. The resultant 3D ArchMap 10.0 (a GIS programme) and creating a join with the faunal database based on the SmartFauna ID. The resultant 3D shapefiles could then be viewed and manipulated within ArcScene, another part of the ArcGIS 10.0 suite of software. This enabled an accurate visual representation of the bone spread, which can be viewed in any of the formats outlined above and can be coded according to the various data fields recorded for the faunal assemblages: examples include by species (Fig. 2), element (Fig. 3), sex (Fig. 4), and taphonomic condition (Fig. 5). As ArchView is a relational database, specific aspects of the assemblage can be selected for a spatial analysis (e.g. only the tibia (Fig. 4); all bones at a particular level (Figs. 1 and 2).

This analysis can be undertaken visually by looking for patterning in the assemblage across a range of views, 2D horizontal, 2D vertical and 3D which includes rotation and a zooming in and/or quantitatively by obtaining statistics for the locations of specific species, elements or categories of bone, e.g. mean height of cattle tibia; species frequency by excavation level; mean orientation of bone fragments, etc. (e.g. see Sections 3.4 and 3.4).

For the Structure 10 bone deposit, the overall aim was to assess the potential of these 3D visualisation techniques for addressing the taphonomic history of this assemblage, and in particular for evidencing structured deposition, i.e. a deliberate placement of individual bones and/or categories of bone as opposed to a more randomised deposition of bone, which would be more consistent with generalised refuse/midden discard. Accordingly, analysis explored the following questions: were bones of different species, element, part, body side or sex found in specific locations; and, did bone orientation exhibit any specific patterning. Spatial variability in bone weathering was explored to address the temporality of the deposit: whether it was formed as a single event; if it was rapidly covered up; or, was left open to the elements for a long period of time. An analysis of spatial variability in fragmentation and of evidence for re-fitting has also been undertaken but is presented in full elsewhere (Mainland et al., in prep). To facilitate an understanding of spatial patterning by depth of the deposit both within and between each excavation trench, the data was arbitrarily split into three ‘spits’ of equal depth: 0–5 cmOD above basal; 5–10 cmOD above basal; 10–15 cmOD above basal.

Bone directionality (i.e. takes into account relative positive of proximal and distal bone ends) and orientation was explored both descriptively (i.e. through a visual appraisal of patterning) and quantitatively. The latter was expressed in terms of two angles, one reflecting variation on the xy plane (i.e. as viewed from above) and one which indicates variation on the yz plane (i.e. as viewed in cross-section). Statistical significance was assessed using Rose diagrams, Rayleigh’s test for uniform distribution in directional data and the Mardia–Watson–Wheeler test for equal mean angle between two groups (Hammer, 2012).

3. Results

3.1. The Structure 10 bone layer

349 individual bones were assigned point pairs during excavation of the Structure 10 bone layer, represented by 2916 bone fragments (Tables 1 and 2). A further 407 fragments were not assigned spatial co-ordinates and derive largely from unidentifiable or long bone fragments (n = 314, 77%). These were typically small fragments dislodged during excavation of the densely packed bone layer in Area 1. In each of the three areas, the layer was almost entirely comprised of cattle tibia (Table 2). Two further species, red deer and sheep, occur very infrequently (Table 1).

Variability was observed in the density of the bone encountered across the structure. Area 1 exhibited a densely packed deposit of bone, c. 15 cm thick with 213 point pairs recorded; in contrast only 29 and 107 point pairs were recorded in Areas 2 and 3, respectively, though the bone was dispersed within a similar depth of soil.
material. Stratigraphically, there were similarities between the three areas, with the bone lying within a similar matrix of silty, stony material (Card and Thomas, 2012, Card, 2013).

Biometrical data could only be obtained from 7 cattle tibiae due to fragmentation. These were augmented by a further 6 recovered from earlier excavations on the st. 10 deposit (Fig. 6). One individual is clearly larger than the others and can be interpreted as male. The smaller cluster may comprise cows and/or castrates but in the absence of whole bones distinction between these groups is difficult (Higham, 1969). Sex could not be assessed for the other species due to sample size and a lack of diagnostic morphological criteria.

Fragmentation indices were only obtained from non-reproducible fragments \((n = 59)\) and suggest that a significant proportion of the assemblage had been fractured while fresh \((n = 36, 61\%)\), likely for marrow. Fracture patterns for the tibia indicate a relatively consistent process in which the bone was broken into 2–3 pieces approximately midway along the shaft. Slight scorching is evident in some fragments suggesting that this activity involved heating of the bone. Together, this is consistent with ‘marrow cracking’, whereby marrow is extracted from bone when fresh, but after the flesh has been removed, with the bone being heated to melt the marrow and make it easier to extract (Rowley-Conwy and Owen, 2011; Sergeantson, 2011). Breakage also occurred when the bone was dry, i.e. post-depositionally \((n = 23)\).

Refits analysis was undertaken to assess both the likelihood of adjacent fragments deriving from individual bones, facilitated by a spatial analysis of bone plotted by body side and portion (Fig. 7) and of fragments from individual bones being dispersed across the st. 10 deposit. This indicated very few conjoining fragments, with only 5 definitive joins identified and a further 8 likely on grounds of colour, fracture angle and morphology. In all but one example, the refits are located in close proximity indicating breakage in situ after deposition.

A low overall frequency of weathered bone was recorded suggesting an assemblage which was not exposed unduly to the elements (Table 3). No correlation between bone survivorship and bone density was observed (Fig. 8).

### 3.2. Spatial variation in the distribution of species, individuals, element, part and sex

Cattle are the dominant species in each of the three excavation areas, and are spatially spread throughout the deposit with an emphasis on lower limb elements, primarily tibiae which comprise 75\% \((n = 179)\) of the elements identified to this species (Figs. 2 and 3; Table 2). MNI was first assessed by a visual matching based on state of fusion, metrical and morphological criteria. For fragments where such diagnostic criteria were absent (due to fragmentation or erosion, e.g.), it was assumed that pairs may feasibly be present but unrecognised and hence MNI for these was based on the maximum value per body side taking into account fusion. A low number of true matching pairs was identified \((n = 2)\) suggesting disparate joints rather than individual animals.

Samples sizes are small for the other species, which makes conclusive detection of trends difficult, but sheep/goat and small ungulate fragments are mostly found in the lower half of the deposit in each area, while red deer is found overlying the deposit, but only in Area 1 (Fig. 2). These latter remains represent the articulated red deer skeleton of a 33–65 month old individual. Articulated red deer carcasses have been found elsewhere at the Ness of Brodgar, in the Structure 10 bone layer \((n = 2)\) and at Structures 1 and 10, and in each case occupy a similar position, in upper deposits, overlying terminal layers.

Variability in the distribution of cattle elements is equally difficult to assess due to the dominance of one element, the tibiae

### Table 1

Species representation in the Structure 10 bone layer: lists for each area the number of bones allocated a unique SmartFauna identification number and the MNI for each species. MNI was calculated for Areas 1–3 as a whole and is based on the proximal tibia and proximal radius for cattle and sheep/goat respectively, and on one partially articulated red deer.

<table>
<thead>
<tr>
<th>Area</th>
<th>Cow</th>
<th>Red deer</th>
<th>Sheep/goat</th>
<th>Large ungulate</th>
<th>Small ungulate</th>
<th>Unidentifiable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ((n = 213))</td>
<td>181</td>
<td>10</td>
<td>6</td>
<td>13</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>2 ((n = 29))</td>
<td>15</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>3 ((n = 107))</td>
<td>41</td>
<td>0</td>
<td>1</td>
<td>28</td>
<td>3</td>
<td>34</td>
</tr>
<tr>
<td>Total</td>
<td>237 ((\text{MNI} = 37))</td>
<td>10 ((\text{MNI} = 1))</td>
<td>7 ((\text{MNI} = 2))</td>
<td>52</td>
<td>4</td>
<td>39</td>
</tr>
</tbody>
</table>
and the small sample sizes for areas 2 and 3. In Area 1, cattle cranial and foot elements are only found in the lower part of the deposit (Fig. 3). Feet elements are dominated by calcaneum, each from different individuals (all left-hand-side). The cattle maxilla, mandible and fragments of cattle skull all likely derive from an individual and are located approximately centrally within the bone spread (Fig. 9). In areas 2 and 3, fragments of cattle skull and other cranial elements (mainly loose teeth) are also found predominately towards the base of the deposit, though not exclusively so, and again in this location may reflect one individual per area (area 3 – 72\% (n = 8) of cattle cranial elements in lower half; area 2 – 100\% of cattle cranial elements (n = 2) in lower half). Although more crudely recorded, cattle cranial elements were also found primarily in the basal deposits of the bone deposit in a sondage cut into cxt 1237 in 2010 (94\% of the 16 cattle cranial elements).

It is difficult to assess how many individuals are potentially represented by the remaining cattle elements recovered (Table 2).

Table 2
Cattle anatomical representation in the Structure 10 bone layer (Areas 1–3 combined) using non-reproducible elements for MNE, %MNE and %MAU. MNI takes into account state of fusion, metrical and morphological criteria (see text for further details).

<table>
<thead>
<tr>
<th>MNI</th>
<th>MNE</th>
<th>%MNE</th>
<th>%MAU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scap</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>Pel</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>Hum p</td>
<td>1</td>
<td>1</td>
<td>3.57</td>
</tr>
<tr>
<td>Fem p</td>
<td>1</td>
<td>1</td>
<td>3.57</td>
</tr>
<tr>
<td>Hum d</td>
<td>3</td>
<td>4</td>
<td>7.14</td>
</tr>
<tr>
<td>Fem d</td>
<td>1</td>
<td>1</td>
<td>3.57</td>
</tr>
<tr>
<td>Rad p</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>Tib p</td>
<td>37</td>
<td>55</td>
<td>100.00</td>
</tr>
<tr>
<td>Uln</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>Rad d</td>
<td>2</td>
<td>3</td>
<td>7.14</td>
</tr>
<tr>
<td>Tib d</td>
<td>21</td>
<td>33</td>
<td>60.71</td>
</tr>
<tr>
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<td>0.00</td>
</tr>
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<td>1</td>
<td>1</td>
<td>3.57</td>
</tr>
<tr>
<td>Ast</td>
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<td>0</td>
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</tr>
<tr>
<td>Cal</td>
<td>7</td>
<td>8</td>
<td>14.29</td>
</tr>
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<td>4</td>
<td>3.57</td>
</tr>
<tr>
<td>Pha 2</td>
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<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>Pha 3</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>Jaw</td>
<td>1</td>
<td>1</td>
<td>3.57</td>
</tr>
</tbody>
</table>

Fig. 6. Metrical data for the Ness of Brodgar cattle tibiae: distal breadth (Bd) against distal depth (DD) (after von den Driesch, 1976).

Fig. 7. An example of spatial mapping used to identify conjoining fragments: shows cattle tibiae coded by portion (Proximal end — yellow; Proximal end and shaft — orange; Distal end and shaft — blue; Shaft — red; Proximal half shaft only — pink; Distal half shaft only — green) for the central bone layer (7a — left-hand-side; 7b — right-hand-side). Refits are numbered with nos. 1 and 2 being definitive conjoins and 3–5 likely from morphology, bone condition and location (see text for further explanation). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
as, unlike the red deer, these are spatially separated within the deposit and no articulating elements are present: e.g. a scapula and humerus which both likely derive from a similarly sized, large individual and which exhibit a comparable degree of weathering could arguably derive from the same animal but this is impossible to state definitively because the articulating joints are not preserved.

The distribution of the tibiae assigned a sex is shown in Fig. 6. The smaller individuals interpreted as females/castrates show no apparent trend, whereas the larger individuals which exhibit a comparable degree of weathering could arguably derive from the same animal but this is impossible to state definitively because the articulating joints are not preserved.

3.3. Spatial variation in bone orientation

Variability in bone orientation was assessed visually for all elements together and for cattle tibiae separately. Tibiae were also sub-divided into proximal and distal parts, and by body side. In addition, the orientation of cattle tibiae was assessed quantitatively (Table 4, Fig. 10). Slight visual differences in orientation of tibia could be detected through the deposit, with those in the basal layers showing more regularity than those deposited higher up where orientation is predominately haphazard (Fig. 10). Neither element part nor side demonstrated any distinct trends. If the deposit is viewed in vertical cross-section, there is, however, some indication that in Area 1 the main deposit of bone, which comprised cattle tibiae, is forming up and around the centrally located cattle skull elements, and perhaps also the large male tibiae (Fig. 9). The statistics for bone direction broadly confirm these observations, suggesting that there is significant variability in the ‘tipping’ angles of bones within the deposits, such that fragments in the lower layers are more horizontally inclined than those higher up where greater variability in evident (Table 4, Fig. 10). Fragment numbers were too low to assess whether a similar trend was apparent in areas 2 and 3.

3.4. Spatial variation in bone weathering

A low overall frequency of highly weathered bone was recorded indicating an assemblage which was not exposed unduly to the elements (Table 3, Fig. 5). The frequency of bone showing slight weathering was higher in the upper levels suggesting that while the deposit was built up relatively rapidly, on completion it may have lain open for a period of time sufficient to cause some damage to bone surfaces but was then covered over.

4. Discussion

4.1. Microscale GIS and faunal analysis

Analyses of the Structure 10 bone layer at the Ness of Brodgar using a combination of high resolution survey and microscale GIS analysis shows the potential of these techniques for identifying selectively in faunal deposition within dense midden-type deposits which are more normally excavated using bulk recovery strategies for bone. An enhanced understanding of the composition of the faunal deposit is enabled through display of accurate spatial information on the location and orientation of bones of individual animals or of specific species, elements, sex, etc. At the Ness of Brodgar, cattle skulls were shown to be located in basal positions within the St. 10 bone deposit, red deer in upper and sheep in lower layers while the potential presence of at least one large Bos individual was demonstrated for the lower half of Area 1. Analyses of bone orientation and tipping angles become possible, here indicating that the cattle tibiae which formed the bulk of the St. 10 assemblage were not subject to a careful or regular placement, but rather were more haphazardly piled up and around a centrally placed cattle skull which was however likely more carefully located. Although not easily illustrated for the Ness of Brodgar assemblage due to low frequencies of refits and paired elements, a further analytical potential of this methodology is the ability to map paired elements and refitted fragments in 3-dimensions (see e.g. Fig. 7). This application would be particularly useful for identifying patterning in assemblages where individual animal bones have been fragmented and spatially distributed across a surface (e.g. floors, and work areas) or where semi-articulated and/or fragmented individuals were deposited within more general midden refuse or in funerary contexts (e.g. Thomas and McFadyen, 2010; Morris, 2011; Hill, 1996).

In integrating a relational database with visualisation software and high resolution metric survey data for individual bone fragments, this method enables a sophisticated 3D spatial interrogation of faunal representation alongside standard tabular analyses. It is this ability to manipulate the GIS-output in 3-dimensions, to move around a deposit, selectively highlighting and removing particular bone fragments (see e.g. Fig. 4) or layers of bones (compare e.g. Fig. 2a–c), i.e. visually recreating the bone deposit and modelling how it may have built up, both qualitatively and quantitatively, which provides the greatest analytical opportunities arising from this methodology. This facility enabled identification of the potential structuring in the St. 10 bone deposit around the cattle skull.
and large male tibia, observations which could then be tested empirically by calculating tipping angles using the metric survey data (x, y, z co-ordinates).

4.2. The Ness of Brodgar St. 10 bone layer and its wider significance

Analysis of the faunal remains within the St. 10 bone layer at the Ness of Brodgar demonstrates that it was almost entirely comprised of cattle tibia, that many of these bones had been broken, likely for marrow extraction shortly before deposition and that the assemblage was not open to the elements for any significant period of time. The emphasis on one element and the absence of paired tibiae implies joints rather than whole carcasses. Metrical analysis of cattle tibia suggests the presence of females/castrates with the occasional bull, and fusion indicates an emphasis on sub-adults and mature cattle. At least 37 cattle are represented in Areas 1–3, with a further 50 recorded from earlier sondages excavated into the deposit. Variability is evident in the quantity of bone around the perimeter of Structure 10, however in each area excavated to date, the nature of the bone deposited is similar in that marrow-fractured cattle tibiae predominate. This overall consistency in the faunal assemblage together with a comparable stratigraphic record in each excavated area is indicative of a single depositional event, or at the very least a series of events occurring over a fairly short time period. The low frequency of refits for the marrow cracked bone may indicate that consumption is taking place elsewhere and that the deposit reflects the re-deposition of such refuse, as has been argued on similar grounds for the extensive Bronze age cattle bone deposit at Gayhurt (Chapman, 2007); alternatively refits may yet to be recovered from the unexcavated fraction of the St. 10 deposit (Fig. 1).

Cattle tibiae are clearly being preferentially selected for deposition in the final phases of activity surrounding Structure 10. There is some evidence that other bones and species may also be selectively utilised in this deposit, cattle skull elements being more common in the basal levels while an articulated red deer is

Table 4

Statistics for bone fragment orientation in Area 1 of the Structure 10 bone layer (statistical significance assessed using Rayleigh’s test for directional data) (statistically significant results are indicated in bold, p < 0.05).

<table>
<thead>
<tr>
<th>Level</th>
<th>Mean</th>
<th>Range</th>
<th>R</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Vertical direction (‘dip’) (zy) 287.73</td>
<td>2396.6–335.9</td>
<td>0.27</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>Planar direction (xy) 232.54</td>
<td>165.1–301.9</td>
<td>0.1937</td>
<td>0.19</td>
</tr>
<tr>
<td>2</td>
<td>Vertical direction (‘dip’) (zy) 263.74</td>
<td>203.5–324</td>
<td>0.1834</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>Planar direction (xy) 218.24</td>
<td>165.3–278.2</td>
<td>0.1839</td>
<td>0.07</td>
</tr>
<tr>
<td>3</td>
<td>Vertical direction (‘dip’) (zy) 210.61</td>
<td>175.6–244</td>
<td>0.3525</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>Planar direction (xy) 313.01</td>
<td>195.3–398.9</td>
<td>0.1872</td>
<td>0.34</td>
</tr>
</tbody>
</table>

Fig. 9. Overview of the Structure 10 bone deposit in vertical cross-section (9a – basal; 9b – central; 9c – top).
found overlying the whole deposit in Area 1. Moreover, it was suggested that the tipping-angles of the tibia in Area 1 may be consistent with bone being deposited up and around a centrally placed cattle skull. No further regularity in the placement of the tibiae was observed. Hence, whilst deposition practice strongly favoured tibiae and likely utilised these in a very specific way in combination with cattle skulls and skeletal elements deriving from bulls and red deer, precisely how the tibiae were laid down appears not to have been important. It may be inferred that any meaning attached to this skeletal element reflects its incorporation into an agglomeration of tibiae, perhaps reflecting excessive consumption, unlike, e.g. the skulls and red deer carcasses which were singled out for individual placement. The significance of these latter trends is however more difficult to evaluate due to the small sample sizes involved and/or the singularity of the observations and hence are subject to confirmation though further excavation of the Structure 10 bone layer. Nevertheless, the occurrence of red deer skeletons elsewhere at Ness of Brodgar in positions which appear to reflect final or ‘closure’ acts of deposition and of an emphasis on articulated carcasses at several other Late Neolithic sites in Orkney may lend some further support to the suggestion that red deer remains are being used in very specific ways during this period (Sharples, 2000; Morris, 2005). Equally, a concern with cattle skulls is evident in the Neolithic/Early Bronze Age settlement at the Links of Noltland on the Orkney island of Westray, where c. 12 cattle skulls were placed in the foundation layers around the perimeter of a Late Neolithic house (Moore and Wilson, 2011).

The selective use of cattle skulls has been demonstrated more widely in the British Neolithic, as has the central importance of cattle in this period, with cattle skulls occurring in significant depositional locations such as ditch terminals, basal deposits of henges, and in funerary contexts (Thomas, 1999; Pollard, 2006; Ray and Thomas, 2003; Serjeantson, 2011). Selectivity involving cattle tibiae to the extent documented at Ness of Brodgar has not, however, been documented elsewhere. The nearest parallels are again to be found in the Early Bronze Age barrow burial at Gayhurst which, dated to 2200 and 1780 cal BC, is slightly later than the Ness of Brodgar bone layer; here limb bones, skulls and mandibles from over 300 cattle placed in a ring ditch surrounding a male burial were interpreted as remnants of a funerary feast (Chapman, 2007).

The Structure 10 bone layer has not yet been excavated in its entirety and hence the total number of cattle involved in this event can only be approximated at this stage. That a MNI of 87 has been recovered so far, from deposits representing c. 20% of the total layer, suggest that the entire bone layer assemblage reflects large numbers of animals, likely in excess of 400 individuals. The Ness of Brodgar Structure 10 bone layer will thus represent a vast amount of meat, perhaps indicative of communal events such as feasting, and of a gathering together of large numbers of people as has also been suggested for Durrington Walls and other Grooved Ware settlements in the UK (Parker Pearson, 2003; Albarella and Serjeantson, 2002; Rowley-Conwy and Owen, 2011; Serjeantson, 2011). In bovids, however, the tibia is not the skeletal element which gives the highest meat yields, but rather ranks higher for marrow (Lyman, 1994, 223–234). This together with evidence for marrow cracking may suggest that meat was not necessarily the only or indeed primary goal with respect to the activities reflected at Structure 10.

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**Fig. 10.** Bone direction (in degrees) in Area 1 of the Structure 10 bone deposit viewed in vertical cross-section (see text for explanation (10a – basal; 10b – central; 10c – top)).
5. Conclusions

In combining high resolution metric survey with GIS-based 'bridging' software and a high end GIS package a multi-dimensional assessment of faunal deposition becomes possible, thus enabling spatial understanding of relationships between elements, species and the intervening soil matrix: essentially, the faunal deposit can be visually reconstructed in 3D for post-extraction analysis. This has significant implications for the future development of taphonomic studies within archaeozoology. Faunal assemblages are normally analysed in ‘bulk’ with no or little understanding of spatial relationships between bones of different species, age or sex, etc.; application of microscale GIS-based analyses to bone spreads will allow higher resolution analyses of depositional processes to be undertaken with consequent impact on our understanding of human behaviour, especially in relation to ritual or symbolic uses of animals (e.g. Pollard, 2006; Thomas, 1992; Hill, 1996; Morris, 2011), evidence for which is often much debated (Rowley-Conwy and Owen, 2011; Orton, 2012; Serjeantson, 2011; Thomas and McFadyen, 2010). While the tools and skills needed to undertake the recording process are those which are already readily available to the archaeologist, the methodology presented here is limited by the time taken during to survey each bone fragment on-site: it took 10 days to recover the bone deposit from Area 1–3; in comparison, in 2010 a similarly sized section of the bone layer was removed in 1–2 days using conventional bulk recovery methods. This may restrict application to the more significant and unusual deposits which warrant such a careful examination. Ongoing research on the integration of point cloud data derived from laser scanning of the Ness of Brodgar bone layer, is however, articulating a methodology which offers a more rapid recovery method for on-site bone mapping (Saunders et al., in prep) and opens up the possibility of high resolution recovery and multi-dimensional spatial analysis of animal bone becoming a routine procedure for on-site recovery of faunal assemblages.

At the Ness of Brodgar, a microscale analysis of the Structure 10 bone layer has provided evidence for the deposition of animal bone in a highly regulated and structured way. The two dominant species present in this deposit, cattle and red deer, have also been recognised elsewhere as having special significance; this deposit reaffirms their importance in Late Neolithic Society. The scale of the feasting implied by this bone would support the theory that the Ness of Brodgar was non-domestic in nature and a communal centre whose importance perhaps transcended the immediate Orcadian context of the site. Happening at a crucial time, that not only marks the end of the Ness but seems to coincide with the demise of the Grooved Ware phenomenon in Orkney, has wider implications for the Neolithic/bronze Age transition.

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