Characterising life in settlements and structures: incorporating faecal lipid biomarkers within a multiproxy case study of a wetland village

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Highlights:

- First application of steroids in a multiproxy spatial study of wetland floor deposits.
- Multiproxy analyses refine characterisations of faecal sources and animal husbandry.
- Faecal proxies show changes in roundhouse use and conditions over time and space.
- Steroid biomarkers identify more subtle faecal sources than traditional proxies.
- Roundhouse has active inner area and flexible functionality.

Abstract

Roundhouses are ubiquitous features of Iron Age landscapes across North West Europe, yet the way they were used internally is not well understood. We demonstrate how spatial analyses of steroid lipid biomarkers advances our understanding of household activities, living conditions and animal management associated with a well-preserved 5th century BCE roundhouse from Scotland's first Iron Age wetland village, Black Loch of Myrton, especially when combined with more traditional archaeological approaches. Faecal steroids (5β-stanols and bile acids) are well preserved within the wetland roundhouse floor deposits. Diffuse faecal inputs are identified within these deposits, limiting the resolution of faecal source discrimination compared with studies of concentrated faecal remains. However, analysis of both 5β-stanols and bile acids enables discrimination between ruminant (sheep, goat and cattle), pig and horse/human faecal remains. By integrating faunal data and entomological dung indicators we are able to characterise the on-site presence of animals associated with these archaeological structures. Steroids indicate short-lived and/or temporary pulses of dung deposition within the Iron Age roundhouse case study structure, which can be very difficult to determine using other archaeological proxies. Furthermore, our multiproxy results demonstrate the molecular preservation of steroids within deposits that have been subjected to regular floor cleaning, which is associated with the removal macrofossil proxies. Comparisons of multiproxy faecal signatures of the inner and outer sections of the structure show temporal and spatial heterogeneity in usage and living conditions. The faecal signature points to temporary sheltering of animals within the inner section of the structure. The multi-use and division of different activities within the roundhouse, determined by steroids, marks an important contribution to broader archaeological debates surrounding structures, their functions and re-use.

Keywords:

Faecal, Sterols, Bile acids, Palaeoecology, Settlement structures, Animal husbandry, Wetland archaeology, Iron Age

1. Introduction

A key advantage of analysing occupation sedimentary deposits, such as floor remains, is the retention of a wealth of information about the use of space in settlement sites (e.g. Manzanilla and Barba, 1990; Middleton and Price, 1996). The characteristics of these structural space uses, which may vary over time, can provide insights into social statuses and roles of houses, animal husbandry practises, food storage, and handcrafts etc. although, as is the case of Alpine Neolithic settlement houses, special functions are rare (Ebersbach, 2013). Almost all environmental proxies have been trialed to reconstruct the use of internal space including geochemistry, molecular proxies, pollen, insects, phytoliths as well as the standard analysis of micromorphology, plant macrofossils and faunal remains. The most effective characterisations rely on a combination of these proxies to provide multiple lines of evidence to support interpretations (Shillito, 2017). However, integration of multiproxy analyses can be complex and should be considered at the project design stage (Shillito, 2017) with clear considerations for the specificity of results obtained from each proxy (e.g. Middleton et al., 2010) as well as the role of the depositional environment as a record of activity (Shahack-Gross, 2011).

Of the biological proxies used to characterise occupation deposits, insects have been widely used due to their early synanthropism (Smith et al. 2020), and host-specific diversity related to almost all aspects of within structure activities as well as the external environment. Some of the best-known examples include the study of Norse North Atlantic farmsteads (Panagiotakopulu et al. 2007) and Viking age houses from 9th AD century Dublin (Reilly et al., 2016). Whilst pollen is less commonly used to characterise occupation deposits than insects, the case study of Pueblo houses in southwest USA demonstrates the ability of pollen spectra obtained from floors to

suggest different room uses such as food processing, ceremonial function or meeting rooms (Morris, 1986). A non-in situ example includes the high concentrations of cereal and grazing indicator pollen adjacent to *crannogs* (artificial island settlements) taken to indicate crop storage/processing (O'Brien et al., 2005) and animal tethering and slaughter (Brown et al. subm.). The use of phytoliths is more common in dryland settlement sites such as Çatalhöyük in Turkey (Ryan, 2011; Shillito and Ryan, 2013), but they have been used successfully in temperate European environments such as Williamson's Moss in Britain (Wade et al., 2019) and have great potential in tropical wetland sites such as the Kuk swamp in Papua New Guinea (Golson et al., 2017).

A commonly applied technique to assess function and use of space is micromorphological analysis of floors with soil phosphate and multi-elemental analysis (Middleton, 2004). Elevated soil phosphate is associated with animal use in a wide variety of environments (Holliday and Gartner, 2007). However, its equifinality has been demonstrated (Middleton et al., 2010) and accumulation patterns within soil requires careful interpretation (e.g. Nielsen and Kristiansen, 2014), particularly in wetland contexts that are impacted by changes in solubility, absorption, resorption, mobilization and leaching, at low pH and Eh, of sediments. In the classic Butser House, England, experiment, Macphail et al. (2004) showed how crust formation was important for phosphate retention and microscopic crust formation, the degree of floor compaction and its mineral content all related to the variability in phosphate depletion from floor surfaces exposed to pedestrian traffic and house cleaning. At the same experimental site, Evershed et al. (1997) highlighted that a manured area could not be clearly identified using concentrations of total phosphorus, but it was detectable using faecal lipid biomarkers (5β-stanols).

116 Recent developments in the refinement of faecal lipid biomarker signatures (Prost et
117 al., 2017; Harrault et al., 2019) now facilitate the application of this approach within
118 widely available bulk anthropic sediments, as well as concentrated faecal remains, to
119 characterise animal husbandry and living conditions. These lipid compounds -
120 termed steroids - have the ability to enhance characterisations of activity areas since
121 they are direct markers of faecal matter produced by higher vertebrates and can
122 identify human-animal interactions. The steroid composition of faecal matter
123 produced by different animals varies according to their food sources, digestive
124 processes and gut bacteria (Leeming et al., 1996). Therefore, diagnostic ratios of
125 faecal and non-faecal sterols (e.g. 5β-stanols vs 5α-stanols) and bile acids can
126 discriminate between human, porcine and herbivore faecal matter (Bull et al., 2002;
127 Prost et al., 2017; Harrault et al., 2019). Steroids have identified the presence and
128 source of faeces in a range of archaeological settings including coprolites and manure
129 (Evershed et al., 1997; Bull et al., 2001; Shillito et al., 2011; Prost et al. 2017; Ledger
130 et al., 2019) and archaeological soils (Simpson et al., 1998; Bull et al., 1999; Harrault
131 et al., 2019).

132 The utility of incorporating steroids within studies of activity areas has been
133 demonstrated using sterol analyses of deposits obtained from experimental
134 settlements and palaeosols. For example, the combined analyses of elements and
135 sterols from an experimental Iron Age settlement identified separate activity areas
136 and provided positive identification of activities in all except one area (Hjulström
137 and Isaksson, 2009). The first spatial analysis of sterols obtained from paleosols
138 identified patterns of animal husbandry from land adjacent to a 5^{th}-11^{th} c. AD
139 Russian fortress-settlement (Harrualt et al., 2019; Anderson et al., 2019). Whilst
140 these studies showcase the ability of sterols to identify spatial patterns of activity

areas and animal husbandry, the use of both sterol and bile acid analyses within wetland archaeological settlement sediment deposits has yet to be tested.

We present the first multiproxy spatial study of Iron Age roundhouse wetland sedimentary deposits from the Black Loch of Myrton (BLM) in southwest Scotland, UK (Figure 1; Crone et al., 2018) using steroid lipid biomarkers (sterols and bile acids), ecofact analysis and micromorphology to investigate the use of space within a roundhouse structure (Structure 2). Excavations of waterlogged Iron Age roundhouses are rare, but other examples from the UK include Flag Fen (Pryor, 2001) and Glastonbury Lake Village (Hill et al., 2018). The BLM excavation offered an opportunity to investigate the usage of an Iron Age roundhouse since the nature of the wetland site means there was excellent structural integrity, providing insight into structural form and construction of the roundhouse (Crone et al., 2018), as well as good organic matter preservation within the archaeological soils. Structure 2 has well-stratified organic rich matrix, important for faecal steroids, which have low water solubility and are absorbed to particulate organic matter preventing vertical movement via leaching (Lloyd *et al.*, 2012). As a result, steroids remain in situ at the point of deposition (Lloyd et al., 2012), are likely well preserved over the Iron Age timescale (Lin *et al.*, 1978; Bull *et al.*, 2001; Prost *et al.*, 2017) and, in the case of coprolitic sources, are preserved in wetland settings (Ledger et al., 2019).

Two models for Iron Age roundhouse space use exist: (1) inner sections are areas of active communal domestic activity, with the outer section as a peripheral area for sleeping and storage (Hingley, 1990); and (2) outer sections of the roundhouse are reserved for stalling of animals (e.g. Kelly, 1988; Banks, 1995). The difference between these two models is dependent on region (Hill, 1995), with centrally focused roundhouse activity areas highlighted in the first model, generally found in northern

regions of Iron Age Britain. To determine the most appropriate model of roundhouse use and to establish whether livestock co-habited spaces with people we need to establish what these inner and outer spaces were used for by integrating multiproxy indicators of humans and animals.

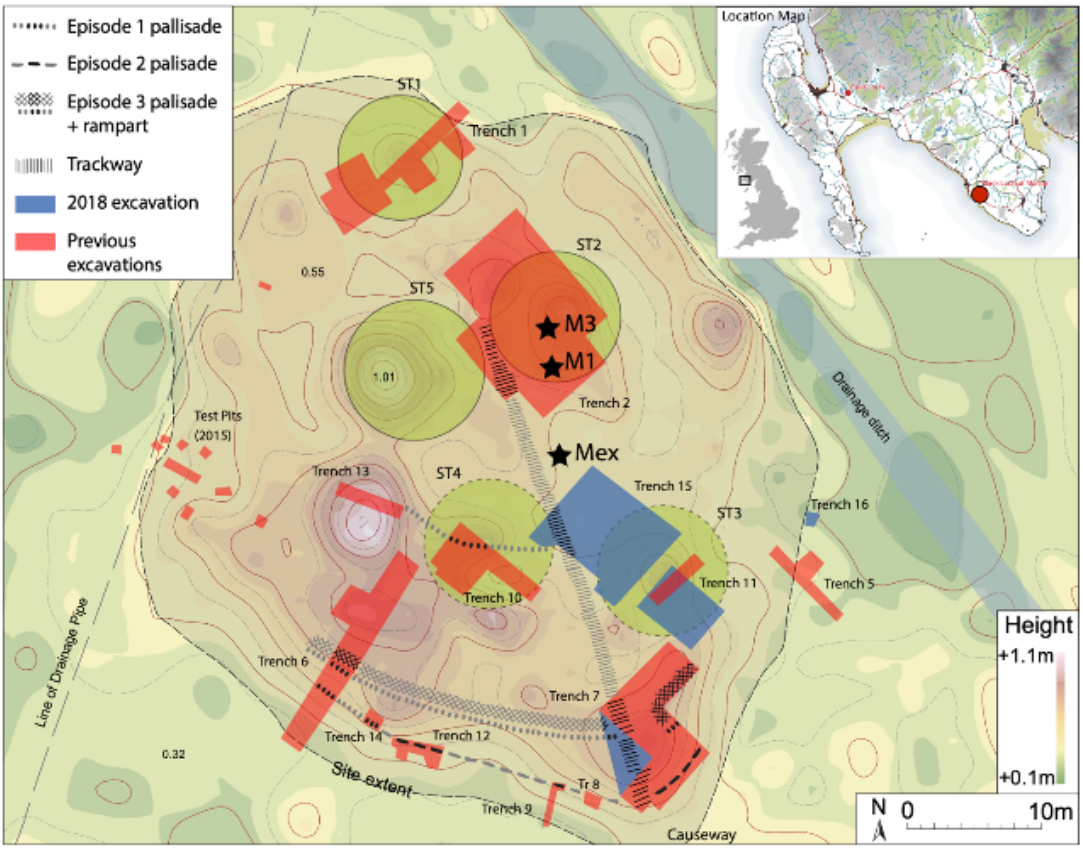
2. Methods

2.1 Study site

The Black Loch of Myrton (BLM) is a drained wetland in southwest Scotland, UK (54°45'13"N 4°32'53"W; Figure 1). Recent excavations show the settlement was constructed on top of a natural peaty island approximately 50 × 60 m within a shallow fen marshland (Crone and Cavers, 2015; 2016). Excavations and dating (radiocarbon-dating and dendrochronology) of five of the settlement mounds show that the date of settlement at BLM was the latter half of the 5th century BCE, ending in the 3rd century BCE with at least three phases of construction and renewal (Crone et al., 2018).

Structure 2 is a large roundhouse 12.8 m in diameter (Figure 1; Crone et al., 2018), the inner and outer sections of which were divided by a ring of posts proximal to the central stone hearth (Crone et al., 2018), likely reflecting a common, conscious organising principle of Iron Age roundhouse structures in Britain (Pope, 2007). The stratigraphy of the hearth, entrance and floor deposits indicate they have been refurbished at least twice, leading to the build-up of stratified acidic layers of plant litter (pH 5.3 ± 0.4), which were used to create the floor surfaces (Crone et al., 2018). Chronological evidence for the construction, occupation and abandonment of

189 Structure 2 brackets it to a 30 to 40-year period from *ca*. 435 BCE – 400 BCE (Crone
190 et al., 2018). Preservation of structural and organic material is excellent due to
191 waterlogging. Despite high-levels of organic matter preservation in BLM Structure 2,
192 evidence for activities that took place within the roundhouse are limited: minimal
193 material culture was recovered (Crone et al., 2018) and the micromorphology and
194 macrofossil remains suggest regular cleaning within the structure, thereby removing
195 anthropogenic activity signals (Robertson and Roy, 2019).



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197 ***Figure 1:*** *Location of Black Loch of Myrton in southwest Scotland. Digital terrain*
198 *modelling characterizes the topography of the site, revealing seven-eight discrete*
199 *mounds, five of which have been excavated. Black stars indicate Structure 2 (ST2)*
200 *sampling locations: M3 = inner roundhouse, M1 = outer roundhouse, M_{ex} = outside*
201 *roundhouse entrance.*

202 **2.2 Sampling**

203 Monolith tin samples were taken in summer 2015 from the inner and outer area of
204 Structure 2 (Figure 2). An additional monolith for organic geochemical analysis was
205 obtained *ca.* 5 m outside of the structure from contemporary archaeological deposits
206 in front of the roundhouse entrance in January 2017, to characterise external dung
207 deposits and/or trampled dung originating from animals entering and leaving the
208 structure (M_{ex}; Figure 2). Samples for steroid analysis and micromorphology were

209 extracted from the internal monoliths at depths corresponding to assigned
210 contextual changes consisting of foundation deposits, primary floor layers and
211 subfloor layers (Crone and Cavers, 2015; 2016).
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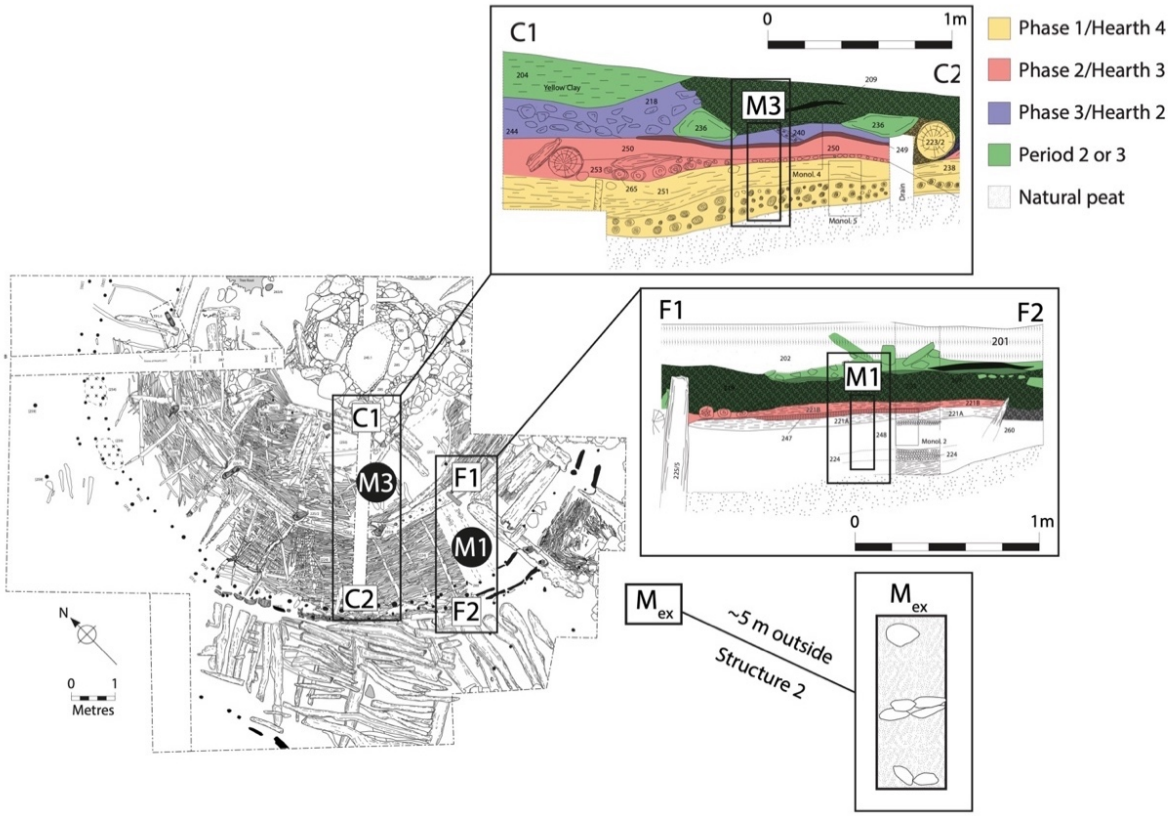

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214 ***Figure 2:*** *Location of monolith samples obtained inside (M1, M3) and outside*
215 *(M_{ex}) Structure 2.*

216

217 **2.3 Faecal steroid analysis**

218 Total lipids were extracted from approximately 1 g of dried, homogenised sediment,
219 spiked with internal standards (androstanol and hyocholic acid), with solvents
220 (DCM:MeOH, 2:1, *v/v*) using microwave assisted extraction (heated to 70 °C over 10
221 mins then held at 70 °C for 10 mins; Kornilova and Rosell-Melé, 2003) and

saponified using 5 M sodium hydroxide in MeOH. Following Bull et al. (2001), extracts were separated into neutral and acid fractions using aminopropyl SPE columns and these fractions were further split using silica gel column chromatography to isolate the sterol fraction and, following methylation using trimethylsilyldiazomethane (TMS-DAM) in toluene/methanol (4:1 *v/v*), the hydroxylated carboxylic acids (containing bile acids). The sterol and bile acid fractions were trimethylsilylated using *N*,*O*-bis(trimethylsilyl)trifluoroacetamide (BSTFA)+ trimethylcholorosilane (TMCS) (99:1 *v/v*).

Both derivatized sterol and bile acid fractions were dissolved in 50-100 μL of ethyl acetate prior to analysis by gas chromatography-flame ionisation detection (GC-FID) and gas chromatography-mass spectrometry (GC-MS). GC-MS analyses were performed using a ThermoScientific ISQ, with an ion source temperature of 300 °C and electron energy of 70 eV. The analyser was set to scan *m/z* 50–650 with a duty cycle time of 0.2 s. Chromatographic separation was performed on an Agilent fused silica capillary column (HP-5, 60 m × 0.25 mm ID × 0.25 μm df). Sterol derivatives were analysed using the following temperature programme: 50 °C (held for 2 min) to 200 °C at 10 °C min^{-1} then to 300 °C at 4 °C min^{-1} and held for 20 min. Bile acid derivatives were analysed using the following temperature programme: 40 °C (held for 1 min) to 230 °C at 20 °C min^{-1} then to 300 °C at 2 °C min^{-1} and held for 20 min. GC-MS peaks were identified through comparisons with known mass spectra (NIST08; Prost *et al.*, 2017 and a laboratory reference library), example chromatograms (Prost et al., 2017) and standards where possible. Analytes were quantified based on internal standards.

Potential faecal sources were identified from the sterol fraction using a ratio of the sum of faecally derived cholesterol reduction products (coprostanol +

epicoprostanol) to the sum of environmentally and faecally derived cholesterol reduction products (5α- cholestanol + coprostanol + epicoprostanol) (Ratio 1; Bull et al., 1999) with ratio values *ca.* ≥0.3 indicative of potential faecal matter input (Prost *et a*l., 2017).

$$\frac{(coprostanol+epicoprostanol)}{(5\alpha\text{–}cholestanol+coprostanol+epicoprostanol)} \quad \text{(Ratio 1)}$$

Ratio 1 does not definitively identify faecal matter in isolation since small proportions of these compounds are also produced by the reduction of cholesterol in the natural environment (primarily to produce 5α- cholestanol), thereby requiring comparative controls. The identification of herbivore faecal matter was indicated by the C_{27} to C_{29} 5β-stanol ratio (Ratio 2; Leeming et al., 1997), with values <0.38 indicative of herbivore faeces.

$$\frac{(coprostanol)}{(coprostanol+5\beta\text{–}stigmastanol)} \quad \text{(Ratio 2)}$$

Evidence for the presence of faecal matter was also supported by the presence of bile acids and the dominant faecal matter source was identified using the ratio of deoxycholic acid (DCA) to lithocholic acid (LCA) ratio (Prost *et al.*, 2017). Based on modern experimental data, the values of this ratio can be ascribed in the following way: <0.4 pigs and/or geese; 0.6 – 4.5 humans and/or horses; >5 ruminants (cattle, sheep and goats) (Prost *et al.*, 2017). Whilst the dominant faecal source can be identified using these ratios, this does not preclude the presence of other faecal sources in smaller quantities.

2.4 Insect analysis

Six bulk sediment samples (2 - 5 L) from floor contexts were processed using the standard paraffin floatation protocol (Coope, 1986). Briefly, sediments were wet-sieved through nested sieves (3 mm and 300 μm) to remove the inorganic clay and silt fraction, respectively. The collected float was washed with detergent then rinsed and stored in ethanol. Insect remains were picked using a large Bogorov sorting tray under a stereo microscope (10 – 60 × magnification) and the insects placed in ethanol for storage.

Beetle remains were identified using modern reference collections and standard published keys (e.g. Lindroth, 1974; Foster et al., 2014) and recorded as Minimum Numbers of Individuals (MNI). The species list and associated ecological information were generated using BUGSCEP (Buckland and Buckland, 2006), following the taxonomy of Duff (2008). Fly and ectoparasite remains were identified using reference materials and manuals (Skidmore, 1985; Smith, 1989; Whitaker, 2007); lice and fleas were identified to species level when heads were available. Muscidae fly puparia were identified to species level whilst remaining individuals could only be identified to genus level. Results presented here are a subset of the insect assemblage data, which are published elsewhere (Davies et al., in prep.), focusing on taxa that display an exclusivity for foul environments, are very common in dung and are closely associated with animals, following Hall and Kenward (1990) and Smith (2012).

2.5 Animal and plant macrofossil remains

Bulk sediment samples were processed using the standard floatation method (Kenward et al., 1980), with waterlogged samples processed by hand to maximise

293 recovery of fragile plant remains. Macrofossils were examined under a microscope
294 (×10 - ×100 magnification) and identifications were made using modern reference
295 material and seed atlases (Cappers et al., 2006; Jacomet, 2006). Charcoal samples
296 containing two or more wood species were designated as fuel waste, whilst those
297 containing larger concentrations of a single species were interpreted as burning
298 events. Bone was identified to element and species with the aid of reference material
299 and skeletal atlases (Schmid, 1972; Hillson, 1986). Where an element could not be
300 identified to species level, it was categorised into large mammal (cattle/horse/deer),
301 medium mammal (sheep/goat/pig) and small mammal (dog/cat/rodent).

302 **2.6 Soil Micromorphology**

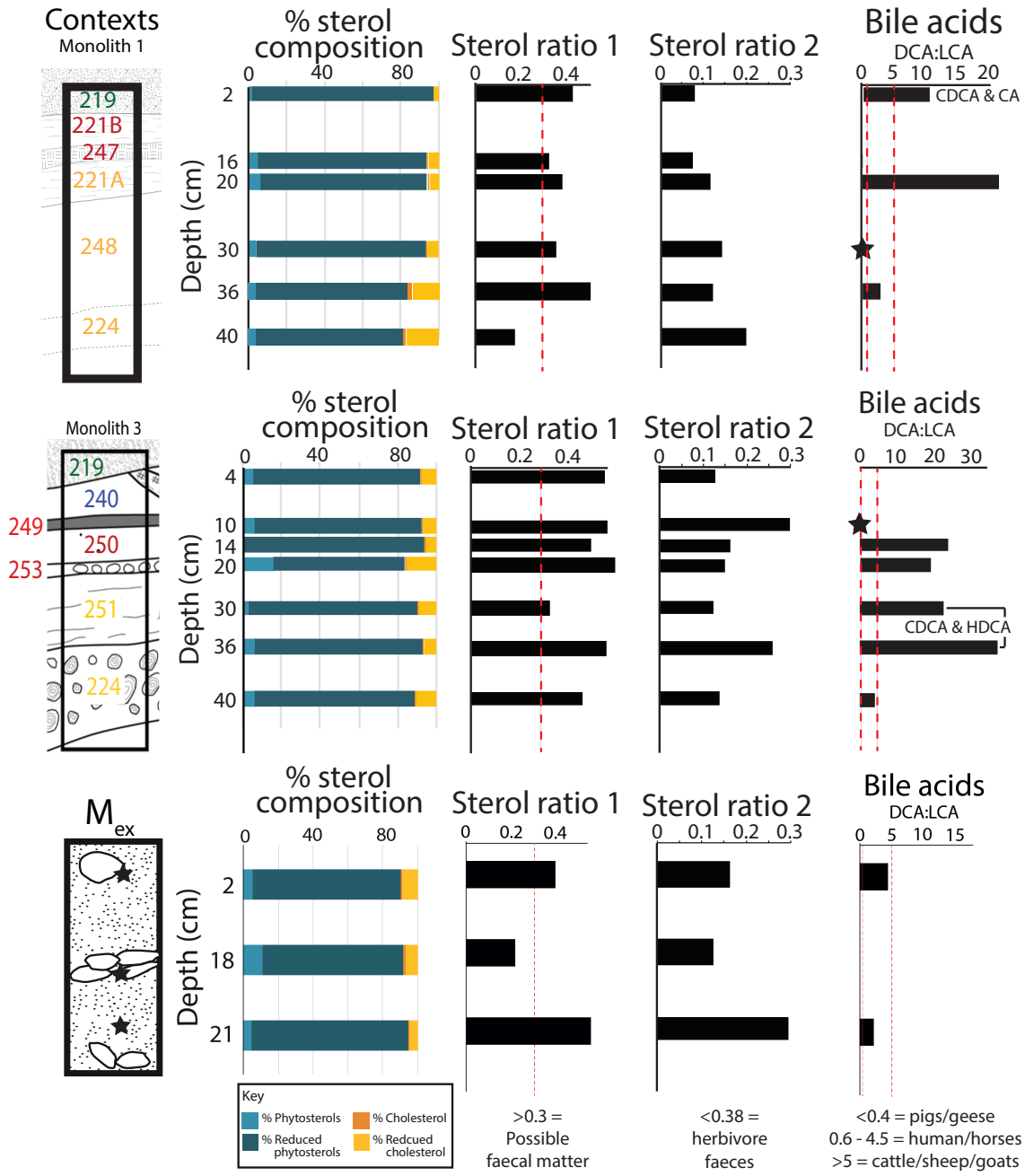
303 Eleven samples were extracted from the internal Structure 2 monoliths,
304 corresponding to contexts targeted for steroid analysis, and prepared for
305 micromorphological analysis after Murphy (1986). Thin section description was
306 conducted using the identification and quantification criteria by Bullock et al. (1985)
307 and Stoops (2003). Abundance of fabric constituents were estimated following
308 categories outlined by Stoops (2003). Deposit types were identified based on particle
309 size, shape and the composition of the coarse and fine fraction, particularly the
310 frequency and type of organic matter, minerals and anthropogenic inclusions.
311 Trampling was indicated by linear and parallel distributions, polyconcave voids and
312 platy microstructures (Courty et al., 1989, Milek, 2012).

3. Results

3.1 Faecal steroids

The total sterol composition of all samples is dominated by plant-derived compounds (phytosterols; campesterol and sitosterol and reduction products of phytosterols; C_{28} and C_{29} stanols), with cholesterol and its reduction products (C_{27} stanols) accounting for <10% (Figure 3).

Ratio 1 returns values of >0.3, indicating a potential faecal input in all samples apart from two: [224] in M1 and 18 cm in M_{ex} (Figure 3, Tables 2 and 3). The lack of faecal matter in these two samples is confirmed by the absence of detectable bile acids. Ratio 1 of one sample ([219; M3]) suggests the possible presence of faecal matter but this is not supported by bile acids. Ratios of detected bile acids (DCA:LCA) constrain dominant animal faecal matter sources in Structure 2 deposits to pigs (<0.4), ruminants (cattle and/or sheep and/or goats (0.6-4.5) and human and/or horses (>5) (Figure 3, Tables 2 and 3). Ratio 2 <0.38, indicates herbivore faecal input in all samples.



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329 ***Figure 3****: M1 (outer), M3 (inner) and M_{ex} (outside roundhouse entrance) steroid*

330 *characteristics. Contexts are coloured by coloured by assigned phases (Phase 1:*

331 *yellow; Phase 2: red; Phase 3: blue; Period 2 or 3: green). The phytosterols*

332 *(campesterol and sitosterol: light blue) and their reduction products (C_{28} and C_{29}*

333 *stanols; dark blue) and those of cholesterol (C_{27} stanols: orange and yellow), reveal*

334 *the degree of biohydrogenation of the Δ^5 unsaturated sterols. Sterol ratios refer to*

335 *those numbered in the main text: (1) is indicative of the possible presence of faecal*

matter when >0.3 and (2) is indicative of herbivore faecal input when <0.38. Bile acid DCA:LCA ratios indicate dominant faecal source <0.4 pigs/geese, 0.6-4.5 human/horses, >5 ruminants. Star symbols highlight where DCA was present in isolation, therefore whilst the diagnostic source value cannot be calculated, faecal matter is present within the sample. Samples containing chenodeoxycholic *acid (CDCA), cholic acid (CA) and hyodeoxycholic acid (HDCA) are also indicated using bile acid abbreviations.*

Table 1*: Summary of faecal steroid results from within Structure 2 by location and phase. Descriptions of floor layers from Crone and Cavers (2015). *Dominant faecal origin is based on bile acid profiles. All samples have sterol ratio 2 values indicative of herbivore faecal matter, therefore a mixed faecal deposit is likely.*

Context	Description	Location	Sample depth (cm)	Phase	Steroid characteristics	Faecal origin*
224	Plant litter subfloor	Inner (M3)	A1: 40 A2: 36	1	Faecal steroids present	A1: Humans A2: Mixed source: ruminants, pigs, humans and/or horses
251	Plant litter subfloor	Inner (M3)	30	1	Faecal steroids present	Mixed source: ruminants, pigs, humans and/or horses
253	Small branchwood	Inner (M3)	20	2	Faecal steroids present, reduced decay indicators	Ruminants
250	Plant litter subfloor	Inner (M3)	14 10	2	Faecal steroids present, reduced decay indicators	Ruminants
249	Carbonised plant litter	Inner (M3)	8	2	n/a (low organics)	None
240	Orange clay floor	Inner (M3)	4	3	No bile acids	n/a
224	Plant litter subfloor	Outer (M1)	40	1	No bile acids	n/a
248	Branchwood and brash	Outer (M1)	36 30	1	Faecal steroids present	Humans and/or horses
221A	Plant litter subfloor	Outer (M1)	20 16	1 & 2	Faecal steroids present	A1: Ruminants A2: Pigs
247	Grey clay, subfloor	Outer (M1)	12	2	n/a (low organics)	None
221B	Plant litter subfloor	Outer (M1)	5	2	n/a (low organics)	None
219	Peaty clay, decomposed floor	Outer (M1)	2	Period 2/3	Faecal steroids present	Mixed source: ruminants, pigs, humans and/or horses

***Table 2**: Summary of faecal steroid results from outside Structure 2 (M_{ex}) by depth. *Dominant faecal origin is based on bile acid profiles. All samples have sterol ratio 2 values indicative of herbivore faecal matter, therefore a mixed faecal deposit is likely.*

Depth	Description	Steroid characteristics	Faecal origin*
2 cm	Organic rich deposit with large stones	Faecal steroids present	Humans and/or horses
18 cm	Organic rich deposit with stones	No faecal steroids present	None
21 cm	Organic rich deposit	Faecal steroids present	Humans and/or horses

3.1.1 Spatial patterns in faecal steroids

Based on the DCA:LCA bile acid ratio (Prost et al., 2017) and sterol ratio 2 (Leeming et al., 1997), the dominant source of faecal matter within the roundhouse originates from ruminants (cattle, sheep and/or goats), with ruminant signals occurring more frequently in the inner section of the roundhouse (M3) than the outer section (M1) (Figure 3, Table 1). Faecal matter from pigs and humans and/or horse are identified in some samples from both the inner and outer sections of Structure 2 based on the presence of hyodeoxycholic acid (HDCA), diagnostic of pig faeces, and chenodeoxycholic acid (CDCA), diagnostic of human and/or horse faeces (Prost et al., 2017). While evidence for human and/or horse faeces is detected in M_{ex}, outside of the roundhouse, there is no clear evidence of ruminant or pig faeces in this outside area (Figure 3, Table 2).

3.1.2 Temporal patterns in steroid biomarkers

The first detection of faecal material occurs during Phase 1, registering earlier in the inner section of the structure than the outer section (Figure 3, Table 1). The initial bile acid ratios in both the inner and outer sections of the roundhouse originate from humans and/or horses, then becomes mixed with input from humans and/or horses (CDCA), pigs (HDCA) and ruminant input (DCA:LCA ratio). The DCA:LCA ratio in

372 Phase 2 indicates ruminant faecal matter and this is the only faecal source detected
373 during this phase in M3 (inner). However, the source of faecal matter in the outer
374 structure (in M1) switches to a human and/or horse dominated signal in latter
375 contexts of Phase 2.

376 **3.2 Ecofacts**

377 **3.2.1 Insects**

378 Insect preservation is high with intact remains, although overall abundance is
379 variable, with abundances ranging from 6 – 91 MNI l^{-1} of sediment (Table 3). The
380 highest concentrations of beetles and ectoparasites are present within [221A] (Figure
381 4) from inner Phase 1, but concentrations between samples from the inner and outer
382 sections of Structure 2 are comparable. There are low abundances of beetle taxa in
383 the 'foul rotting' category e.g. *Aphodius spp*. and *Aphodius distinctus* (Müll) *(*Atty,
384 1983), but they are present in samples from both the inner and outer sections in
385 conjunction with species associated with the dung of large herbivores (e.g. *Cercyon*
386 *quisquilius* (L.), *Aphodius prodromus/sphacelatus* (Panz)/(Brahm), *Cercyon*
387 *melanocephalus* (L.), *Aphodius contaminatus* (Hbst.)(Koch 1989, Duff 1993)). Lice
388 were found in both phases, *Bovicola bovis* (cattle louse) and *Pulex iritans* (human
389 flea) [250] (Phase 2, inner section) and *Bovicola ovis* (sheep louse) (Phase 1, outer
390 section). Fly puparia are common in both Phases 1 and 2 but are more abundant in
391 samples from the outer areas of the roundhouse.

392 ***Table 3**: Summary of common dung and animal-associated insects from Structure*
393 *2 by location and phase (n.d. = non detected). MNI = Minimum number of*
394 *individuals per L^{-1} (all taxa). Foul decomposers = beetle species primarily*
395 *associated with foul, rotting organic matter (often dung) as defined by Hall and*
396 *Kenward (1990) & Smith (2012).*

Context	Description	Location	Phase	Conc. (MNI l^{-1})	Dung and Foul matter beetles (total counts)	Ectoparasites and flies (total counts)
251	Plant litter subfloor	Inner	1	24	*Aphodius Distinctus* (1)	*Musca domestica* (3) *Stomoxys calcitranus* (3)
250	Plant litter subfloor	Inner	2	32	*Cercyon quisquilius* (1) *Aphodius prodromus/ sphacelatus* (1)	*Bovicola bovis* (3) *Pulex iritans* (1) Phthiraptera indet. (10) *Musca domestica* (13) *Stomoxys calcitranus* (4)
249	Carbonised plant litter	Inner	2	9	n.d.	n.d.
248	Branchwood and brash	Outer	1	48	*Cercyon melanocephalus* (1) *Aphodius contaminatus* (1) *Aphodius spp.* (1)	*Bovicola ovis* (1) Phthiraptera indet. (3) *Musca domestica* (4) *Stomoxys calcitranus* (4)
221A	Plant litter subfloor	Outer	1	108	*Cercyon pygmaeus* (1) *Cercyon unipunctatus* (1) *Aphodius distinctus* (1)	Lice spp. indet. (1) *Musca domestica (37)* *Stomoxys calcitranus (10)*
221B	Plant litter subfloor	Outer	2	32	*Aphodius ater (1)* *Aphodius* spp. (1)	*Musca domestica (46)* *Stomoxys calcitranus (14)*

Figure 4: Example of preservation level of beetle remains from context [221A]. A large number of elytra are from the hydrophilid genus *Cercyon* (especially *Cercyon analis*) alongside staphylinids and other hydrophilids.

3.2.2 Macroplant remains

Macroplant remains primarily consist of three categories: food and food processing waste; fuel debris and flooring materials (Table 4, Figure 5). The food waste consisted of cereals and wild food sources with the majority of this material carbonised but with small amounts that are waterlogged. The cereal and wild food remains were detected within contexts from both the inner and outer sections of the roundhouse: cereal remains were concentrated in inner Phase 1 [251] and outer Phase 3 [219], and wild food remains were most abundant in [251], from inner Phase 1, but were also present in [248] (outer Phase 1), [247] (outer Phase 2) and [250] (inner Phase 2). The main type of fuel used was wood, represented by a mixture of species, but there was also a

small quantity of charred peat. There was no evidence for other types of fuel such as dung in any of the contexts under discussion. The materials used for flooring consisted primarily of bracken, sedges, rushes, woodrush and woody brash.

Table 4: *The waterlogged and carbonised macroplant assemblage for food and food processing waste and fuel debris categories. Key: *≤ 10, **=10-29, ***=29-100, ****≥100. All carbonised macroplants are recorded in brackets and all other plant remains are preserved through waterlogging.*

Phase		**1**	**1**	**1**	**2**	**2**	**2**	**2**	**3**	**3**
Location (Out = outer, In = inner)		**Out**	**Out**	**In**	**Out**	**In**	**In**	**In**	**Out**	**In**
Context		**221**	**248**	**251**	**247**	**249**	**250**	**253**	**219**	**240**
Sample Vol (kg)		2.5	2.5	2.5	2	1.9	2.5	0.7	20	5
% Sorted		50	50	50	50	50	50	100	100	100
Vernacular name	**Plant part**									
Hordeum vulgare L.	Caryopses								(*)	
Hordeum var *nudum* L.	Caryopses								(*)	
Hordeum sp.	Caryopses			*					(**)	
Triticum dicoccum L.	Caryopses								(*)	
Triticum dicoccum L.	Glumes			**					*	
Triticum dicoccum/spelta L.	Caryopses								(**)	
cf. *Triticum aestivum/compactum* L.	Caryopses								(*)	
Triticum sp.	Caryopses								(**)	
Triticum sp.	Glume		*	***						
Cerealia indet.	Caryopses		**	* (*)					* (*)	
Cerealia indet.	Glume									(*)
Wild food										
Corylus avellana L.	Nutshell frgs		*(*)	*			*			
Corylus avellana L.	Buds and/or bud-scales				*					
Rubus idaeus L.	Seeds			***	*(*)					
R. fruticosus agg	Seeds				*					
Fuel										
Charcoal (weight in g)			5.5	2.5		2.5		11.5	56.2	91
Charred peat			*	**		****	**			

Figure 5: *Examples of macroplant and faunal remains extracted from Structure 2 bulk samples. A: hazelnut [219], B: burnt bone [219], C: cereal grains [219], D: charcoal [219], E: chaff [240]*

3.2.3 Faunal remains

The majority of faunal remains recovered from Structure 2 were small burnt bone fragments, 90% of which were not identifiable to species. There were small quantities of unburnt bone and teeth present. The number of identifiable specimens present in Structure 2 were cattle (61), sheep/goat (4), pig (2), large mammals (47) and medium mammals (164) (Table 5; Figure 5).

***Table 5**: Summary of burnt bone results from within Structure 2 by location and phase*

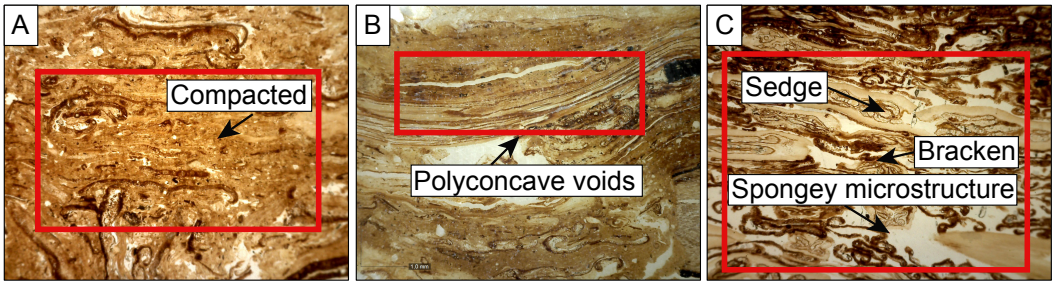
Context	Location	Phase	Bones present	Identifiable species/mammals
251	Inner	1	1.6g, 7 fragments	Large mammal long bone shaft Medium mammal rib (cut mark)
253	Inner	2	0.01g, 2 fragments	None identifiable
250	Inner	2	None	
249	Inner	2	2.8 g, 14 fragments (8 unburnt)	Cattle bone Cattle premolar, molar Medium mammal rib
240	Inner	3	51.7g, 56 fragments (10 unburnt)	Large and medium mammal long bone shafts Medium mammal mandibles, rib and vertebrae
248	Outer	1	5 g, 12 fragments (6 partly charred)	Medium mammal long bone shaft x 2 (burnt), phalanx and partly charred premolar
221	Outer	1 and 2	None	
247	Outer	2	None	
219	Outer	Period 2/3	44.5 g, 26 fragments (< 50 mm, burnt)	Cattle molar (unburnt) Sheep/goat humerus (burnt)

3.4 Micromorphology

The primary constituent of the floor material is plant organic matter, which is exceptionally preserved throughout the samples (Figure 6), but differences exist in the birefringence of organic matter with less degradation exhibited in samples from the outer area of the structure. Occasional thin excremental pedofeatures (<100 μm) caused by microfauna, indicative of limited bioturbation, are restricted to outer Phase 1 [248] and inner Phases 1 and 2 [250] and [251]. Anthropic indicators, based on micromorphology, are limited in most of the samples from the outer contexts as there are very few small wood and bark chips. Small amounts of coprolitic material, although not identified to species level, was observed in the inner section from context [251] (Phase 1) and possibility [240] (Phase 3) (Table 6).

The identification of trampling, a possible transfer mechanism of faecal material in organic sediments under waterlogged conditions is difficult to detect, as water and compression during burial causes swelling of sediment and masks trampling

447 indicators. However, the presence of loam and distinct microstructures suggests some
448 trampling in both the inner and outer sections of the roundhouse during Phase 1
449 (contexts [224], [251] and [248]) but only in the inner section during Phase 2 [250]
450 (Figure 6, Table 6).



451

452 ***Figure 6**: Examples of morphology from Structure 2 samples. A:*
453 *compacted/trampled organic layer [224], B: polyconcave voids [250] (inner), C:*
454 *spongy microstructure and layers of bracken and sedge material [250] (outer)*

455
456 **Table 6**: Summary of micromorphology results from within Structure 2 by location
457 and phase (n.d = non detected)

Context	Location	Phase	Coprolitic material	Trampling indicators
224	Inner	1	n.d	Lenticular microstructure. Loam/soil clasts brought in from outside embedded within matrix.
251	Inner	1	Unknown source	Compacted, lenticular to massive microstructure. Loam/soil clasts embedded within matrix.
253	Inner	2	n.d	n.d
250	Inner	2	n.d.	Linear compaction and striation of coarse material. Polyconcave voids
249	Inner	2	n.d.	n.d.
240	Inner	3	Possible herbivore	n.d
224	Outer	1	n.d.	Parallel arrangement of inclusions, massive microstructures, polyconcave voids, low porosity, loam/soil clasts.
248	Outer	1	Soil microfauna only	Possible (dusty clay coatings to voids indicative of rotational movement of sediment caused by trampling)
221	Outer	1 and 2	Possible (yellow phosphatic filling)	n.d
247	Outer	2	n.d	n.d
219	Outer	Period 2/3	n.d	n.d

458 **4. Discussion**

459 **4.1 Occupation floor deposits: detection of faecal matter and source**
460 **organisms using steroid biomarkers**

461 The majority of samples analysed from both the inner and outer sections of Structure
462 2 contained evidence of faecal matter as supported by the presence of bile acids,
463 which are deposited in the excreta of vertebrates (Haslewood et al., 1967; Hofmann
464 and Hagey, 2008). Comparisons of bile acids and 5β-stanols within this study
465 highlight the importance of considering context when applying sterol ratio threshold
466 values (Grimalt et al., 1990; Bull et al., 1999) to definitively identify faecal sources
467 within wetland settlement deposits: all ratio 1 values within this study were <0.7,
468 which would only indicate the *possibility* of a faecal source based on Grimalt et al.
469 (1990) thresholds, despite the majority of samples analysed within Structure 2
470 containing conclusive evidence of faecal matter deposition based on bile acids
471 profiles. The ratio 1 threshold value was designed for modern sewage samples
472 (Grimalt et al., 1990) and its validity in archaeological contexts has been critiqued
473 (Bull et al., 1999, 2001, 2005; Simpson, 1998; Prost et al., 2017). The application of
474 ratio thresholds to identify faecal inputs has been shown to be particularly
475 challenging within organic rich soils, such as those obtained from Structure 2, owing
476 to the abundance of 5α-stanols derived from plant remains (Birk et al., 2011); this
477 drives faecal sterol ratio below the indicative thresholds even when faecal matter is
478 present (e.g. Fritzsmons et al., 1995; Birks et al., 2011).

479 Whilst the dominance of a 5α-stanol input in organic rich soils could call for a
480 lowering of faecal sterol threshold values, one sample analysed from the inner
481 section of the roundhouse contained a sterol ratio within the 'possible faecal matter'

range despite having no corresponding bile acids and therefore no supporting evidence for faecal matter. This example echoes findings from other studies reporting the presence of 5β-stanols despite no other evidence for faecal deposition (e.g. Bethel et al., 1994; Bull et al., 2001; Evershed et al., 1997). Multiple lines of faecal evidence, including both 5β-stanols and bile acids are therefore a more robust approach than changing threshold values when working with diffuse faecal sources in sedimentary settings.

Several studies have successfully circumvented sterol ratio threshold problems for faecal identification by comparing background sediment 5β-stanols concentrations with those from anthropic samples (e.g. Birk et al, 2011; Harrault et al., 2019). Alongside this contextual approach, our results demonstrate the importance of analysing both the sterol and bile acid lipid fractions from the same sediment sample when characterising diffuse faecal sources. This combined approach, also encouraged by Bull et al. (2002) and Prost et al. (2017) for more concentrated faecal inputs, not only provides greater confidence in faecal identification and constraining faecal sources, but also mitigates against possible difficulties in obtaining contemporary non-anthropic sediment samples required to accurately establish background concentrations. An example of such difficulty within the Iron Age setting of this study, is achieving adequate chronological control for comparisons of different sampling locations when dates fall within the Hallstatt plateau (Becker and Kromer, 1993), a period of minimal discernible changes in radiocarbon calibration curve between 750 -400 cal BCE, when most radiocarbon determinations have calibrated age ranges in the order of several centuries (Crone et al., 2012).

Our steroid results demonstrate the presence of faecal matter from

506 cattle/sheep/goats, pigs and horse and/or humans in Structure 2. The presence of
507 ruminants is supported by the faunal evidence which includes bones and teeth from
508 cattle and sheep/goat. There is no evidence for pig or horse faunal remains in the
509 contexts analysed, although the presence of pigs on site is supported by faunal
510 remains from other contexts and insect remains are indicative of large herbivores
511 contemporaneous with human/horse faecal signals (Figure 7). Steroid analyses of
512 Structure 2 provide evidence for a greater diversity of animals associated with each
513 context compared with faunal analysis where the acidity of the soils (pH 5.3 ± 0.4)
514 hinders calcified bone survival.

515 The steroid results from Structure 2 have enhanced characterisation of animals
516 associated with the roundhouse, however, the resolution of some identified faecal
517 sources is lower than expected based on ratios obtained from modern reference
518 material in concentrated archaeological faecal deposits (e.g. Prost et al., 2017;
519 Harrault et al., 2019). This likely represents the difficulties of identifying faecal
520 sources using diagnostic ratios and key indicator compounds when faecal inputs
521 originate from a mix of source organisms (Prost et al., 2017) and are incorporated
522 within organic-rich sedimentary archives (Birk et al., 2011). In such instances, the
523 dominant faecal source organism(s) may be identified, but the refinement of faecal
524 source identification relies on bile acid preservation (Prost et al., 2017). Faecal sterol
525 distributions have also been used to refine differentiation of faecal sources, such as
526 multivariate analyses of eleven 5β-stanol compounds (Harrault et al., 2019).
527 However, the full suite of 5β-stanol compounds required for faecal source
528 differentiation are not present in all lipid extracts, including samples from this study
529 and those analysed by Leeming et al. (1996), thereby limiting the resolution of faecal
530 source identification. Such differences in 5β-stanol characteristics between studies

may relate to differences in diet, which controls compound distributions (Prost et al., 2017; Harrault et al., 2019), or the dominance of plant-derived sterols and other polar lipid compounds within organic-rich sediments, which mask low 5β-stanol concentrations despite extensive sample clean-up within the lipid analytical protocol.

Whilst multiple lines of steroid evidence must be considered when identifying faecal sources (Prost et al., 2017), an important consideration is the sensitivity of diagnostic ratios to different faecal sources. For example, since ruminants have a characteristic bile acid-derived DCA:LCA value, which is an order of magnitude higher than pigs and in some cases human and/or horses, their faecal signal has the potential to dominate a mixed source DCA:LCA ratio even if they were not the dominant faecal input. Therefore, whilst the dominance of ruminant faecal matter may be a robust feature within Structure 2 and is supported by sterol ratio 2, it may also be influenced by the sensitivity of the DCA:LCA ratio to ruminant faecal input. Experimental studies are essential to refine these diagnostic ratios and steroid distributions for diffuse faecal inputs within sedimentary deposits using approaches such as mixing models.

4.2 Multiproxy comparisons of faecal indicators

Approximately 60% of analysed floor deposits contained dung indicators within the steroids compared with 50% from insect analyses and 10-20% from micromorphology (Figure 7). There are no conclusive dung indicators within the macroplant remains, although distinguishing between dung, fodder and floor deposits from macroplant remains is complex since plant assemblages are similar within these sources. Context [251] from Phase 1 of the inner section of the roundhouse does contain a high abundance of raspberry (*Rubus idaeus* L.) seeds,

555 which may originate from faecal deposition (e.g. Buckland, 1976; Miller and Smart,
556 1984). Confirmation of faecal matter within this context is provided by the mixed
557 steroid signal and the identification of coprolitic remains within the
558 micromorphology (Figure 7), thus demonstrating the value of multiproxy
559 comparisons, as also presented by Shillito et al. (2011).

560 Multiproxy dung comparisons across Structure 2 demonstrate the presence of
561 steroids, low abundances of dung/foul indicator insect species and minimal
562 micromorphological and macrofossil evidence, which suggests dung deposits that are
563 transient or restricted (rather than persistent or large scale) within the roundhouse.
564 The low quantities of domestic debris and sharp contacts between floor layers point
565 towards active floor cleaning and/or removal of dung from Structure 2 and may
566 explain the low insect signal throughout the structure. Despite the removal of floor
567 material, the geochemical faecal signature has been preserved within the remaining
568 floor surfaces. Similar practices of floor cleaning have been identified at other
569 Scottish Iron Age structures e.g. Cnip in Lewis (Armit, 2006) and Cults Loch in
570 Wigtownshire (Roy, 2018; Robertson, 2018), where removal and replacement of
571 floor layers were identified from excavated stratigraphy. Incorporating steroid
572 analysis of archaeological structures therefore has the potential to provide a more
573 holistic insight in to occupation conditions of Iron Age roundhouses. This is
574 especially true where floor clearing has occurred and many of the more traditional
575 microscopic anthropic signals have been removed, or preservation conditions for
576 macro-organic materials is poor.

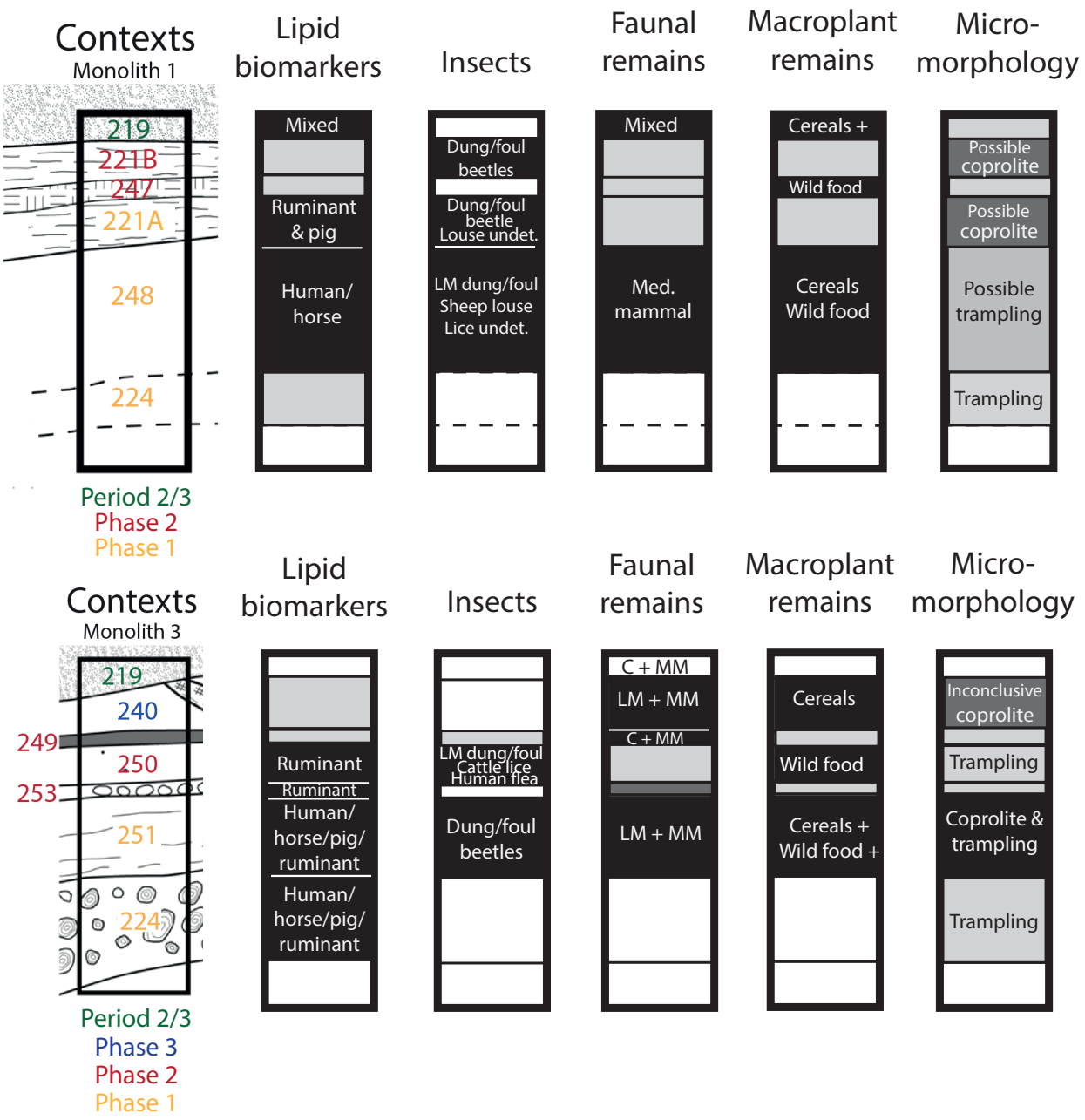


Figure 7: *M1 (outer) and M3 (inner) proxy comparisons. Black indicates clear evidence of large mammals, faecal sources or domestic food waste, dark grey indicates possible evidence of large mammals or faecal sources, light grey indicates no evidence of mammals, faecal matter or domestic food waste detected and white represents contexts with no data. Contexts with micromorphological evidence of trampling are also noted and source of dung/animal indicator listed (C=cattle, LM= large mammal, MM = medium mammals).*

585 ## 4.3 Multiproxy characterisation of Iron Age wetland roundhouse use

586 ### 4.3.1 Spatial patterns of use associated with Structure 2

587 Our steroid results show clear spatial differences between inside and outside of
588 Structure 2, with ruminant bile acid profiles detected in M3 and M1, but are absent
589 from outside in M_{ex} (Figure 3). The ruminant faecal signal also differs within the
590 structure, with a stronger ruminant signal present in the inner section of the
591 roundhouse (Figure 8). This faecal signal in the inner section is concomitant with
592 *Bovicola bovis* (cattle louse) (Table 3, Figure 7) and is consistent with evidence from
593 the micromorphology, since the inner section contained more contexts with
594 confirmed trampling indicators and the only confirmed coprolitic remains were
595 detected in context [251] from the inner section. The presence of faeces in context
596 [251] is supported by the archaeobotanical evidence which contains the highest
597 abundance of uncharred raspberry seeds, likely deposited within dung (e.g. Miller
598 and Smart, 1984). The spatial distribution of faecal matter within Structure 2 could
599 be related to (a) ruminant faecal matter being transferred into the inside of the
600 roundhouse via trampling; (b) animal dung being used as hearth fuel and/or hide
601 processing and (c) animals being kept within the structure.

602 The absence of evidence for ruminant faecal matter outside of the roundhouse based
603 on M_{ex} would suggest that trampling could not be a source of ruminant faecal matter
604 into Structure 2. Proxy comparisons further support this: for example, context [244]
605 in M1 contains micromorphological evidence of trampling, yet no faecal signal is
606 detected in the steroids. Steroid dung signals are also more prominent in the inner
607 sections of Structure 2 (i.e. in M3 next to the central hearth structure), but if

608 trampling was the key process then one would expect faecal matter to be widely
609 distributed throughout the roundhouse.

610 Disentangling the causes of the stronger ruminant faecal signal near the hearth is
611 difficult. It is possible this is related to dung storage, most likely for fuel, but we
612 cannot rule out animal waste being produced in situ. If dung was kept close to the
613 fire for ease of access, then this is likely to have accumulated on the floor surface
614 surrounding the hearth. However, the main fuel identified from the macroplant
615 analyses was charcoal and there is no clear evidence of burnt dung from the
616 macroplant or micromorphological results or charred insect remains. Without
617 geochemical analyses such as magnetics (e.g. Peters et al., 2004), XRF (e.g.
618 Braadbaart et al., 2017) or phosphates (Macphail et al., 1997) on hearth deposits
619 from Structure 2 it is difficult to eliminate dung as a fuel source. Based on the insect
620 remains, the absence of charred dung and the wood charcoal in the macro-plant
621 analysis, it is unlikely dung was a dominant source of fuel and therefore the faecal
622 signal, within Structure 2.

623 The distribution of steroids most likely reflects the presence of designated livestock
624 stalls within Structure 2. The more persistent faecal signal by the hearth could be
625 explained by the deliberate placement of tethered animals proximal to the heat
626 source to aid survival of the young or sick. Support for animal sheltering to improve
627 the survival rates of new-born or unwell ruminants is evident from modern farming
628 and veterinary studies as exposure is a key determinant of new-born mortality rates
629 in wet and cold climatic conditions typical of Iron Age Scotland (e.g. Pollard, 2006;
630 Hinch and Brien, 2014, Rawson et al., 1989). Placement by the hearth would also
631 mimic the modern frost bite treatment for calves of rapid warming (Pelton et al.,
632 2000).

4.3.2 Temporal patterns of use within Structure 2

During Phase 1 of the occupation of the structure, the first source of faecal matter detected in both the inner and outer sections is horse and/or human and this indicates relatively foul living conditions, based on dung indicators across all proxies (Figure 7, Figure 8), suggesting greater persistence or abundance of faecal matter. With the detection of charcoal and food debris, such as bones and seeds, this suggests the inner section of Phase 1 contains household debris.

In Phase 2 of the occupation, the bile acid results suggest that the faecal source changed to ruminants in both sections of the structure. The insect assemblage of dung-associated taxa, flies and lice, and the resemblance of the micromorphology of context [250] to stabling environments, as well as the digested berry seeds identified within the macrofossils, also point to animal activity and the accumulation of dung. The number of dung-associated taxa and concentrations of fly puparia present a strong argument for the presence of dung in a foul deposit, but it remains difficult to conclude the specific activities from the insect evidence alone as is the case with other studies with greater insect numbers (Forbes and Milek 2014). The low concentrations and diversity of the dung insect community could be explained by regular removal and replacement of floor layers. The structure size would also limit the number of animals that could be housed (and thus the amount of dung produced) and the overall numbers of dung beetles would be reduced due to barriers to the outside created by walls (Smith *et al.*, 2014). The presence of *Bovicola bovis* in the inner section of the roundhouse highlights the complementary nature of faecal steroids and insect analyses, as the steroids confirm the presence of dung and insect indicator species refine the ruminant signal to confirm cattle and/or cattle hides were present.

4.3.3 Implications for use of Structure 2 and daily Iron Age life

Possible functions of Structure 2 include space for sleeping, storage, food preparation, craft working and/or animal stalling (Pope, 2007). Our multiproxy analyses show there is no overwhelming evidence for sleeping in this particular structure, as insect concentrations are low with only one human louse identified and there is minimal structural evidence for bedding. Similarly, there is no conclusive evidence for craft working because there is no debris associated with this activity in the micromorphology and macroplant remains. Evidence for food preparation in the inner section of the roundhouse comes from small quantities of domestic debris within the macroplant remains and micromorphology, as well as the presence of cereal caryopses and chaff, which suggest small scale grain processing was likely to have been occurring. Storage within the outer section of structure 2 is possible, but there is no evidence for storage remains and the presence of the large hearth structure indicates storage is likely be a secondary rather than primary function of Structure 2.

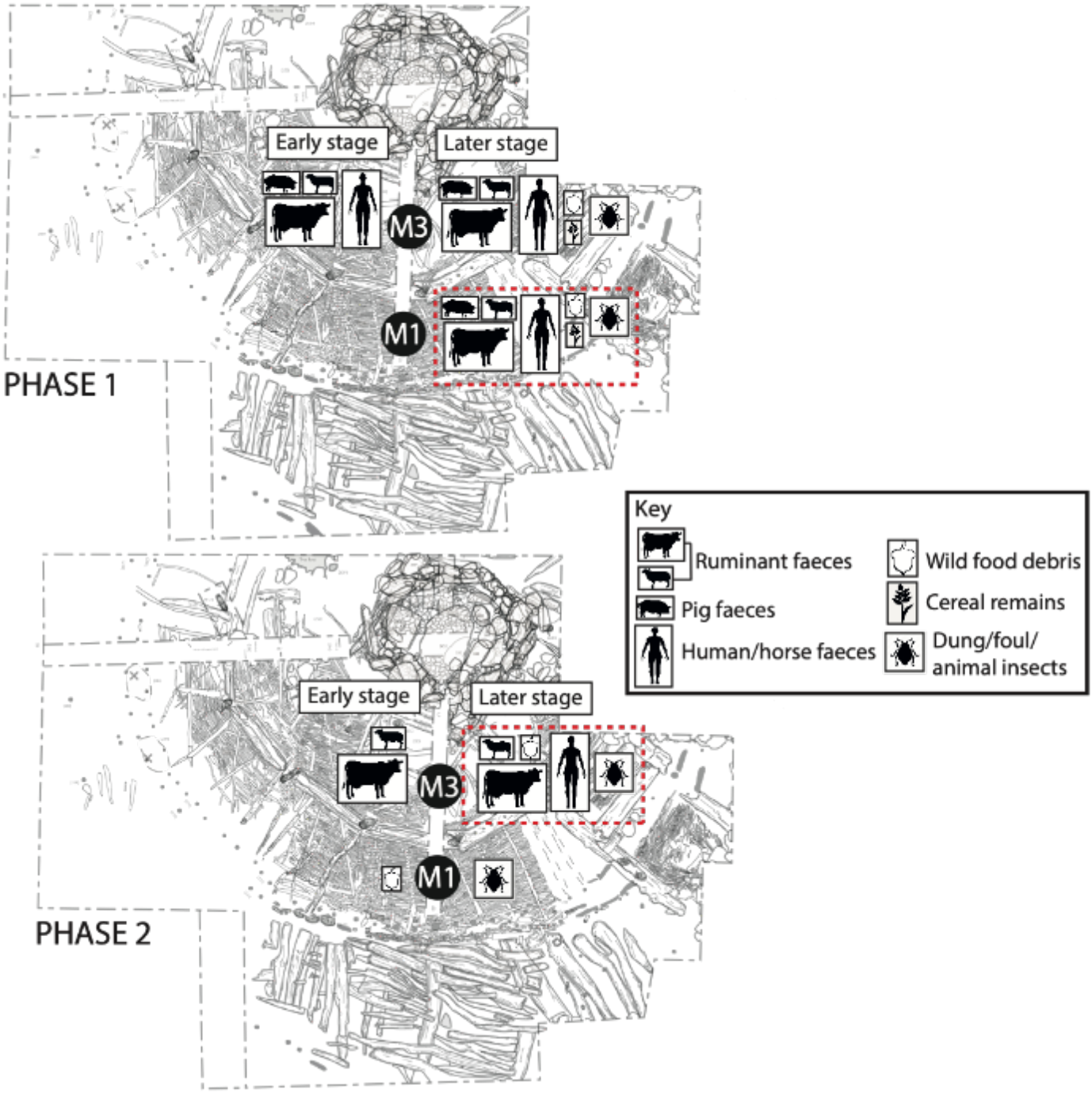
The steroid evidence from Structure 2 suggests animals were present within the roundhouse, however, the combined evidence across all proxies does not support a long-term and/or intensive stabling environment. The absence of animal-derived steroids from M_{ex}, located outside of Structure 2, indicates that the roundhouse was used as a temporary or small scale area of human-animal cohabitation since we would expect to see a strong steroidal faecal signal outside the structure as a result of trampling and animal movement in and out of the roundhouse if this was a significant stabling environment. The ability to detect animal movement linked to stabling practises has been demonstrated using 5β-stanols analysed from the entrance of a stabling area in a modern experimental study of a reconstructed Iron

683 Age roundhouse, which, unlike results from Structure 2, reported the entrance had
684 similar sterol signatures to deposits located within the stable (Hjulström and
685 Isaksson, 2009).

686 There is a lack of evidence for dedicated stabling structures or permanent 'byre-
687 houses' (*sensu* Harding, 2004; 2009) in British Iron Age sites (Sørensen, 2007). The
688 clearest evidence for co-habitation comes from outside Britain, from Nørre Tranders,
689 Denmark (Nielsen, 2007). Interior stalling has been inferred from structural
690 evidence and high phosphate levels at Woodend Farm in Dumfries and Galloway
691 (Banks, 2000; Duncan, 2000) and excavations at Dun Vulan, South Uist suggest
692 byre structures occurred within enclosures (Pearson and Sharples, 1999). The
693 possible temporary presence of animals within occupied Iron Age structures has
694 been identified from floor deposits after a rebuilding phase at Glastonbury Lake
695 Village, England (Hill *et al.*, 2018). The results from both Glastonbury Lake Village
696 and Black Loch of Myrton (this study) indicate associations between animals and
697 Iron Age roundhouses likely changed over time, reflecting variability of roundhouse
698 usage. Whilst both structures may have been used as temporary small-scale co-
699 habitations of humans and animals, there is no evidence to suggest they were
700 permanent byre-houses.

701 The internal activity within Structure 2 based on our steroids, micromorphology and
702 archaeobotanical remains (Figure 8), follows Hingley's model of an active central
703 area and peripheral outer area (Hingley, 1990) and supports the dominance of this
704 model in Iron Age roundhouses in Northern Britain (*sensu* Hill, 1995, Pope, 2007). A
705 peripheral, less frequently used outer area may also explain the abundance of flies
706 detected in the outer section of the roundhouse since the reduced disturbance would
707 facilitate fly larval pupation. Despite minimal evidence for activity in the outer

708 section of the roundhouse compared with the inner section, micromorphological
709 insights into floor cleaning and rebuilding in the outer section highlight the
710 importance of maintaining the cleanliness of this area even under difficult
711 waterlogged conditions. Hawkes (1994) suggested outer roundhouse areas were not
712 characterised by inactivity but rather served important 'cleaner' functions, such as
713 storing foodstuffs and firewood or sleeping. Interpretations of the multiproxy results
714 across Structure 2 highlight efforts to frequently clean and maintain this roundhouse
715 and support use as a shelter, likely with different primary functions depending on
716 requirements over time.



717

718 ***Figure 8:*** *Summary of multiproxy results highlighting differences in spatial and*

719 *temporal use within Structure 2. Red boxes represent periods of multiproxy*

720 *evidence for dominant dung/animal presence and household debris.*

721

5. Conclusions

Our study highlights the power of multiproxy approaches and the incorporation of steroids to advance insight into structure use, particularly when the sampling resolution facilitates characterisation of within-structure spatial and temporal patterns. Analyses of the Black Loch of Myrton's Structure 2 deposits provide evidence of floor cleaning and changes in use over time, demonstrating flexibility in roundhouse use over their short life cycle (*ca*. 30-40 years in this case). There is a more persistent faecal signal in the inner section compared with outer section of the roundhouse and this supports the 'active central area' roundhouse model (Hingley, 1990). In this case at Black Loch of Myrton, our data suggest small-scale temporary stabling within Structure 2, but likely only as a secondary function. Our results, however, highlight spatial complexity in roundhouse use as the outer area was less actively used and foul conditions persisted thus questioning the use of this space for 'clean conditions' (cf. Hingley, 1990).

Our application of steroids has successfully captured signals from short-lived/temporary pulses of faecal matter that are more difficult to extract from other traditional archaeological proxies. Our results also demonstrate steroids are particularly effective in archaeological settings with acidic soils, since they can identify the presence of animals where uncalcified bones do not preserve. Furthermore, faecal steroids provide valuable information about archaeological structures that have been subjected to the act of cleaning since they persist when visible indicators are removed or diminished.

The identification and characterisation of diffuse faecal input to the wetland settlement floor deposits within this study relies on analyses of both sterols and bile acids, supporting this combined analytical approach advocated by Bull et al., (2002)

747 and Prost et al. (2017) to effectively overcome known issues relating to sterol ratio
748 threshold values and help refine faecal source characterisations. The diffuse faecal
749 steroid input associated with this Iron Age roundhouse has limited the resolution of
750 faecal source characterisation compared with that achieved in more concentrated
751 faecal remains (e.g. Prost et al., 2017; Harrualt et al., 2019). However, the achieved
752 source resolution is sufficient to advance understanding of human-animal
753 interactions and cleanliness within the structure, and has benefited from further
754 refinement through multiproxy comparisons.

755 The utility of incorporating steroid analysis is not restricted to wetland Iron Age
756 structures, but is equally applicable to other periods and types of structures in
757 different depositional settings. What is needed, however, are floors, inter-floor
758 deposits, cleaning deposits or sealing layers contemporaneous with the
759 abandonment of the structure. This study has highlighted the need for further
760 experimental work focusing on diffuse faecal deposition in bulk occupation
761 sediments to address questions raised about sensitivities of diagnostic ratios in such
762 settings. A problem also highlighted here is where the controls should come from,
763 especially within a settlement of several houses. An excavation of a small test pit
764 outside the habitation area would seem most appropriate. As this study also shows,
765 the combination of steroids with other proxies can help verify interpretations but
766 may also raise new questions for investigation.

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References

Anderson, D.G, Harrault, L., Milek, K.B., Forbes, B.C, Kuoppamaa, M. and Plekhanov, A.V. 2019. Animal domestication in the high Arctic: Hunting and holding reindeer in the IAmal peninsular, northwest Siberia. Journal of Anthropological Archaeology 55, 101079.

Armit, I. 2006. Anatomy of an Iron Age Roundhouse: The Cnip Wheelhouse Excavations, Lewis. Edinburgh: Society of Antiquaries of Scotland.

Atty, D.B. 1983. Coleoptera of Gloucestershire. Published by the author, Cheltenham, U.K.

Banks, I. 1995. Phosphate and magnetic susceptibility, in J. Terry Excavations at Lintshie Gutter unenclosed platform settlement, Crawford, Lanarkshire, 1991, Proceedings of the Society of Antiquaries of Scotland 125, 417–421.

Banks, I. 2000. Excavation of an Iron Age and Romano-British enclosure at Woodend Farm, Johnstonebridge, Annandale, 1994 and 1997., Proc Soc Antiq Scot 130, 223-281.

Becker B., Kromer B. 1993. The continental tree-ring record – absolute chronology, 14C calibration and climate change at 11 ka. Paleogeography, Paleoclimatology, Paleoecolog 103, 67- 71.

Bethel, P.H., Goad, L.J. and Evershed, R.P. 1994. The study of molecular markers of human activity: the use of coprostanol in soil as an indicator of human faecal material. Journal of Archaeological Science, 21, 619-643.

Birk, J.J., Teixeira, W.G., Neves, E.G., Glaser, B. 2011 Faces deposition on Amazonian anthrosolds as assessed from 5β-stanols. Journal of Archaeological Science 38 (6) 1209-1220.

Braadbaart F., van Brussel T., van Os, B. and Eijskoot Y. 2017. Fuel remains in archaeological contexts: Experimental and archaeological evidence for recognizing

remains in hearths used by Iron Age farmers who lived in peatlands. The Holocene 27 (11): 1682-1693.

Brown, A.G., Van Hardenbroek, M., Fonville, T., Davies, K., Mackay, H., Murray, E., Head, K., Barratt, P., McCormick, F., P, Ficetola, G.F., Henderson, A., Crone, A., Cavers, G., Langdon, P.G., Whitehouse, N. J., Alsos, I.G., Pirrie, D. Subm. Slaughter and feasting revealed by DNA and lipids from Celtic Islands (Crannogs).

Buckland, P.C. 1976. The environmental evidence from the church street roman sewer system. London: Council for British Archaeology & York Archaeological Trust.

Buckland, P.I. and Buckland, P.C. 2006. BugsCEP Coleopteran Ecology Package. IGBP PAGES/World Data Center for Paleoclimatology Data Contribution Series # 2006-116. NOAA/NCDC Paleoclimatology Program, Boulder CO, USA.

Bull, I. D., Simpson, A. A., Dockrill, S. J. And Evershed, R. P. 1999. Organic geochemical evidence for the origin of ancient anthropogenic soil deposits at Tofts Ness, Sanday, Orkney. Organic Geochemistry 30 (7): 535-556.

Bull, I. D., Evershed, R. P. and Betancourt, P. P. 2001. An organic geochemical investigation of the practice of manuring at a Minoan site on Pseira Island, Crete. Geoarchaeology 16 (2) 223-242.

Bull, I. D., Lockheart, M., Elhmmali, M., Roberts, D. and Evershed, R., 2002. The origin of faeces by means of biomarker detection. Environment International 27 (8): 647 – 654

Bullock, P., Fedoroff, N., Jongerius, A., Stoops, G., Tursina, T. and Babel, U. 1985. Handbook for soil thin section description. Wolverhampton: Waine research Publications.

Cappers R.T.J., Bekker R. M. and Jans J. E. A. 2006. Digital seed atlas of the Netherlands. Groningen: Barkhuis Publishing.

Coope, G.R., 1986. The invasion and colonisation of the North Atlantic islands: A palaeoecological solution to a biogeographic problem. Philos. Trans. R. Soc. London, B314, 619–635.

836 Courty, M., Goldberg P. and Macphail, T. 1989. Soils and Micromorphology in
837 Archaeology. Cambridge University Press: Cambridge.

838 Crone, A. and Cavers, G. 2015. The Black Loch of Myrton: An Iron Age Village in
839 South-West Scotland. Antiquity Project Gallery 89 (346).

840 Crone, A. and Cavers, G. 2016. Black Loch of Myrton. An Iron Age Village. British
841 Archaeology Issue 151: 36–41.

842 Crone, A., Cavers, G., Allison, E., Davies, K., Hamilton, D., Henderson, A., Mackay,
843 H., McLaren, D., Robertson, J., Roy, L. and Whitehouse, N. 2018. Nasty, brutish and
844 short?; the life cycle of an Iron Age roundhouse at Black Loch of Myrton, SW
845 Scotland. Journal of Wetland Archaeology 18 pp138-162.

846 Davies, K., Whitehouse, N., Allison, E., Mackay, H., Cavers, G., Crone, A., Fonville T.,
847 van Hardenbroek, M., Henderson, A., Langdon, P., Wyatt, N. and Brown, A. in
848 preparation. Fossil Insect Assemblages from the Black Loch of Myrton: Insights into
849 prehistoric wetland settlements.

850 Duff, A. 1993. Beetles of Somerset: their status and distribution. Somerset
851 Archaeological and Natural History Society.

852 Duff, A. 2008. Ed. Checklist of Beetles of the British Isles, Pemberley Books, UK.

853 Duncan, J. S. 2000. Phosphate analysis in Banks, I. Excavation of an Iron Age and
854 Romano-British enclosure at Woodend Farm, Johnstonebridge, Annandale, 1994
855 and 1997, Proc Soc Antiq Scot 130, 223-281.

856 Ebersbach, R. 2013. Houses, households, and settlements. Architecture and living
857 spaces. In: F. Menotti & A. O'Sullivan, eds. The Oxford handbook of wetland
858 archaeology. Oxford: Oxford University Press, pp. 283–301.

859 Evershed R. P., Bethell P. H., Reynolds P. J., Walsh N. J. 1997 5β-Stigmastanol and
860 related 5β-Stanols as biomarkers of manuring: analysis of modern experimental
861 material and assessment of the archaeological potential. J Archaeol Sci 24:485–495.

862 Forbes, V. and Milek, K. 2014. Insects, activity areas and turf buildings' interiors: An
863 ethno-archaeoentomological case study from 19th to early 20th-century Þverá,
864 northeast Iceland, Quaternary International, Volume 341, Pages 195-215.

865 Foster, S. P., Paul V. L., Slater R., Warren A., Denholm I., Field, L. M. and
866 Williamson, M. S. 2014. A mutation (L1014F) in the voltage-gated sodium channel of
867 the grain aphid, Sitobion avenae, associated with resistance to pyrethroid
868 insecticides. Pest Management Science 70: 1249– 1253.

869 Golson, J., Denham, T., Hughes, P., Swadling, P., Muke, J. 2017. Ten Thousand years
870 of cultivation at the Kuk swamp, Papua New Guinea. Terra Australis 46, Australian
871 National University, Canberra.

872 Grimalt J. O, Fernández P, Bayona J. M, Albalgés J. 1990. Assessment of fecal sterols
873 and ketones as indicators of urban sewage inputs to coastal waters. Environ Sci
874 Technol. 24: 357–363.

875 Hall, A. R. and Kenward, H. K. 1990. Environmental evidence from the Colonia:
876 General Accident and Rougier Street. Archaeology of York 14(6). London, Council for
877 British Archaeology.

878 Harding, D. W. 2004. The Iron Age in Northern Britain: Celts and Romans, Natives
879 and Invaders. Routledge: Abingdon.

880 Harding, D. W. 2009. The Iron Age Round-house; Later Prehistoric Building in
881 Britain and Beyond, Oxford University Press: Oxford.

882 Harrault, L., Milek, K., Jardé, E., Jeanneau, L., Derrien, M. and Anderson, D. G.
883 2019. Faecal biomarkers can distinguish specific mammalian species in modern and
884 past environments. PLoS ONE 14(2): e0211119.

885 Haslewood G.A. Bile salt evolution. J. Lipid Res. 1967; 8: 535–550. pmid:4862128

886 Hawkes, S. C. 1994. Longbridge Deverill Cow Down, Wiltshire, House 3: a major
887 roundhouse of the Early Iron Age, Oxford Journal of Archaeology 13 (1), 49–69.

888 Hill, J. D. 1995. The pre-Roman Iron Age in Britain and Ireland (ca. 800 BC to AD
889 100): an overview. Journal of World Prehistory 9 (1), 47–98.

890 Hill, T.C.B., Hill, G.E., Brunning, R. Banerjea, R.Y., Fyfe, R.M., Hogg, A.G.,
891 Jones J., Perez, M. and Smith D.N. 2018 Glastonbury Lake Village revisited: a multi-
892 proxy palaeoenvironmental investigation of an Iron Age wetland settlement, Journal
893 of Wetland Archaeology, 18:2, 115-137.

894 Hillson S. 1986. Teeth. Cambridge, Cambridge University Press.

895 Hinch, G. N. and Brien, F. 2014. Lamb survival in Australian flocks: a review. Animal
896 Production Science 54, 656-666.

897 Hingley, R. 1990. Domestic organisation and gender relations in Iron Age and
898 Romano-British households, in R. Samson (ed.), The Social Archaeology of Houses,
899 125–147. Edinburgh: Edinburgh University Press.

900 Hjulström, B. and Isaksson, S. 2009. Identification of activity area signatures in a
901 reconstructed Iron Age house by combining element and lipid analyses of sediments.
902 Journal of Archaeological Science 36(1):174-183.

903 Hofmann A, Hagey L. 2008. Bile acids: chemistry, pathochemistry, biology,
904 pathobiology, and therapeutics. Cellular and Molecular Life Sciences. 65: 2461–
905 2483.

906 Holliday, V.T. and Gartner, W.G. 2007. Methods of soil P analysis in archaeology.
907 Journal of Archaeological Science 34(2):301-333 DOI: 10.1016/j.jas.2006.05.004

908 Jacomet, S. 2006. Identification of Cereal Remains from Archaeological Sites (2nd
909 Edition). Basel: Archaeobotany Lab IPAS, Basel University.

910 Kelly, R.S. 1988. Two late prehistoric circular enclosures near Harlech, Gwynedd,
911 Proceedings of the Prehistoric Society 54, 101–151.

912 Kenward, H. K., Hall, A. R. and Jones, A. K. G. 1980. A tested set of techniques for
913 the extraction of plant and animal macrofossils from waterlogged archaeological
914 deposits. Science and Archaeology, 22, 3-15.

915 Koch. K. 1989. Die Kafer Mitteleuropas (Ökologie Band 2) Goecke and
916 Evers, Krefeld.

917 Kornilova O., Rosell-Melé A. 2003. Application of microwave-assisted extraction to
918 the analysis of biomarker climate proxies in marine sediments. Organic
919 Geochemistry 34 (11): 1517-1523

920 Ledger, M. L. Grimshaw, E., Fairey, M., Whelton, H. W., Bull, I. D., Ballantyne, R.,
921 Knight, M. and Mitchell, P. D. 2019. Intestinal parasites at the Late Bronze Age
922 settlement of Must Farm, in the fens of East Anglia, UK (9th century B.C.E.)
923 Parasitology 146, 1583-1594.

924 Leeming R., Ball A., Ashbolt N., Nichols P. 1996. Using faecal sterols from humans
925 and animals to distinguish faecal pollution in receiving waters. Water Res. 30: 2893–
926 2900.

927 Leeming R, Latham V, Rayner M, Nichols P. 1997. Detecting and distinguishing
928 sources of sewage pollution in Australian inland and coastal waters and sediments.
929 Molecular Markers in Environmental Geochemistry. In: Eganhouse Robert P, editor.
930 Molecular markers in environmental geochemistry. Washington, DC: American
931 Chemical Society; pp. 306–319.

932 Lin D. S., Connor W. E., Napton L. K. and Heizer R. F. 1978. The steroids of 2000-
933 year-old human coprolites. J Lipid Res 19:215 – 21.

934 Lindroth, C. H. 1974. Coleoptera. Family Carabidae. Handbooks for the identification
935 of British insects. Vol IV, Part 2. Reprinted 1996 Royal Entomological Society,
936 London.

937 Lloyd, C. E. M., Michaelides, K., Chadwick, D. R., Dungait, J. A. J. and Evershed, R.
938 P. 2012. Tracing the flowdriven vertical transport of livestock-derived organic matter
939 through soil using biomarkers, Org. Geochem., 43, 56–66.

940 Macphail, R. I., Courty, M. A., Wattez, J. and Hather, J. 1997. The Soil
941 Micromorphological Evidence of Domestic Occupation and Stabling Activities.
942 In Arene Candide: A Functional and Environmental Assessment of the Holocene

943 Sequences Excavated by L. Bernabo' Brea (1940–1950), edited by R. Maggi, pp. 53–
944 88. Istituto Italiano di Paleontologia Umana, Rome.

945 Macphail, R.I., G.M. Cruise, G.M., Allen, M.J., Linderholm, J., Reynolds, P. 2004.
946 Archaeological soil and pollen analysis of experimental floor deposits; with special
947 reference to Butser Ancient Farm, Hampshire, UK, Journal of Archaeological Science
948 31, 175-191.

949 Manzanilla, L.R. and Barba, L. 1990. The study of activities in classic households:
950 two case studies from Teotihuacan. Ancient Mesoamerica 1 (1) 41-49.

951 Middleton, W. D., and Price, T. D. 1996. Chemical analysis of modern and
952 archaeological house floors by means of inductively coupled plasma-atomic emission
953 spectroscopy. Journal of Archaeological Science, 23(5), 673–687.

954 Middleton, W.D. 2004. Identifying chemical activity residues in prehistoric house
955 floors: a method and rationale of a mild acid extract of anthropogenic sediments.
956 Archaeometry 46, 47-65.

957 Middleton, W. D., B. Luis, P. Alessandra Pecci, H. B. James, Q. Agustin, S.
958 Laura, and R. S. Roberto. 2010. The Study of Archaeological Floors: Methodological
959 Proposal for the Analysis of Anthropogenic Residues by Spot Tests, ICP-OES and
960 GC-MS. Journal of Archaeological Method and Theory 17: 183.

961 Milek K. B. 2012. Floor formation processes and the interpretation of site activity
962 areas: an ethnoarchaeological study of turf buildings at Thverá, northeast Iceland. J
963 Anthropol Archaeol 31:119–137

964 Miller, N.F. and Smart, T. L., 1984. Intentional burning of dung as a fuel: a
965 mechanism for the incorporstion of charred seeds into the archaeological record.
966 Journal of Ethnobiology 4(1), 15-28.

967 Morris, D.P. 1986. Archaeological investigations at Antelope House, Canyon de
968 Chilly. National Parks Service, US Department of the Interior, Washington.

969 Murphy, C. P. 1986. Thin section preparation of soils and sediments. Berkhamsted:
970 AB Academic Press. site formation processes and human activities World
971 Archaeology 29: 281-308.

972 Nielsen, J. N. 2007. The burnt remains of a house from the Pre-Roman Iron Age at
973 Nørre Tranders, Aalborg. In Iron Age Houses in Flames. Testing House
974 Reconstructions at Lejre. Rasmussen, M. (ed.). Lejre Historical-Archaeological
975 Experimental Centre: Lejre 16 – 31.

976 Nielsen N.H., Kristiansen S.M. (2014) Identifying ancient manuring: traditional
977 phosphate vs. multi-element analysis of archaeological soil. J Archaeol Sci 42:390–
978 398.

979 O'Brien, C.E., Selby, K.A., Ruiz, Z., Brown, A. G, Dinnin, M. Caseldine, C., Langdon,
980 P. and Stuijts, I. 2005 Sediment-based Multi-proxy Approach to the Archaeology of
981 Crannógs: A Case Study from Central Ireland. The Holocene 15, 707-719.
982 Doi:10.1191/0959683605hl845rp

983 Panagiotakopulu, E., Skidmore, P., Buckland, P. 2007. Fossil insect evidence for the
984 end of the Western Settlement in Norse Greenland. Naturwissenschaften 94, 300–
985 306.

986 Pearson, M. P. and Sharples, N. 1999. Between Land and Sea, Excavations at Dun
987 Vulan, South Uist (S.E.A.R.C.H. 3) Sheffield Academic Press: Sheffield.

988 Pelton, J.A. & Callan, R., Barrington, G. and Parish, S. 2000. Frostbite in Calves.
989 Compendium on Continuing Education for the Practicing Veterinarian. 22. S136-
990 S141.

991 Peters, C., Church, M. J. & Batt, C. M. 2004. Applications of Mineral Magnetism in
992 Atlantic Scotland Archaeology 1: Techniques, Magnetic Enhancement and Fuel
993 Sources. In R. Housley and G. Coles (eds) Atlantic Connections and Adaptations:
994 Economies, Environments and Subsistence in Lands Bordering the North Atlantic:
995 86-98. Oxford: Oxbow Books

996 Pollard, J. 2006. Shelter for lambing sheep in New Zealand: A review. New Zealand

997 Journal of Agricultural Research - NZ J AGR RES. 49. 395-404.

998 Pope, R.E. 2007. Ritual and the roundhouse: a critique of recent ideas on domestic
999 space in later British prehistory, in C.C. Haselgrove and R.E. Pope (eds), The Earlier
1000 Iron Age in Britain and the Near Continent, 204-28. Oxford: Oxbow.

1001 Prost K, Birk JJ, Lehndorff E, Gerlach R, Amelung W, 2017. Steroid Biomarkers
1002 Revisited – Improved Source Identification of Faecal Remains in Archaeological Soil
1003 Material. PLoS ONE 12(1): e0164882

1004 Pryor, F. 2001. The Flag Fen Basin: archaeology and environment of a Fenland
1005 landscape. Swindon: English Heritage

1006 Rawson, R. E., Dziuk, H.E., Good, A. L., Anderson, J. F., Bates, D. W. and Ruth, G. R.
1007 1989. Thermal insulation of young calves exposed to cold. Canadian Journal of
1008 Veterinary Research 53: 275-278.

1009 Reilly, E., Lyons, S., O'Carroll, E., O'Donnell, L., Stuijts, I. and Corless, A. 2016.
1010 Building the towns: the interrelationship between woodland history and urban life in
1011 Viking Age Ireland, in Jervis, B., Broderick, L. and Grau-Sologestoa, I. (Eds).
1012 Objects, Environment and Everyday Life in Medieval Europe. Brepols, Turnout. 67-
1013 92.

1014 Robertson J. 2018. The Macroplant Assemblage. In A Lake Dwelling in its
1015 Landscape; Iron Age Settlement at Cults Loch, Castle Kennedy, Dumfries &
1016 Galloway, G. Cavers and A. Crone, 82–87. Oxford: Oxbow Books.

1017 Robertson, J. and Roy. L. M. 2019. A Scottish Iron Age Wetland Village Built from
1018 Nature's Bounty: Understanding the Formation of Plant Litter Floors. Environmental
1019 Archaeology. pages 1-16.

1020 Roy, L. 2018. Micromorphology. In A Lake Dwelling in its Landscape; Iron Age
1021 settlement at Cults Loch, Castle Kennedy, Dumfries & Galloway, edited by G. Cavers
1022 and A. Crone, 91–93. Oxford: Oxbow Books.

1023 Ryan, P. 2011. Plants as material culture in the Near Eastern Neolithic: Perspectives
1024 from the silica skeleton artifactual remains at Çatalhöyük. Journal of Anthropological
1025 Archaeology 30 (3): 292-305.

1026 Schmid, E. 1972. Atlas of animal bones for prehistorians, archaeologists and
1027 Quaternary geologists. Elsevier Publishing Company, Amsterdam.

1028 Shahack-Gross, R. 2011. Household Archaeology in Israel: Looking into the
1029 Microscopic Record. In Household Archaeology in Ancient Israel and beyond Brill,
1030 edited by A. Yasur-Landau, J. R. Ebeling, and L. B. Mazow, 27–36.
1031 Leiden, Netherlands: Koninklijke Brill Nv.

1032 Shillito, L-M. 2017. Multivocality and multiproxy approaches to the use of space:
1033 lessons from 25 years of research at Çatalhöyük. World Archaeology 49. 237-259.

1034 Shillito, L.-M., and P. Ryan. 2013. Surfaces and Streets: Phytoliths,
1035 Micromorphology and Changing Use of Space at Neolithic Çatalhöyük
1036 (Turkey). Antiquity 87 (337): 684–700.

1037 Shillito, L.-M, Bull, I. D., Matthews, W., Almond, M. J., Williams, J. M. and
1038 Evershed, R. P. 2011. Biomolecular and micromorphological analysis of suspected
1039 faecal deposits at Neolithic Çatalhöyük, Turkey. J. Arch. Sci. 38. 1869-1977.

1040 Simpson, I. A., Dockrill, S. J., Bull, I. D., Evershed, R. P., 1998. Early anthropogenic
1041 soil formation at Tofts Ness, Sanday, Orkney. J. Arch. Sci. 25, 729-746.

1042 Skidmore, P., 1985, The biology of the Muscidae of the world. Junk, Dordrecht.
1043 Series entomologica, 29, xiv 550p.

1044 Smith, K.G.V., 1989. An Introduction to the Immature Stages of British Flies. In:
1045 Handbooks for the Identification of British Insects, 10(14):1-280. Royal
1046 Entomological Society of London, London.

1047 Smith, D.N. 2012. Insects in the City: An Archaeoentomological Perspective on
1048 London's Past. British Archaeological Reports, British Series 561. Archaeopress,
1049 Oxford, U.K.

Smith, D., Nayyar, K., Schreve, D., Thomas, R. and Whitehouse, N. 2014. Can dung beetles from the palaeoecological and archaeological record indicate herd concentration and the identity of herbivores? Quaternary International. 341.

Smith, D., Hill, G. Kenward, H. and Allison, E. 2020. Development of synanthropic beetle faunas over the last 9000 years in the British Isles. Journal of Archaeological Science 115, 105075.

Sørensen, M. L. S. 2007. English and Danish Iron Ages – a comparison through houses, burials and hoards in Haselgrove, C and Pope, R (eds) The Earlier Iron Age in Britain and the near Continent. Oxbow: Oxford, 328-337.

Stoops, G. 2003. Guidelines for analysis and description of soil and regolith thin sections. Soil Science Society of America, Inc. Madison, Wisconsin.

Wade, K., Shillito, L.-M, Marston, J. M. and Bonsall, C. 2019 Assessing the potential of phytolith analysis to investigate local environment and prehistoric plant resource use in temperate regions: a case study from Williamson's Moss, Cumbria, Britian.

Whitaker, A. 2007. Fleas (Siphonaptera). RES Handbooks for the Identification of British Insects Vol. I Part 16 (2nd Ed.) 178pp. Royal Entomological Society, St Albans.