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Published in:
Geoarchaeology
Publication date:
2016

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Download date: 05. Dec. 2018
A Palaeoenvironmental Investigation of Two Prehistoric Burnt Mound Sites in Northern Ireland

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Received
18 September 2014
Revised
1 September 2015
Accepted
2 September 2015

Scientific editing by Jamie Woodward

This paper provides a summary of the palaeoenvironmental evidence from a spread of late Mesolithic burnt material and two late Neolithic to early Bronze Age burnt mounds. The burnt mounds were up to 10 m diameter, had an amorphous shape, and were consistently less than 0.8 m thick. Monoliths were collected from two sites, Ballygawley and Roughan, in Co. Tyrone, Northern Ireland. This provided an opportunity to use a detailed palaeoecological approach for the first time to investigate the use and function of burnt mounds. Pollen, non-pollen palynomorphs, micro- and macroscopic charcoal were used to place these features within their environmental context, and to establish if such an approach could provide further insights into their function. The palynological results shared similar characteristics: high microscopic charcoal values, repetitive fluctuations in tree and shrub taxa, increased Sphagnum, and the presence of non-pollen palynomorphs (NPPs) HdV-114 and HdV-146, all of which could be diagnostic indicators of burnt mounds in palynological records. While the data do not allow us to ascribe a specific function for the burnt mounds, their environmental setting is discussed. A “see-saw” pattern of arboreal pollen, combined with the macroscopic charcoal data, indicate possible species selection and management of local woodland for fuelwood. © 2016 Wiley Periodicals, Inc.

INTRODUCTION

Anthropogenically constructed mounds commonly appear in the archaeological record and have various ages, shapes, and sizes, as well as different types of construction material, including earth, stone, and remnants of burnt fuel. These include presumed burial mounds, dating back 6000 years in Louisiana (Keenan & Ellwood, 2014), earthen burial and platform mounds in southeast and southwest of North America (Lindauer & Blitz, 1997; Pluckhahn et al., 2015), the Stege Mounds (middens) of California (Eerkens et al., 2014), monumental building of flat-topped mounds in central Georgia, USA (Bigman & Lanzarone, 2014), and numerous Pre-Columbian earthworks to build dwellings in the Amazon (Lombardo & Prumers, 2010). Outside the Americas, mounds are also widely distributed including the Anatolian mounds in the Near East (Steadman, 2000), the monumental mound of Silsbury Hill and burial mounds in southern Britain (Semple, 1998; Bayliss, McAvoy, & Whittle, 2007), and burnt mounds across the British Isles (Buckley, 1990).

Burnt mounds or “fulacht fiadh” are a common feature in the Irish and British archaeological record (Brindley, Lanting, & Mook, 1989; Buckley, 1990; Feehan, 1991). They date from the Neolithic to the medieval period (Anthony et al, 2001; Ó Néill, 2009) and were widely used during the second millennium B.C. They occur in various shapes and sizes. Crescent- or horseshoe-shaped burnt mounds are typical in Ireland, but they can also be circular, oval, and d-shaped. Their size ranges from over 1 m in height and range over 30 m in diameter (O’Sullivan & Downey, 2004), whereas in north Wales burnt mounds have more amorphous shapes and sizes ranging from 3 m in diameter to spreading over 15 m (Fairburn, personal communication). Despite being ubiquitous, we know little about their function. The most favored hypothesis is cooking (O’Kelly, 1954; Hawkes, 2013), but this theory...
continues to be contested. Other alternative uses include brewing (Quinn & Moore, 2007; Wilkins, 2011), butter making (Sayce, 1945), bathing (O’Drisceoil, 1988), dyeing and textile processing (Jeffrey, 1991), butchery (Tourench, 2008), leather working, saunas/sweat lodges and baths (Barfield & Hodder, 1987; O’Sullivan & Downey, 2004), the rendering of animal fats (Monk, 2007), and funerary and ritual practices (Bradley, 1978). However, cooking continues to be the most likely activity (Hawkes, 2013). There have been few attempts to progress these generalized interpretations. While these functions are plausible, all are falsifiable and require convincing evidence. Consequently burnt mounds remain an archaeological enigma.

Few palaeoenvironmental studies have focused specifically on understanding the function and wider environmental context of burnt mounds (e.g., Innes, 1998; Gonzalez et al., 2000). Palaeoenvironmental analyses can provide useful insights into the history and function of an archaeological site and provide an environmental setting for past activities (Dimbleby, 1985; Whittington & Edwards, 1994; Tipping et al., 2009). The combination of palynological and anthropocological studies is now well established to provide complementary data sets to investigate changes in woodland composition (Gowen, Ó Néill, & Philips, 2005; Newman et al., 2007; Nelle, Dreibrodt, & Dannath, 2010) and management (Ludemann, Michiels, & Nöken, 2004; Mighall, Timberlake, & Crew, 2010; Wheeler, 2011; Crew & Mighall, 2013). Such an approach is adopted in this study. The study aims to (i) place these burnt mounds into their environmental context; (ii) reconstruct any vegetational changes associated with the use of the burnt mounds using pollen, nonpollen palynomorphs (NPPs), microscopic charcoal data, and archaeoastronomical data; and (iii) determine if the palaeoenvironmental record can provide insights into the function of burnt mounds.

**ARCHAEOLOGY AND SITE DETAILS**

This study centers around two late Neolithic/early Bronze Age burnt mounds from two sites, Ballygawley and Roughan. Palaeoenvironmental sampling was carried out as part of the archaeological evaluation and excavation strategy associated with the A4/5 road improvement scheme between Dungallen and Ballygawley, Co Tyrone, Northern Ireland, undertaken by Headland Archaeology Ltd. A total of 25 sites were evaluated, with 12 of these sites going on to excavation, between August 2006 and April 2007. Excavation across these sites revealed 29 burnt mounds and associated features (e.g., hearths and troughs), Bronze Age cremation burials and ring ditches, two early Christian ringforts, and an early Christian cemetery (Figure 1 and b).

**Ballygawley**

The Ballygawley site is located in low-lying pasture approximately 5 km east of the Ballygawley Water, on the edge of the flood plain that lies at the foot of higher ground formed by drumlins (Figure 1 and c). Palaeochannels and alluvial islands, representing a system of lateral migration and anastomosing channels (Lewin, Macklin, & Johnstone, 2005), run across the site. These palaeochannels were infilled with intercalated deposits of peats and alluvial silts and clays (Figure 1). Upon excavation, 23 burnt mounds were discovered, including 10 wooden and wicker-lined troughs (in eight different styles) dating from the Neolithic to the medieval period (e.g., Supplementary Figure 1a and b), some being *Sphagnum* lined and with associated pits and hearths (Bailey, 2010a; Bamforth, Gray, & Taylor, 2010). The analysis of planks and wattle sails, which were made of mainly hazel, used in the construction of troughs associated with the burnt mounds suggest that some form of woodland management was practiced, possibly coppicing or new growth cut within an interval of less than 10 years (Bamforth, Gray, & Taylor, 2010). One burnt mound deposit (9031) was sampled at this location, measuring 3.7 m × 3.2 m. The deposit was up to 0.14 m thick (Bailey, 2010a).

A monolith was collected from the northern limit of excavation and truncated a single-phase section of burnt mound [context no. 9031] (Figure 1). Charcoal from the base of the feature was radiocarbon-dated to 3865 ± 35 (2465–2210 cal. yr B.C., 2σ; GU-17350). A section of the stratigraphy of the sediments is shown in Figure 2.

A radiocarbon chronology of these features indicates that activity took place at Ballygawley from c. 3350 cal. yr B.C. to cal. yr A.D. 1270 (Supplementary Figure 2); with six burnt mounds dated to the late Neolithic to early Bronze Age. The earliest radiocarbon date from a burnt mound is dated to 2830–2475 cal. yr B.C. (2σ) and the youngest has been dated to cal. yr A.D. 1040–1220 (2σ). A hiatus of activity of approximately 900 years occurred between the late Iron Age and early medieval period at the site, yet the overall longevity of activity indicates Ballygawley was a place that people returned to in order to use hot stone technology. The construction of new burnt mounds followed the migration of the palaeochannels and their changing course to maintain access and proximity to a water supply (Figure 1).

The finds assemblage recovered from Ballygawley is among the largest from any Irish burnt mound complex,
A palaeoenvironmental investigation in Northern Ireland

Figure 1 Location of study sites (a) in Northern Ireland; (b) in Co Tyrone, Northern Ireland; (c) excavation site at Ballygawley showing the palaeochannels and burnt mounds (circles); (d) excavation site at Roughan showing Area C; (e) the location of the monoliths and burnt mounds in Area C, Roughan.

with a considerable quantity of material coming from the palaeochannel deposits. The majority of finds were of prehistoric age, including pottery fragments relating to five different vessels from the late Neolithic/early Bronze Age, together with 16 flint scrapers and two bone points indicative of butchery practices and hide preparation. Butchery is also indicated by the faunal bone assemblage, which consists of cattle, pig, and sheep/goat, largely contains parts associated with slaughter (skull, mandible, lower leg bones) and primary butchery (upper leg bones) (Tourunen, 2009). However, the lack of blades recovered suggests meat preparation was not taking place (Lochrie, 2010a,b,c).

Roughan

Roughan is located on an area of low-lying pasture approximately 9 km to the south west of Ballygawley (Figure 1), fringing an area of reclaimed peat land. The site lies within a small valley running from east to west with ground rising to the north and further low-lying land to the south. Excavations at Roughan revealed a group of six burnt mounds, which are amorphous in shape ranging from 1 to 10 m diameter and less than 1 m thick (Figure 1). Burnt mound (8413) measured 8.80 m × 4.90 m and up to 0.25 m thick. Associated features included troughs and pits. Troughs were found to be mainly unlined, although one trough did contain a layer of organic material which may have been the remains of a lining (Bailey, 2010b).

Observations made during the course of the excavation indicated that there had been two possible attempts to stabilize the surface of the peat around the burnt mounds during prehistory. The first used collected brushwood (no evidence of tool marks were found [Bamforth, Gray, & Taylor, 2010]) and the second utilized actual burnt mound material in a linear spread leading from one of the mounds (Bailey, 2010b). There was a dearth of finds at Roughan.

A monolith was taken through the base of one of the burnt mounds [context no. 8413] (Figures 1 and 2c). A radiocarbon date (3885 ± 35; 2466–2208 cal. yr B.C.; GU-15850) places this feature into the Bronze Age, and is comparable with a series of radiocarbon dates from other features, which suggest that burnt mound use took place during the third millennium B.C. between c. 2900 to 2100 cal. yr B.C. (Supplementary Figure 3). An earlier spread of burnt material was discovered at the base of the monolith, confirmed by radiocarbon dating to be of late Mesolithic age c. 6400–5900 cal. yr B.C. (Supplementary Figure 3).
METHODS AND MATERIALS

In order to obtain pollen sequences that could be linked directly to periods of burnt mound use, it was decided to take samples directly through the mounds. Monoliths were analyzed, which encompassed the burnt mound layers (charcoal and heat-fractured stone), together with intercalated peat and/or alluvial deposits. This allowed for
the close-interval sampling for periods of activity immediately preceding, during, and after burnt mound use.

**Microfossils**

Subsamples from both monoliths were taken over selected intervals (112–66 cm at Ballygawley and from 58 to 18 cm at Roughan). Each 1 cm³ subsample was prepared for pollen and NPPs analyses following Barber (1976). The organic component of each subsample was separated from the mineral component using density flotation (Nakagawa et al., 1998). A sum of 500 total land pollen (TLP) was achieved for all subsamples except for the burnt mound material at Ballygawley. Data are expressed as a percentage of the TLP, with spores and aquatic taxa excluded from the TLP sum. NPPs were also counted during routine pollen analysis (cf. van Geel, Hallewas, & Pals, 1982/1983; van Geel et al., 2003) and they are expressed as a percentage of TLP plus total NPPs. Rare types are indicated by a cross (+), where one cross is equal to one pollen grain or NPP. Pollen samples were spiked with *Lycopodium clavatum* tablets (Stockmarr, 1971) in order to calculate pollen concentrations using the method described by Benninghoff (1962). Identification, including cereal-type pollen, was aided by reference keys in Faegri et al. (1989), Moore, Webb, & Collinson (1991), Beug (2004), and Reille (1999), and supported by a modern type-slide reference collection housed at the University of Aberdeen. As the separation of *Myrica gale* from *Corylus avellana* type can be difficult, these pollen grain types are classified as *C. avellana* type (Edwards 1981). Plant nomenclature follows Stace (2001). Basic land use designations interpreted from the pollen records follow Brown, Carpenter, & Walling (2007). Microscopic charcoal was counted in three fractions (<21 μm, 21–50 μm, and >50 μm). Loss on Ignition percentages (LOI) were also determined (Schulte & Hopkins, 1996).

**Radiocarbon Dating**

Selected bulk sediment, humic acid fraction, or charcoal samples were carefully extracted from the monoliths and submitted to the NERC Radiocarbon Laboratory and Poznań Radiocarbon Laboratory for Accelerator Mass Spectrometry (AMS) radiocarbon dating.

**Macroscopic Charcoal**

A maximum of fifty charcoal fragments were selected from each subsample based on size to allow for positive species identification and also to maximize ring curvature data. The standardized quantitative sampling strategy (Asouti, 2001; Wheeler, 2007) was deemed appropriate to provide adequate material for interfeature/intersite assessments. Standard methods of identification followed Leny and Casteel (1975) with charcoal samples being fractured to reveal the three sectional surfaces (transverse section [TS], tangential longitudinal section [TLS], and radial longitudinal section [RLS] necessary for microscopic wood-type identification to genus. Charcoal fragments were securely positioned onto slides for examination under an incident light microscope at magnification 100×, 200×, and 400×. Identifications were assisted by using wood keys by Schweingruber (1990) and a modern reference collection. Nomenclature follows Schweingruber (1990). Ring curvature was measured using the key in Marguerie & Hunot (2007): where weak curvature is thought to denote large-sized timbers; medium curvature, medium-sized timbers; and strong curvature representative of small-sized timbers or branch wood. When ring curvature could not be observed or genus not identified, an indeterminate result was recorded.

**RESULTS**

**Stratigraphy**

The monoliths were described using the Troels Smith (1955) classification and they are provided in Supplementary Table SI.

**Radiocarbon Dating**

All radiocarbon dates quoted in this paper are listed in Table I and Supplementary Figures 1 and 2. The radiocarbon dates are given to ±1σ and calibrated ages to a two σ age range, using Calib 7.0 software (Reimer et al., 2009) in conjunction with Stuiver and Reimer (1993). An age-depth model for Roughan was constructed using CLAM (Blaauw, 2010) and shown in Figure 3. Clay dominated the stratigraphy at Ballygawley, which prevented the recovery of reliable dates on sediment above the burnt mound material. Only two radiocarbon dates were determined at the top and bottom of the burnt mound and this is considered an insufficient number to model. There are some uncertainties with all radiocarbon dates and some of these might apply to this study. There has been some discussion over which fraction of the peat to date (Shore, Bartley, & Harkness, 1995; Brock et al., 2011). Dating the humic acid fraction of a sample can be problematic as humic acids are mobile and generally yield dates that are younger than the humin fraction of the same sample (Shore, Bartley, & Harkness 1995; Brock et al., 2011). For example, Bartley & Chambers (1992) suggest that the humin fraction is preferable for dating purposes although Johnson, Tallis, & Wilson...
Table I Radiocarbon dates from the burnt mound monoliths (Ballygawley and Roughan).

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Material Description</th>
<th>Laboratory Number</th>
<th>$^{14}$C Age (B.P.)</th>
<th>Calibrated Age Range (95.4%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roughan</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monolith</td>
<td>18–19 Corylus avellana charcoal GU-15850</td>
<td>3885 ± 35</td>
<td>2466–2208 B.C.</td>
<td></td>
</tr>
<tr>
<td>Monolith</td>
<td>42–43 Peat—humic acid GU-15852</td>
<td>7125 ± 40</td>
<td>6068–5913 B.C.</td>
<td></td>
</tr>
<tr>
<td>Monolith</td>
<td>50–51 Bulk sediment Poz-46459</td>
<td>7380 ± 50</td>
<td>6385–6100 B.C.</td>
<td></td>
</tr>
<tr>
<td>Ballgawley</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monolith</td>
<td>92–93 Peat—humic acid GU-15849</td>
<td>3850 ± 35</td>
<td>2460–2200</td>
<td></td>
</tr>
<tr>
<td>Monolith</td>
<td>103–104 Corylus avellana charcoal GU-17350</td>
<td>3865 ± 35</td>
<td>2465–2210</td>
<td></td>
</tr>
</tbody>
</table>

(1990) recommend using the humic acid fraction in certain contexts. AMS dates from bulk sediment can also be badly skewed by small amounts of intrusive material (e.g., Chapman & Gearey, 2013). There could be a significant old wood offset with radiocarbon dates obtained from charcoal and charcoal of different ages could have been included in the same deposit (Pilcher, 1991). Moreover, the differences in ages between GU-15850 and GU-15852 indicate a possible hiatus or very slow rates of accumulation. There is significant potential for disturbance to the on-site deposits given the evidence for repeated human activity.

While recognizing the limitations described above, radiocarbon dates from the humic acid fraction and charcoal at Ballygawley (GU-15849 and GU-17350) do not have any great offset compared to one another,
and dates from bulk sediment and the humic acid fraction at Roughan produce similar ages (GU-15852 and Poz-46459). Furthermore, the radiocarbon dates from Ballygawley and one from Roughan (GU-15850) fit the chronological framework provided by the radiocarbon dates from other archaeological structures at these sites (Supplementary Figures 2 and 3). Any age-offset is therefore not considered to adversely affect comparisons with the palaeoenvironmental records and the archaeological features.

When interpreting fossil peat archives, Telford, Hegaard, & Birks (2004) and Piotrowska et al. (2010/2011) consider that all radiocarbon dates and all age-depth models are uncertain. The limited number of radiocarbon dates (three for Roughan) associated with the monolith sequence compromises the robustness of the CLAM age-depth model (Figure 3). Therefore, the model should be treated with caution. Unless stated otherwise all cited ages are derived as best estimates from the CLAM model.

Microfossils

The pollen and NPPs diagrams for both monoliths were constructed using Tilia.graph (Grimm, 2004) and are presented in Figures 4, 5, 6, and 7. The diagrams have been divided into local pollen assemblage zones (LPAZs) using CONISS (Grimm, 1987). Preservation is variable across all zones in both diagrams. Poor pollen preservation ranges between 20% and 40% across all damaged categories and has the ability to fix nitrogen (van Geel, 2005). An aquatic pioneer, is indicative of nutrient-poor conditions. Eutrophication is suggested by the presence of HDV-150 and HDV-167. A marker for erosion in fluvial/lacustrine contexts (van Geel, Bos, & Pals, 1983; van Geel et al., 2003) but not for peat (Kolaczek et al., 2013). HDV-184 is associated with the deposition of sandy-clay (van Geel, 1983).

Relatively high amounts of indeterminate, degraded, folded/crumpled, and corroded pollen grains occurred throughout the zone, which most likely represents inwash from the palaeochannels (Delcourt & Delcourt, 1980; Moore, Webb, & Collinson, 1991). Pollen corrosion and degradation can also be caused by chemical and biochemical oxidation, raised pH (Moore, Webb, & Collinson, 1991), and/or the result of increased eutrophication. Eutrophication is suggested by the presence of HDV-150 and HDV-167. Gloeotrichia (HDV-146), an aquatic pioneer, is indicative of nutrient-poor conditions and has the ability to fix nitrogen (van Geel, 2005). Consistently higher numbers of Sphagnum spores and the occurrence of Tilletia sphagni (HDV-27) at 106 cm were recorded. The earliest burnt mound use (BM 9003, see Figure 1) at the site is dated to 2833 to 2475 cal. yr B.C. and therefore the changes described above could be associated with contemporary burnt mound use.

INTERPRETATION

Ballygawley

BG1 (113–102 cm) (Figures 4 and 5)

A late Neolithic date (c. 2470–2270 cal. yr B.C.) was determined for the top of this zone. Tree and shrub percentages exceed 60% TLP and indicate local woodland. As Martin & Mehringer (1965) have shown, most pollen found in alluvial sediments is derived from a local source. Therefore, the high values of Alnus, Salix, and possibly C. avellana type are indicative of a local carr (Waller et al., 2005). Deciduous woodland, while local, was probably situated on higher ground, and is characterized by Quercus, C. avellana type, Betula, and Ulmus with Polypodium occupying shaded areas beneath the woodland canopy. Repetitive peaks and troughs create a “see-saw” pattern in the pollen curves for C. avellana type and also for Quercus, Alnus, and Poaceae at the base of the burnt mound material (from 107 cm up core). Rough, wet pasture is inferred by the representation of Plantago lanceolata, Ranunculaceae, Rumex acetosa, Aster-type, and Caryophyllaceae (Brown, Carpenter, & Walling, 2007). Cyperaceae, Pedicularis palustris type, Peucedanum palustre type, and Filipendula are all commonly found on fens. Indicators of disturbance include Chenopodiaceae and Urtica.

The pollen record in the basal zone, immediately before the deposition of the burnt mound deposits, is characterized by a number of noteworthy observations. As expected, microscopic charcoal counts, indicative of burning, increased from 105 cm with this rise sustained until 94 cm. Wood detritus can be inferred from the occurrence of scalariform perforation plates (SPPs; HDV-114), which peaked at 106.5 cm, and grazing and/or the presence of decayed wood from Sordaria-type (HDV-55A). Small peaks in Gnomus cf. fasciculatum chlamydospores (HDV-207) between 107 and 105 cm may also represent an inwash of debris as this particular NPP is considered to be a marker for erosion in fluvial/lacustrine contexts (van Geel, Bos, & Pals, 1983; van Geel et al., 2003) but not for peat (Kolaczek et al., 2013). HDV-184 is associated with the deposition of sandy-clay (van Geel, 1983).

LP stages: BG1 (113–102 cm) (Figures 4 and 5)

The radiocarbon date tentatively places this zone between c. 2470 and 2200 cal. yr B.C. At 103 cm, the stratigraphy changed from clay to burnt mound material. The burnt mound material appears to have been deposited over a short period of time as indicated by the radiocarbon dates. High microscopic charcoal values characterize this zone, indicative of intense burning. This has adversely affected the preservation of pollen, probably as a result of exposure to high temperatures (Havinga, 1967;
Delcourt & Delcourt, 1980). This possibly explains the loss of the repetitive fluctuations of tree taxa and the decline in total tree pollen percentages. Although the latter might also be the result of a loss of woodland cover as a result of sustained burnt mound use from c. 2800 cal. yr B.C. to 1420 cal. yr B.C. *Sphagnum* (used as a lining in the burnt mound troughs) peaked but SPPs (HdV-114) and *Gloeotrichia* (HdV-146) were only recorded in trace amounts until 96 cm when both increased in percentage. HdV-184 was regularly recorded in trace amounts, being associated with the deposition of sandy-clay.

The occasional trace of Poaceae >35 μm may be representative of cereal-types and/or wild grasses (Dickson, 1988; Edwards & Borthwick, 2010), possibly in wet meadow/fen or within the flood plain system along with Cyperaceae and *P. palustre* type. The lack of cultural, herbaceous pollen taxa is probably the result of poor pollen preservation rather than a lack of human activity or grazing. *Cercophora*-type (HdV-112) and *Sordaria*-type (HdV-55A) were recorded at the end of the LPAZ, suggesting low intensity grazing and/or the presence of decayed wood. The reoccurrence of *Glomus cl. fasciculatum*...
chlamydospores (HdV-207) can be associated with the inwash of eroded material.

**LPAZ BG3 (94.5–75 cm)**

The age range of this zone is uncertain given the lack of radiocarbon dates for the top 90 cm. An immediate decline in microscopic charcoal in this zone suggests the use of the burnt mound (context no. 9031; Figure 1) subsided. The continual presence of microscopic charcoal implies less intense burning in the immediate vicinity (>50 μm fraction), and/or more distant burning, most probably within the wider burnt mound complex (<21 μm and 21–50 μm fractions). However, the radiocarbon chronology across the site suggests a pause in burnt mound use between c. 2100 and 1900 cal. yr B.C.

The pollen and NPP records replicate those observed in the end of LPAZ BG1. Relatively stable total arboral pollen (AP) percentages, similar to those noted just before the deposition of the burnt mound material, were recorded. Repetitive changes in *C. avellana* type and possibly *Quercus* continued until 89 cm, but the pattern is less evident for *Alnus*, *Ulmus*, and *Betula*. Wet pasture/marsh indicators were present including Poaceae >35 μm, *R. acetosa* and *P. lanceolata*; *Cyperaceae*, *Galium*-type and *P. palustris* type; together with indicators of disturbed ground, such as Chenopodiaceae and Apiaceae (Brown, Carpenter, & Walling, 2007). Coprophilous fungi *Cercophora*-type (HdV-112) and *Sordaria*-type (HdV-55A) were also recorded suggesting that herbivores grazed nearby (Mighall et al., 2008).

*Sphagnum*, SPPs (HdV-114) and *Gloeotrichia* (HdV-146) all reappeared and may relate to continued burnt mound use, which could have continued for approximately another 100 years in proximity of the sampling site. These patterns continued until approximately 87 cm when the
sampling resolution becomes coarser and/or activities on the site either changed or ceased. Microscopic charcoal values increased slightly at 85 cm and may reflect a resumption of burnt mound use at the site (e.g., BM9011 at location 9009; Figure 4). This activity did not have a major impact on woodland cover. Total tree and shrub percentages did not diminish but show a pattern of occasional decline and recovery. Grazing indicators *Cercophora*-type (HdV-112) and *Sordaria*-type (HdV-55A) occurred in trace amounts. A suite of herbaceous taxa normally associated with pasture (Brown, Carpenter, & Walling, 2007) were recorded in trace amounts, including *Ranunculaceae*, *Rumex acetosella*, and *Plantago media/major*. *Caryophyllaceae*. *Urtica*, *Sphagnum*, SPPs (HdV-114), and *Gloeotrichia*-type (HdV-146) were also regularly recorded, but at much lower values. *Tilletia sphagni* (HdV-27) occurred sporadically.

**LPAZ BG4 (75-66cm)**

Mixed carr and deciduous woodland, comprising *Alnus*, *Salix*, *C. avellana* type, *Quercus*, and *Ulmus*, were still present locally. *Corylus avellana* type pollen values see-sawed again. *Poaceae* has an inverse pattern with *C. avellana* type. The appearance of cereal-type pollen at 72 cm and *Triticum*-type (wheat) pollen at 70 cm implies
the onset of small-scale cereal cultivation. Their occurrence corresponds with a continual presence of *P. lanceolata* and *P. media/major*. Aster-type and other indicators of disturbed ground and pasture remained present from the preceding zone, but only in trace amounts. Any grazing, as suggested by the presence of *Sordaria*-type (HdV-55A), appears to have been at a lower intensity at this time. LOI peaked at 72 cm, suggesting that inwash from the palaeochannel has subsided. Microscopic charcoal values remained fairly stable and might be related to another phase of burnt mound activity. *Gloeotrichia*-type, SPPs (HdV-114), and *Sphagnum* were all recorded but sporadically and in low values. If changes in these taxa were related to burnt mound use, they were minor, despite the sampling site being within 100–150 m.

**Roughan**

**LPAZ Rou1 (Figures 6 and 7)**

The radiocarbon date of 6385–6100 cal. yr B.C. at 51–52 cm (Poz-46459) confirms a late Mesolithic date for this LPAZ. *Corylus avellana* type pollen was abundant, peaking at 51–50 cm, indicating a strong local presence of hazel and typical of early Holocene woodlands across the British Isles (Huntley, 1993). Its abundance might relate to quantitative overrepresentation (Binney et al., 2005). *Pinus, Betula, Quercus,* and *Ulmus* formed mixed woodland with *Corylus*. Fluctuations in the pollen of *C. avellana* type, and to a lesser extent, *Quercus, Ulmus, Betula,* and *Salix* created a “see-saw” pattern in the total tree and shrub pollen sum leading up to the deposition of burnt material. The presence of *Viburnum* in association with *Prunus*-type (*P. avium* and *P. spinosa* were both present in the charcoal record) suggests open woodland, possibly comprising fringe vegetation with enough shade to support pteridophytes. Carr woodland, comprising *Alnus* and *Salix,* was also present. Rough wet grassland and/or damp woodland floor indicators were present, including Poaceae, Cyperaceae, *Aster*-type, *Narthecium ossifragum, Filipendula,* and *Galium*-type. Disturbed ground taxa (e.g., *Urtica* and Apiaceae) also occurred (Brown, Carpenter, & Walling, 2007). The presence of *Urtica* suggests that local soils had relatively high nutrient levels (Yeloff et al., 2007).

SPPs (HdV-114), indicative of woody debris, and *Gloeotrichia* cf. *fasciculatum* chlamydospores (HdV-207) appear to be associated with the inwash of eroded material.
HdV-150 and 167 indicate shallow eutrophic water. In contrast, Gloeotrichia-type (HdV-146) indicates the presence of nitrogen-poor conditions (van Geel, 2005). Sphagnum was also consistently recorded.

**LPAZ Rou2**

This LPAZ represents the burnt material. Two radiocarbon dates either side of this deposit confirm the burning took place during the Mesolithic (Table I). There is a cross-fraction increase of microscopic charcoal across the LPAZ boundary and values remain much higher throughout the burnt material. It is not clear whether this represented a fire deliberately set by humans or a natural occurrence (cf. Chambers, 1993). An increase in the total amount of tree pollen was characterized by Alnus and Quercus, whereas C. avellana type declined from 72% to 56% TLP, allowing for the greater representation of other trees and shrubs (Waller et al., 2005). This fluctuation could represent an actual change in woodland structure, or alternatively be a taphonomic variable. Ilex and Prunus-type suggest that woodland was open.

Higher percentages of Poaceae suggest that open areas existed within the woodland or at the woodland edge. Some taxa, considered to be disturbance indicators (e.g., Apiaceae and Urtica; Brown, Carpenter, & Walling, 2007), recorded in the microfossil diagrams may reflect natural perturbations operating in a flood plain environment (e.g., Anderson et al., 2000). Herbivores may have grazed pasture and/or wet meadow close by as Sordaria-type HdV-55A also occurred. Sordaria-types HdV-55A/B are commonly recorded during Mesolithic disturbance phases, suggesting the presence of dead wood and/or that animals were making use of openings in woodland (Mighall et al., 2008). Obligate coprophilous fungi, however, have not been recorded. The lack of these fungi supports the idea that these disturbances are natural as it is possible that the fungi occurred on dead wood. Woody debris is also indicated by the presence of SPPs (HdV-114) throughout the burnt material. Glomus cf. fasciculatum (HdV-207) and Euryergus cf. lamellatus (HdV-72D) may also represent an inwash of debris (van Geel, Hall, was, & Pals, 1982/1983 van Geel et al., 2003).

Wet meadow/fen vegetation is inferred locally by the presence of Poaceae (including those >35 μm), Cyperaceae, Filipendula, and P. palustre type. Taxa often associated with pasture and disturbance were also recorded in trace amounts, including Apiaceae, Ranunculaceae, P. lanceolata, R. acetosa, Aster-type and Caryophyllaceae (Brown, Carpenter, & Walling, 2007). Indicators of nutrient-poor conditions included Sphagnum and Gloeotrichia-type (HdV-146).

**LPAZ Rou3**

The radiocarbon date of 6070–5910 cal. yr B.C. (GU-15852) at 43–42 cm provides a late Mesolithic date for the beginning of this LPAZ, which culminates in the late Neolithic, c. 2470–2415 cal. yr B.C. A phase of carr and mixed woodland expansion is suggested by the steady, gradual rise of total tree pollen. Immediately after the deposition of burnt material ends a see-saw pattern was observed in many of the tree and shrub taxa and Poaceae percentages. Percentages of Salix and, to a lesser extent, Pinus, Betula, Quercus, C. avellana type, and Cyperaceae have an inverse relationship to Alnus and Poaceae. A strong signal of Salix pollen suggests local on-site growth (Waller et al., 2005), which may have replaced Corylus on the flood plain as its percentages decrease from the start of the zone to 38 cm. A constant background signal for burning is inferred from the microscopic charcoal, which is dominated by the <21 μm fraction, until the upper part of the LPAZ. These patterns continued until approximately 38 cm (c. 5520 cal. yr B.C.) when the sampling resolution becomes coarser.

There was a major increase in Poaceae and Cyperaceae values indicating an expansion of wet grassland/fen. Taxa often associated with pasture and disturbance were also recorded in trace amounts, and albeit more sporadically than compared to the previous zone. Such taxa include Apiaceae, Ranunculaceae, P. lanceolata, R. acetosa, Aster-type, Artemisia-type, Caryophyllaceae, and Urtica. Isolated traces of Sordaria-type (HdV-55A) and Cercophora-type (HdV-112) indicate grazing may have occurred locally. Agropyron-type (wheat-grass) is recorded as a rare-type mid-LPAZ; it is possible that it was used by humans as the leaves, tuber, and seeds are edible, and the roots also produce a gray dye (Coon, 1978).

The total percentage of trees and shrubs peaked at 23 cm. The finer resolution of the pollen data reveals a see-saw pattern particularly for Salix and Poaceae. The major tree taxa also fluctuate: Pinus, Quercus, Ulmus, and Corylus generally have an inverse relationship with Alnus. These changes may be a response to the decline of relatively high pollen producers such as Alnus and Poaceae. Once Alnus and Poaceae recover and started to produce large quantities of local pollen, the dispersal of pollen particularly from the trunk space and canopy signal from the trees on higher, drier ground became spatially restricted.

Grazing intensity appeared to increase from 22 cm as the amount of Sordaria-type (HdV-55A) rose. This observation is supported by the increased occurrence of pasture and disturbance indicators, including Poaceae and Chenopodiaceae from 24 cm to the top of the LPAZ. Microscopic charcoal values peaked at 22 cm and remained slightly higher, especially the <21 and 21–50 μm
fractions. This suggests increased burning, and may represent a major phase of burnt mound use at the site. A burnt spread (context 8467) and mound (context 8422) have been radiocarbon dated to the Neolithic period c. 2850 cal. yr B.C. (Supplementary Figure 3), which equates to 22 cm in the pollen diagram. This represents a new phase of activity at the site with activity lasting until c. 2040 cal. yr B.C. Local soils appear to become less eutrophic at this time as *Urtica* percentages fall in value throughout the LPAZ.

*Sphagnum* was recorded at consistently higher levels from 34 cm onward, together with HdV-146 (*Gleotrichia*-type). The occurrence of HdV-62, HdV-128, and HdV-143 on the upper LPAZ zone boundary indicates that the water was meso- to eutrophic (van Geel, 1978; van Geel et al., 2003). Woody debris and decomposed wood are indicated by HdV-114 and an isolated occurrence of *Kretzschmaria deusta* (HdV-44). This may indicate the presence of local trees as the ascospores are generally dispersed only several meters from their source (van Geel, 2005), but they may have traveled further within the palaeochannel network.

**LPAZ Rou4**

The radiocarbon date at 19–18 cm provides a late Neolithic/early Bronze Age date of 2466–2208 cal. yr B.C. (GU-15850; Table I) for the charcoal (considered part of the burnt mound material) at the top of the sequence. Repetitive fluctuations in *C. avellana* type, *Alnus*, *Quercus*, *Pinus*, and *Ulmus* were apparent in the arboreal and shrub pollen sums. The synchronicity between *Alnus* and Poaceae weakened. *Alnus* and *Quercus* had an inverse relationship with *C. avellana* type. Fluctuations were also witnessed in the Poaceae and Cyperaceae pollen curves. Rises in micro-charcoal counts across all fractions also began at this point, being most evident in the lowermost sample of the burnt material.

Other changes observed in association with burnt material were also recorded. *Sphagnum* increased slightly, together with possible woody debris indicators *Sordaria*-type (HdV-55A) and SPPs (HdV-114); the latter being representative of *Betula*, *Alnus*, or *Corylus* (van Geel, 1978; Hather, 2000). Increases in eutrophy are suggested by the presence of *Zygnemataceae* (HdV-62), *Diporotheca rhizophila* (HdV-143) and HdV-128 (van Geel, Bos, & Pals, 1983; Kuhry, 1985).

Fen/wet meadow vegetation remained present, which may have been used for grazing animals due to the presence of possible disturbance indicators *Cicuta virosa*, *P. media/major* pollen, and the reappearance of coprophilous fungal spores: *Sporormiella*-type (HdV-113) and *Cercophora*-type (HdV-112; van Geel et al., 2003). Their presence coincided with a large increase of microscopic charcoal at 18.5 cm, and, assuming the monolith chronology is sufficiently robust, the probable resumption of burnt mound use across the site (Figures 5 and 6).

**Macroscopic Charcoal**

The charcoal results presented are collated from those burnt mounds and associated features (e.g., troughs and pits) that have been dated to the late Neolithic to early Bronze Age period and are shown in Figures 8 and 9. Notwithstanding the limitations of the age-depth models, they are of broadly comparable age to the pollen sequences taken at Ballygawley through burnt mound [9031], and at Roughan through burnt mound [8413].

The charcoal condition varied from firm and well preserved to poor and friable. In some cases, charcoal fragments were partially vitrified, caused by exposure to temperatures in excess of 800°C (Prior & Alvin, 1983). A fraction of the charcoal assemblage was in a poor condition due to orange mineral discoloration, a common feature associated with material from burnt mounds, as waterlogged conditions can result in the charcoal incorporating minerals, such as calcium and iron, which hinders identification (Stuijts, 2007). The anthracological information gained from the charcoal analysis provides a complementary data set to the pollen analysis and reveals the presence of insect pollinated arboreal taxa, such as Maloideae sp. fruitwoods and *Sorbus* sp. Trace amounts of *Pruinus*-type are regularly recorded at both sites. However, these taxa are low pollen producers, with their pollen being difficult to detect, unless they grow close to the sampling site (Stuijts, 2005).

**Ballygawley**

A total of 1109 charcoal fragments were analyzed from six burnt mound groups of late Neolithic to early Bronze Age date (Figure 8). Eleven different taxa were identified as fuelwood from the burnt mound deposits. Individual mounds have fuelwood assemblages of between 1 and 10 taxa. However, a potential skewing of results is acknowledged as some burnt mound features have more samples analyzed than others (e.g., burnt mound [9782] compared with burnt mound [9031]). The most dominant taxa within the assemblage are *Alnus glutinosa* and *C. avellana*, with *A. glutinosa* in particular being prominent in all six burnt mound deposits, and especially from burnt mounds 9782, 9034, and 9986. Other taxa present include *Salix* sp., *Quercus* sp., Maloideae sp. (a group including *Pyrus communis*, *Malus sylvestris*, and *Crataegus* sp.,
which cannot be differentiated based on their anatomical composition), *Ulmus* sp., and *Prunus avium*, together with *P. spinosa*.

The growth ring curvature of the charcoal fragments indicates that all taxa were representative of small- to medium-sized wood, with strongly to moderately curved growth rings, suggesting the bulk of the fuelwood assemblage consisted of branch wood. Large-sized timbers, such as trunk wood, indicated by weakly curved growth rings were also present in the assemblage, and were limited to three taxa: *Quercus* sp., *C. avellana*, and *A. glutinosa*.

### Roughan

A total of 601 charcoal fragments were analyzed from five burnt mound (or spread) groups of late Neolithic to early Bronze Age date (Figure 9). Eight taxa were identified at Roughan. *Alnus glutinosa* is the dominant fuelwood, but it is not most prevalent in all burnt mound fuelwood deposits. *Corylus avellana* and *Quercus* sp. are the most abundant species within the assemblage. Other taxa identified include *Betula* sp., *Salix* sp., *Ulmus* sp., *Prunus avium* and *P. spinosa*.

The growth ring curvature of the charcoal fragments from Roughan is similar to that at Ballygawley with all taxa present being represented by strongly to moderately curved growth rings. This indicates the use of small- to medium-sized timbers suggestive of branch wood. However, there is more variety of taxa with weakly curved growth rings, suggesting the utilization of large-sized timbers with six taxa represented: *Quercus* sp., *C. avellana*, *Betula* sp., *A. glutinosa*, *Salix* sp., and *P. avium*.
**DISCUSSION**

**Mesolithic Burning**

The earliest evidence of burning has been dated to the late Mesolithic period at Roughan. This episode of burning has been labeled a “burnt spread” as no related features or finds were discovered. Only a single fragment of *C. avellana* charcoal was found in the spread. The pollen data indicate that burning of *Corylus*-scrub woodland took place (Figure 6). Burning appears to have been spatially...
constrained as other tree and shrub taxa do not appear to have been adversely affected except Salix that was possibly used for fuel but without charcoal data it is difficult to establish.

Simmons & Innes (1996) suggested that Mesolithic peoples deliberately burnt the ground layer of woodlands or exploited naturally created openings to encourage browsing of animals. In the absence of any archaeological evidence for Mesolithic activity in this study, it is not possible to firmly ascribe this burning episode to human activity. Tipping (2004) has suggested that the likelihood of natural fire was arguably much higher during the early Holocene. However, the changes recorded in the Roughan pollen diagram (Figure 6 and b) do share similar characteristics with woodland openings attributed to Mesolithic activity. Support for disturbance to create areas of browse for wild animals is suggested by taxa often linked with disturbance (e.g., Innes & Blackford, 2003) from the pollen assemblage in the burnt material. Evidence for herbivore grazing from the NPP record was less forthcoming with only Sordaria-type (HdV-55A; Figure 7) present in trace amounts. In the absence of red deer and other major herbivores, it has been suggested that Mesolithic people in Ireland did not have a reason to maintain clearings (Woodman, McCarthy, & Monaghan, 1997). The primary target for any hunters would be wild pig (Woodman, Anderson, & Finlay, 1999): Pteridium is a favored food of wild pigs (Grigson, 1982) and it features in the latter part of LPAZs Rou1 and Rou2 (Figure 6). Rumex and Pteridium occur naturally in woodlands and they would respond in increased numbers and wider dispersal if the woodland canopy was more open (Tipping, 2004). Alternatively the disturbance indicators simply could be responding to natural perturbations in and around the palaeochannel system.

Evidence for Mesolithic burning is rarely recorded in pollen studies from Northern Ireland, possibly because previous studies have not included microscopic charcoal analysis as part of their study (e.g., Pilcher, 1973; Pilcher & Smith, 1979; Smith & Goddard, 1991). Peaks in microscopic charcoal have been recorded at Ballynahatty, Co. Down, and they were interpreted as a possible domestic fire as there was no evidence for any detrimental impact on the woodland (Plunkett et al., 2008). However, the presence of late Mesolithic populations is well established from archaeological evidence (e.g., Bayliss & Woodman, 2009; Meiklejohn & Woodman, 2012), in particular along the Bann River Valley (e.g., Mitchell, 1955; Woodman, 1977, 1985; Spaulding et al., 1999), while finds of Mesolithic flints occur in Co. Tyrone (Ivens & Simpson, 1988). The phase of burning at Roughan adds to this body of evidence and it represents possibly the only Mesolithic archaeology discovered along the new road corridor.

Late Neolithic/Early Bronze Age

Environmental setting of the burnt mounds

Pollen evidence from the late Neolithic/early Bronze Age phase of burnt mound use (c. 2860 cal. yr B.C. to 2140 cal. yr B.C.) reveals that this activity took place in a landscape where mixed woodland and Alnus carr were both locally predominant (Figures 4 and 6). High pollen percentages of Alnus and Corylus derived from trees growing on both flood plains places the burnt mounds at a fen carr edge, where the pollen source area could have been limited to anywhere between 50 and >100 m radius (Binney et al., 2005; Bunting et al., 2005).

A decline in total AP percentages at Ballygawley coincided with the deposition of the burnt material. This possibly represents a short-lived phase of woodland clearance associated with the use of the burnt mound. However, this decrease might be artificial as the pollen content of the burnt material was extremely low. Therefore, counts will not be an accurate reflection of the local vegetation. Moreover, AP percentages recover to their original values when the deposition of the burnt material ends at 93 cm (Figure 4). The radiocarbon chronology is insufficient to firmly ascertain the impact of later burnt mound use in the local area. Assuming that that subsequent period of use is recorded in the peat above burnt mound deposit, and notwithstanding the coarser sampling resolution, the microfossil and microscopic charcoal records suggest that any impact was mute. Microscopic charcoal values remained low and there were no major perturbations in total AP or for individual tree and shrub taxa. Non-AP taxa and coprophilous fungi commonly associated with human activity and disturbance only occurred in trace amounts and sporadically. This suggests that the impact of other burnt mounds close to the sampling site was not detected due the pollen source area being spatially restricted (Figure 1).

There was an apparent hiatus in the Roughan archaeological record between the Mesolithic and the latter half of the third millennium B.C. The coarse resolution of the pollen diagram in LPAZ Rou3 hinders any attempt to identify any human impact (Figure 6 and b). Radiocarbon dates from a stone spread (8502), a burnt spread (8467), and a burnt mound (8422) (Supplementary Figure 3) provide the next definitive evidence for human activity at Roughan c. 2870 cal. yr B.C. Notwithstanding the crude chronology and slow sediment accumulation rate between 43 and 18 cm, this phase of activity tentatively correlates with around 21 cm in the pollen diagram. This
is slightly later than the resumption of the see-saw pattern in the AP and the increase and/or regular presence of pollen taxa and NPPs often associated with human activity (Figures 6a and b and 7). Microscopic charcoal values also increased during this time. Until the chronology is improved, it is unclear as to whether this represents human presence before the burnt mounds were used. Notwithstanding this, the evidence for human activity is still relatively mute given the close proximity of the burnt mounds.

The data have also revealed a common set of features in the pollen and NPP records at both sites, which appear to be associated with the burnt material. These trends are discussed further below.

1. Regular fluctuations in the pollen of the tree and shrub taxa.

Regular fluctuations in the pollen values of tree and shrub taxa have been recorded prior to and following the burnt spread and mounds recorded in the two monoliths. The exact reason for what we describe as the “see-saw” pattern is unknown. In particular, these peaks and troughs are recorded in the pollen curves of Quercus and C. avellana type at Ballygawley and Pinus, Ulmus, Salix, and to a lesser extent, Alnus, Quercus, and C. avellana type at Roughan (Figures 3 and 5). The high values of both Alnus and C. avellana type pollen infer that these tree types were growing near to the burnt mound sites (Brown, 1999; Waller et al., 2005). The macroscopic charcoal records suggest that they were used for fuelwood (Figures 8 and 9).

In order to determine if the see-saw pattern was real rather than an artifact of expressing the pollen data as percentages, and to negate the effect of the abundance of one pollen type depressing the value of others (Simmons & Innes, 1988), concentrations were also calculated. Pollen concentrations for major taxa from Ballygawley and Roughan are shown in Supplementary Figures 4 and 5a and b. With the exception of some minor differences, they show a consistent pattern that suggests that they have been influenced by changing sediment accumulation rates and possible variations in pollen productivity. When the pollen concentrations are normalized against the total pollen concentrations (excluding each taxon), the see-saw pattern is clearly seen (Supplementary Figure 4c–e). This suggests that the see-saw pattern observed reflects real changes in the vegetation. The normalized pollen concentrations patterns are in good agreement with the percentage data for each taxon. Such see-saw patterning in pollen diagrams is enigmatic. The patterns could be the result of several processes, including woodland management, natural fluctuations, or taphonomic processes. A discussion of each of these possibilities follows.

**Human activity**

The see-saw pattern seen in the pollen data infers that some form of management may have been practiced to maintain local woodland availability. This might have been inadvertent assuming there were sufficient trees available to provide a continuous supply of wood fuel for the burnt mounds or through deliberate coppicing and/or pollarding. Rackham (2006) also observes that trees such as C. avellana are best coppiced on a short rotation cycle so that the wood can be easily worked. Thus, if the hot stone technology associated with the burnt mounds required a significant volume of wood fuel, the use of fairly intensive coppicing (4–7 years) may have been required in order to resource this activity without completely removing areas of woodland.

Attempts to recognize episodes of coppicing within pollen diagrams have met with limited success (e.g., Waller & Schofield, 2007). Waller, Grant, and Bunting (2012) also found it difficult to identify cutting cycles and growth responses within pollen diagrams. Using a modeled scenario of coppice within A. glutinosa carr on a 20-year rotation, Waller, Grant, and Bunting (2012) showed a shift in pollen productivity (declining A. glutinosa and increasing C. avellana). This scenario might explain the inverse relationship between these taxa in the pollen record at Roughan. Despite being dominant species in the charcoal record (Figure 8), Alnus does not demonstrate a see-saw pattern at Ballygawley. If this species was managed, any rotation or management markers could not be identified in the pollen record.

*Corylus avellana* type is the second most abundant type of charcoal recovered from the burnt mounds (Figures 8 and 9). Its exploitation may explain the see-saw pattern in the pollen percentage and concentration data Figures 4 and 6, Supplementary Figures 4 and 5). However, the known rotation patterns described above (6–20 years) are probably much shorter than the see-saw pattern observed in the pollen records here. The pollen data are constrained by a limited chronology and the time span encapsulated in a 0.5-cm thick sample is unknown.

*Quercus* and *Betula* are also common in the Roughan macroscopic charcoal assemblages. At Llwyn Du, northwest Wales, a see-saw pattern for both taxa was reconstructed from fine resolution pollen data during iron production at a medieval bloomery. Crew and Mighall (2013) argued that the pattern was probably caused by woodland management of oak and birch. Wheeler (2007, 2011) also observed correlating see-saw patterns at Rievaulx and Bilsdale in North Yorkshire.
et al. (2010) observed that short rotation coppicing (2–3 years) of willow can lead to a higher wood yield, which may explain the see-saw pattern in the *Salix* pollen record at Roughan, although *Salix* wood was only recovered in small quantities (Figure 9).

*Corylus*, *Quercus*, and *Alnus* charcoal is commonly recovered from burnt mounds (Stuïts, 2005; O’Donnell, 2007, 2009; Miller and Ramsey, 2009). The differences in the frequency of trees from site to site may also reflect changes in the composition of woodland (Ludemann, Michiels, & Nöken, 2004; Ludemann, 2009) rather than preferential selection.

Growth ring curvature of the charcoal fragments indicates that the majority of the fuelwood was derived from small to medium-sized wood such as twigs, branch wood, and possibly rods/stemwood. These sizes might indicate the deliberate collection through coppicing and/or pollarding (Morgan, 1983; Boyd, 1988). Larger pieces of wood were also used, probably trunk wood, suggested by charcoal fragments displaying weakly curved growth rings (Marguerie & Hunot, 2007). At Ballygawley, these larger timbers are restricted to *C. avellana*, *A. glutinosa*, and *Quercus* sp., while at Roughan they include *Betula* sp., *Salix* sp., and *Prunus avium*, suggesting some deliberate selection or simply a wider availability.

The worked wood analysis of planks and wattle sails used in the construction of troughs also suggest that some form of woodland management was practiced. Wattle sails were mainly constructed from long straight hazel stems that had similar ring counts (4–7 years) and diameter sizes (10–30 mm). This stemwood may have been from coppiced or new growth cut within an interval of less than 10 years (Bamforth, Gray, & Taylor, 2010).

### Natural fluctuations and taphonomic processes

Other explanations may have also influenced the pattern of pollen percentages and concentrations. Fluctuations in AP assemblages are to be expected within local *Alnus* carr woodland, reflecting natural cycles of woodland in a flood plain environment (Waller, 1998; Waller et al., 2005). These *A. glutinosa* dominated communities often exhibit small-scale heterogeneity due to the instability of the ground substrates and tree weight (Rodwell, 1991). Changes in the herbaceous pollen assemblage, mainly of Poaceae and Cyperaceae pollen, also may indicate some opening of the local carr and increased presence of fen reedswamp.

1. **Increases across the cross-fraction micro-charcoal.**

There is a cross-fraction increase in microscopic charcoal values during burnt mound activity (Figures 5 and 6). These elevated charcoal levels are expected given the nature of the hot stone technology and large quantities of macroscopic charcoal present. This is particularly evident in the >50 μm size class, signifying the intensification of local on-site burning.

2. **Greater presence of wood detritus.**

An increase in probable dead wood indicators, SPPs (HdV-114) and *Sordaria*-type (HdV-55A) (van Geel, Bos, & Pals, 1983, 2003) in levels associated with burnt mound deposits occurred at both sites. *Kretzschmaria deusta* (HdV-44) was also present at Roughan and HdV-72D also feeds off vegetation debris. It is likely that the SPPs represented a combination of decomposed *C. avellana*, *A. glutinosa*, and *Betula* sp. remains (Schweingruber, 1990). Chopping and/or storing of wood fuel may have occurred near to the burnt mounds with fungi (e.g., *Sordaria* sp.) attacking stored wood (Feist, Springer, & Hajny, 1973). Fungal hyphae were observed within macroscopic charcoal fragments, which could also represent the use of deadwood for fuel (Marguerie & Hunot, 2007) or simply woody debris derived from the catchment. There is no evidence of working debris from the water-logged wood recovered from Ballygawley. Wood may have been fashioned prior to being brought to site to line the troughs.

Alder bark can also be used to create a black dye (Stuïts, 2005), so an increase in SPPs indicative of detritus may be related to bark stripping. Stone scrapers were present within the finds assemblage (Lochrie, 2010b).

3. **Presence of herbivores and cereal cultivation.**

It appears that burnt mound activity is strongly associated with a pastoral economy.

Coprophilous fungal spores occur in both assemblages suggest that animals were present locally. Cugny, Mazier, and Galop (2010) consider *Cerrophora*-type (HdV-112) to be a reliable dung indicator. Evidence for pasture is strong in the pollen records and the discovery of burnt bone has indicated that animal butchery was taking place at Ballygawley (Tourunen, 2009). Such activity has also been advocated for other burnt mound sites in Ireland (Tourunen, 2008).

Evidence for cereal cultivation is less forthcoming. Only one *Triticum*-type was recorded at Ballygawley and it is not associated with the burnt mound. Poaceae grains (>35 μm in diameter) were recorded at both sites. However, these could be wild grasses such as *Glyceria* and *Elytrigia* (Stace, 2001; Tweddle, Edwards, & Fieller, 2005). Moreover, the poor dispersal ability of large grasses and cereal pollen, combined with relatively dense woodland, might have dampened any cultivation signal in the pollen record (Vuorela, 1973; Tweddle, Edwards, & Fieller, 2005).
5. Increased levels of eutrophy and peaks in Sphagnum.

Sphagnum peaks occur during the phase of burnt mound use and could be related to the use of bog moss in the lining of troughs. Increased levels of meso- or eutrophy were also implied by D. rhizophila (HdV-143), HdV-62, HdV-128, and possibly HdV-55A at Roughan (Pals, van Geel, & Delfos, 1980; van Geel, Bos, & Pals, 1983). This could be the result of water either used in the troughs, pooling during periods of nonactivity, or from stagnant water lying close by. In contrast, high amounts of Gloeotrichia-type (HdV-146) are indicative of nutrient-poor conditions.

CONCLUSIONS

The results of this study suggest that burnt spread and mound activity can be characterized in the following way:

1. Activity appears to have had a small nonpermanent impact on the local environment during the Mesolithic, late Neolithic, and Bronze Age. The spatial impact of such activity appears to have been restricted, but needs to be constrained by multiple pollen profiles and more robust chronologies for the palaeoenvironmental deposits.

2. Activity took place at water side locations in small clearings with pasture close by, as suggested by the occurrence of herbs associated with pasture and the regular presence of coprophilous fungi. However, despite the wealth of local activity especially from the late Neolithic onward, the occurrence of non-AP taxa associated with human activity is generally limited to trace amounts. This might be due to taphonomic effects, including a limited pollen source area and/or pollen filtering by high AP producers and relatively dense woodland. Natural perturbations in a flood plain environment could also account for some of the changes recorded.

3. Burnt mound use appears to be associated more with local pasture rather than cereal cultivation. Cereal-type pollen only occurred in trace amounts and then only sporadically in the pollen records. Although not conclusive, evidence for animal butchery and pasture point toward cooking and/or hide preparation as the most likely activity.

4. Each burnt mound deposit/burnt spread was associated with specific changes in the pollen, NPPs, and microscopic charcoal records, irrespective of the age of the burnt material. These included a repetitive see-saw pattern in the pollen percent-ages and concentrations of major trees, shrubs, and herbs; high microscopic charcoal values, presence of coprophilous fungi, peaks in Gloeotrichia-type (HdV-146), SPPs (HdV-114) and peaks in Sphagnum. Whether these are indicative of burnt mound use is unclear but possible.

5. It is reasonable to suggest that: (a) charcoal is associated with fuelwood and repetitive exploitation of wood for fuel (e.g., deliberate cyclical coppicing) is known in prehistory (Rasmussen, 1990), which could be implied in the context of the burnt mounds at Ballygawley and Roughan; (b) increases in SPPs (HdV-114) and Sordaria-type (HdV-55A) may represent detritus from possible wood preparation (e.g., chopping/leaf stripping/bark removal, etc.), which may have been taken from trees that were naturally present in the flood plain environment; (c) Sphagnum was used to line and seal the troughs; and (d) burnt mound activity changed water conditions leaving them eu- to mesotrophic. These markers may be diagnostic indicators of burnt mound use in the palaeoecological record but this hypothesis now requires further testing.

Although the results of this study provide little direct insight into the function of burnt mounds, they do provide us with a greater understanding of human–environmental interaction at these enigmatic sites. Further multiproxy studies would provide useful information.

Road services Northern Ireland, Jacobs and Headland Archaeology funded this project. Thanks to Audrey Innes for the pollen preparations, Alison Sandison and Jenny Johnston for drafting illustrations. Two anonymous reviewers and Jamie Woodwood provided useful comments that helped to improve the paper. Thanks are also due to Roads Ireland, Jacobs, the Department for Regional Development, Mouchel Parkman, and John Cronin Associates.

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