Deforestation and Human Agency in the North Atlantic Region: Archaeological and Palaeoenvironmental Evidence from the Western Isles of Scotland

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APPENDIX S1: METHODOLOGY
(full description)

Field methods

In 1997, Simon Fraser of Calanais village discovered a possible anthropogenic feature within a coastal peat bank on the edge of East Loch Roag, at Aird Calanais, less than 1 km from the main Calanais I monument (NGR: NB 206 335; Figs 1–3). The site comprised a charcoal lens enclosed by a semi-circular stone alignment, which was overlain by an extensive wood layer. These features were buried under approximately 1.1 m of peat and lay directly above a palaeosol.

The eroding section was cleaned, drawn and photographed prior to excavation, following standard archaeological excavation procedures (Fig. 4). The semi-circular stone alignment extended approximately 0.9 × 0.6 m into the section and so a 2 × 1 m trench was excavated to allow a thorough investigation of the feature. The wood layer, associated contexts and the charcoal fill of the semi-circular stone alignment were collected in their entirety (100% sampling: *sensu* Jones 1991), and bulk samples were taken from the remaining contexts (total sampling: *sensu* Jones 1991). A column sample was taken approximately 30 cm back from the main trench and was stored at 4°C prior to laboratory sub-sampling.

Laboratory methods

The stratigraphy and soil colour of the column sample were described (Munsell Color 1975; Rural Development Service 2006), and loss-on-ignition was measured on contiguous 1 cm^3 sub-samples at 550°C for 4 hours (Heiri *et al*. 2001). The volume-specific magnetic susceptibility (κ) of air-dried and sieved (2 mm) sediment was measured using a Bartington MS2G Single Frequency Sensor (Dearing 1994; Bartington Instruments Ltd nd). Following Kenward *et al.* (1980), 200 ml sub-samples from archaeological contexts 3, 5, and 8 were wet-processed using four sieves (1 mm to 125 μm) to extract uncarbonised palaeo-environmental material. The remaining bulk samples were then processed in the Environmental Archaeology laboratories of Durham University, following Uig Landscape Project archaeobotanical protocols (see Nesbitt *et al.* 2011, 38–40), using microscopy up to ×600 magnification. Plant macrofossil and charcoal remains were fully quantified, but due to their abundance in the samples, the waterlogged remains of non-plant material (Acari (mite), Cladocera (waterflea), and fungal sclerotia (fungal spores)) were recorded semi-quantitatively. Plant macrofossil identifications were made using botanical literature (Beijerinck 1947; Berggren 1969; 1981; Anderburg 1994; Schweingruber 1990; Hather 2000; Cappers *et al.* 2006) and modern reference material from the Department of Archaeology, Durham University. Following Hather (2000), Salicaceae wood/charcoal was not identified to genus or species due to the difficulty in distinguishing the taxa in this family using microscopic characteristics. Plant nomenclature follows Stace (2010).

Pollen samples from the column sample were taken from the main stratigraphic phases of the site to assess whether there was a woodland decline contemporary with the archaeological site. The samples were prepared following standard techniques (Moore *et al*. 1991), including sieving between 10 and 125 μm, acetolysis, density separation, and mounting in silicone oil. Coprophilous fungal spores were also recorded (van Geel *et al.* 2003). Samples were counted to a minimum of 300 TLP and a maximum of 326 TLP (total land pollen: Rull 1987) at ×400 or ×1000 magnification. Pollen grain damage was recorded following

Wilmshurst & McGlone (2005). Identifications followed Moore *et al.* (1991) and Beug (2004) for pollen and spores, and nomenclature follows Bennett (1994).

Two single-entity plant macrofossils from key archaeological contexts and three 1 cm^3 bulk peat samples from the column sample were submitted for AMS radiocarbon dating at the Scottish Universities Environmental Research Centre (Table 1). Dates were calibrated and a Bayesian 'P_Sequence' age-depth model created for the pollen sequence using IntCal13 (Reimer *et al*. 2013) in OxCal v 4.2.4 (Bronk Ramsey 2009; see *Synthesis of palynological data*). Due to the mixed nature of the earliest organic soil horizon (archaeological context 6; see Appendix S2), the base of the peat (archaeological context 5) was used as the lowest boundary in this model.

Synthesis of plant macrofossil data

A database of Western Isles Neolithic sites with identified charred remains from trees and shrubs (charcoal, seeds, fruits, nuts) was compiled by searching through relevant literature, with unpublished reports also obtained from relevant individuals (see acknowledgements). Radiocarbon-dated wood layers within peat sequences were synthesised from Bohncke (1988), Fossitt (1996), Rees and Church (2000), and Wilkins (1984).

Synthesis of palynological data

Palynological evidence from the Western Isles was collated from existing reviews (Church 2006; Edwards *et al.* 2000) and more recent published sources (see Table 4). Records with significant hiatuses, no data after 6000 cal BC, or fewer than two reliable radiocarbon dates were excluded. A total of 24 records remained for analysis.

The timing and amplitude of the decline in tree pollen in the different records was identified using a standardised methodology. Following the approach established by Farrell *et al*. (2014) for Orkney on the basis of studies of modern pollen rain in the region (Fossitt 1994, 374; Brayshay *et al.* 2000, 375; Bunting 2002), <20% arboreal pollen (AP) was assumed to indicate an open environment with, at most, scattered trees, and >20% AP as indicating an environment with at least occasional woodland stands. The AP category included all woodland/scrub woodland 'tree' and 'shrub' taxa (Stace 2010), with 'dwarf shrubs' of the Ericaceae family that are common on open moorland and heath excluded. *Corylus*-type pollen was considered to represent predominantly *Corylus avellana* L., on the grounds that this was commonly the major taxon of the native woodland habitats in this ecological location (eg, Brayshay 1992, 333; Lomax 1997, 4).

Major woodland declines were defined for sites starting with over 20% AP and declining by >20% over <10 samples, with arboreal pollen levels sustained at a level of 20% less than the pre-decline levels for at least a further ten samples or maintained to the top of the sequence (if <10 samples above the decline). All AP percentages were of total land pollen (TLP). These criteria were designed to identify major reductions in overall woodland extent as consistently as possible: though sampling interval and peat accumulation rates would have varied between cores, the method is suitable for identifying major sustained woodland declines, and the identified declines corresponded very closely with the major woodland declines identified by the original authors of the pollen site papers.

A standardised method was used to estimate the date of each woodland decline. Following Bronk Ramsey (2008) and Blockley *et al*. (2008), and using OxCal v4.2.4 (Bronk Ramsey 2009), new Bayesian P_sequence age-depth models were created for each sequence. The 'variable k' method was used to estimate the parameter k (which controls the variability of the modelled age-depth relationship), with k set between 10^{-2} and 10^{2} (Bronk Ramsey & Lee 2013). Where there was no age estimate for the top of the sequence, it was modelled to lie between 2000 cal BC and 2000 cal AD. The calibrated ages of the identified woodland declines were estimated by incorporating the depths of these points within the models. Where peat slices of several centimetres thickness were dated, the mid-point was taken as the sample depth. The minimum and maximum AP percentages for each sequence, and the minimum and maximum AP values before, during and after the Neolithic (4000–2500 cal BC), were recorded to indicate the timing of the changes in woodland cover. Asterisks (*) are used throughout the paper and this supplementary file to indicate interpolated rather than raw radiocarbon determinations.

APPENDIX S2: EXCAVATION RESULTS
(full description)

The site stratigraphy was divided into a series of phases of similar age, each comprising one or more contexts (identified in the text below by numbers in square brackets; see Table 2). Five major stratigraphic phases were identified. Artefacts were absent from all of the excavated horizons.

Phase 1 represents the earliest natural horizons: a green-grey boulder clay [12], overlain by a brown sandy-silt containing sand and gravel lenses [13].

Phase 2 is the earliest organic soil horizon at the site: a very dark-grey clayey-silt layer containing occasional charcoal flecks [6]. This soil is a palaeosol of early–mid Holocene date, with two carbonised hazel (*Corylus avellana* L.) nutshell fragments producing Late Mesolithic dates of 5659–5551 cal BC and 4604–4456 cal BC (Table 1). These single entity dates precisely date the season in which the hazelnuts grew, so the large interval between these dates suggests that this soil developed over a long period.

Phase 3 represents a coherent, semi-circular stone hearth structure [7] and associated layers, which were placed directly upon the palaeosol [6] (Figs 3 & 4). Although approximately half of the semi-circular stone structure had been eroded prior to excavation, it clearly resembled a hearth. The hearth was filled by a well-preserved charcoal layer [10] – the lower hearth fill – dated to 3637–3384 cal BC (Early Neolithic). The radiocarbon dated birch (*Betula* sp.) leaf buds provide a reliable date for the hearth, because they represent just one season of tree/shrub growth before the death/removal of the buds. A deposit of stones [11] and the upper hearth fill – a dark brown silty-clay containing occasional charcoal flecks [8] – immediately overlay the lower hearth-fill and abutted against the hearth stones [7]. Additionally, an irregular linear stone feature [9] was identified above the palaeosol [6]. This feature was spatially distinct from the hearth and probably represents a natural accumulation of stones.

Phase 4 is interpreted as the remains of a phase of major woodland decline. Immediately above the hearth was a layer of compact clay-rich peat containing occasional wood fragments [5], overlain by a distinct layer of intact twigs and bark [3] (Fig. 3a). This wood layer [3] covered most of the trench, with the exception of the eastern side of the eroded edge of section A–B, and extended into all the trench edges (Figs 3 & 4). The abundance of the wood varied across the excavated horizon, from dense concentrations to more sparsely scattered twig patches. The combined date of the two birch twigs from this horizon was 2912–2881 cal BC (Late Neolithic). The twigs provide a secure date for the formation of the layer, because they were 1 year old before they were separated from the trees/shrubs. The wood layer [3] was overlain by a thin layer of peat containing occasional twigs [4]. Throughout most of the trench, [3] and [4] were visible as two distinct layers, but where [3] was relatively thin, the boundary between these contexts was indistinct. For example, within the column sample there was no clear distinction between these layers and hence they were recorded as [4/3].

Phase 5 comprises the most recent deposits: the hagged peat [2] and the peaty topsoil and turf [1]. The peat reached a depth of 105 cm and immediately overlay [3].

Plant macrofossil results

The late Mesolithic palaeosol ([6], phase 2) contained just three carbonised hazel (*Corylus avellana* L.) nutshell fragments and 28 charcoal fragments, which were predominantly willow/poplar, together with some birch (*Betula* sp.: Table 3).

The Early Neolithic lower hearth fill ([10], phase 3) was also dominated by willow/poplar charcoal, which formed >50% of the assemblage, whilst birch and hazel charcoal comprised approximately 30% and 10–20% respectively. The charcoal was very fragmented and only six tiny fragments had complete pith-to-bark transverse sections: five birch twigs between 2 and 11 years (2–8 mm in diameter) and a 4-year-old (3.5 mm in diameter) hazel twig. All of the incomplete roundwood fragments of birch, hazel and willow/poplar had less than 14 rings, with most of the willow/poplar and birch fragments having 2–5 rings and most hazel fragments 6–14 rings.

A single unidentified charred seed and seven birch, hazel and willow/poplar charcoal fragments were recorded in the upper hearth fill ([8], phase 3). All of these charcoal fragments were abraded, perhaps due to re-deposition. Small quantities of uncarbonised Soft-rush (*Juncus* cf. *effusus* L.) seeds, cinquefoil (*Potentilla* sp.) achenes and fungal sclerotia (*Cenococcum geophilum*) were also present.

Both the Late Neolithic wood layer ([3], phase 4) and compact peat ([5], phase 4) contained birch twigs (Table 3). The roundwood was of a small size (2–44 mm in diameter) and young age (1–10 years; Fig. 5). These contexts also contained significant quantities of uncarbonised Soft-rush (*Juncus* cf. *effusus* L.) seeds, with uncarbonised cinquefoil (*Potentilla* sp.) achenes, violet (*Viola* sp.) seeds, sedge (*Carex* sp.), nutlets and fungal sclerotia also present. Cladocera and Acari remains were also abundant in the wood layer.

Palaeoenvironmental results and interpretation

The Late Mesolithic palaeosol ([6], phase 2) had a low but positive magnetic susceptibility and an organic content of 17–45% (Figs 6 & 7). The pollen samples from this context were very poorly preserved, with large numbers of indeterminate, degraded pollen grains. These assemblages are relatively poor in arboreal pollen (*Betula* sp., *Corylus*-type) and rich in *Calluna vulgaris*, *Filipendula* sp. and fern spores that are typical in early Holocene lake sediment records from the Western Isles (eg, Fossitt 1996). The pollen spectrum and poor preservation suggest that the pollen accumulated in a weakly stratified, partially aerated soil over a long duration. Though the pollen preservation in the uppermost sample from this context was sufficient for vegetation reconstruction, owing to the poor preservation, the pollen data from the three lowest samples are probably not a reliable guide to the palaeovegetation (and these are shown in a dashed line in Fig. 6). However, the poor preservation itself is consistent with the interpretation of this context as a palaeosol.

In contrast, the Late Neolithic deposits ([5], [4/3]: phase 4, and [2], the base of phase 5) in the column sample have a high organic content (55–99%) and negative magnetic susceptibility, which is typical for diamagnetic peat. The pollen from [5] and [4/3] is well preserved. *Betula* sp. is the dominant taxon throughout, increasing from 32% at the top of the Late Mesolithic palaeosol ([6], phase 2), to 73% at *2916–2878 cal BC, at the base of the Late Neolithic wood layer ([4/3], phase 4). Smaller quantities of *Corylus*-type, *Salix* sp., and other tree/shrub taxa are also present, and among the heath taxa, *Calluna vulgaris* is moderately abundant. Before the *Betula* sp. peak, *Corylus*-type, and *Salix* sp. decline at *3015–2908 cal BC ([5], phase 4) from *c*. 4–5% to <1%. The herb assemblages are low in diversity and dominated by Poaceae and Cyperaceae, with *Potentilla* sp. and *Plantago* sp. the only numerically important accessories. Arboreal pollen assemblages in Scottish peats are typically representative of the vegetation within a few hundred metres (*c*. 300 m) of the sampling site (Bunting 2002), although 10–20% of the total land pollen may come from further afield (Fossitt 1994; Brayshay *et al*. 2000).

The total proportion of arboreal pollen declines slightly at *2896–2831 cal BC, at the top of the Late Neolithic wood layer ([4/3], phase 4) prior to the initiation of the hagged peat ([2], phase 5) at *2881–2819 cal BC. In the samples from the hagged peat ([2], phase 5)), the proportions of *Betula* and other tree pollen are substantially reduced, with Cyperaceae, *Potentilla* sp. and *Sphagnum*, typical of acidic sedge peats, becoming abundant. Overall, arboreal pollen declines substantially and rapidly in the late Neolithic from 78% at the base of the late Neolithic wood layer ([4/3], phase 4: *2931–2881 cal BC) to 16% at the base of the hagged peat ([2], phase 5: *2863–2809 cal BC), and finally to 5% at the top of the analysed pollen sequence (*2856–2726 cal BC). Spores of only one type of fungus usually associated with animal dung or decaying wood, type HdV-55A (*Sordaria*-type: van Geel *et al.* 2003), were observed infrequently in the samples and had no obvious stratigraphic pattern.

BIBLIOGRAPHY

Anderburg, A.L. 1994. *Atlas of Seeds, Part 4, Resedaceae – Umbelliferae*. Stockhom: Swedish Museum of Natural History

Bartington Instruments Ltd. nd. *Operation Manual for MS2 Magnetic Susceptibility System*. Oxford: Bartington Instruments Ltd

Beijerinck, W. 1947. *Zadenatlas der Nederlandsche Flora*. Wageningen: Veenman and Zonen

Bennett, M. 1994. Plant lore in Gaelic Scotland. In R.J. Pankhurst & J.M. Mullin (eds), *Flora of the Outer Hebrides*, 56–60. London: HMSO

Berggren, G. 1969. *Atlas of Seeds, Part 2, Cyperaceae*. Swedish Museum of Natural History. Sweden: Stockhom

Berggren, G. 1981. *Atlas of Seeds, Part 3, Salicaceae – Cruciferae*. Swedish Museum of Natural History. Sweden: Stockholm

Beug, H.-J. 2004. *Leitfaden der Pollenbestimmung*. Munich: Friedrich Pfeil

Blockley, S.P.E., Bronk Ramsey, C., Lane, C.S. & Lotter, A.F. 2008. Improved age modelling approaches as exemplified by the revised chronology for the Central European varved lake Soppensee. *Quaternary Science Reviews* 27, 61–71

Bohncke, S.J.P. 1988. Vegetation and habitation history of the Callanish area, Isle of Lewis, Scotland. In H.H. Birks, H.J.B. Birks, P.E. Kaland & D. Moe (eds), *The Cultural Landscape: Past, present and future,* 445–61. Cambridge: Cambridge University Press

Brayshay, B. 1992. *Pollen Analysis and the Vegetational History of Barra and South Uist in the Outer Hebrides, Scotland.* Unpublished PhD thesis, University of Sheffield

Brayshay, B.A., Gilbertson, D.D., Kent, M., Edwards, K.J., Wathern, P. & Weaver, R.E. 2000. Surface pollen-vegetation relationships on the Atlantic seaboard: South Uist, Scotland. *Journal of Biogeography* 27, 359–78

Bronk Ramsey, C. 2008. Deposition models for chronological records. *Quaternary Science Reviews* 27, 42–60

Bronk Ramsey, C. 2009. Bayesian analysis of radiocarbon dates. *Radiocarbon* 51(1), 337–60

Bronk Ramsey, C. & Lee, S. 2013. Recent and planned developments of the program Oxcal. *Radiocarbon* 55, 720–30

Bunting, J.M. 2002. Detecting woodland remnants in cultural landscapes: modern pollen deposition around small woodlands in northwest Scotland. *The Holocene* 12, 291–301

Cappers, R.T.J., Bekker, R.M. & Jans, J.E.A. 2006. *Digital Seed Atlas of the Netherlands*. Groningen: Barkhius

Church, M.J. 2006. The vegetation history of the Western Isles. In D.D.A. Simpson, E.M. Murphy & R.A. Gregory (eds) *Excavation at Northton, Isle of Harris,* 4–9. Oxford: British Archaeological Report 408

Dearing, J. 1994. *Environmental Magnetic Susceptibility*. Kenilworth: Chi Publishing

Edwards, K.J., Mulder, Y., Lomax, T.A., Whittington, G. & Hirons, K.R. 2000. Human environmental interactions in prehistoric landscapes: the example of the Outer Hebrides. In D. Hooke (ed.) *Landscape: the Richest Historical Record,* 13-45. Amesbury: Society for Landscape Studies

Farrell, M., Bunting, J.M., Lee, D.H.J. & Thomas, A. 2014. Neolithic settlement at the woodland's edge: palynological data and timber architecture in Orkney, Scotland. *Journal of Archaeological Science* 51, 225–36

Fossitt, J.A. 1994. Modern pollen rain in the northwest of the British Isles. *The Holocene* 4, 365–76

Fossitt, J.A. 1996. Late Quaternary vegetation history of the Western Isles of Scotland. *New Phytologist* 132, 171–96

Hather, J.G. 2000. *The Identification of the Northern European Woods: A guide for archaeologists and conservators*. London: Archetype

Heiri, O., Lotter, A.F. & Lemcke, G. 2001. Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. *Journal of Paleolimnology* 25, 101–10

Jones, M. 1991. Sampling in palaeoethnobotany. In W. Van Zeist, K. Wasylikowa & K. Behre (eds) *Progress in Old World Palaeoethnobotany,* 53–62. Rotterdam: A A Balkema

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

Lomax, T.M. 1997. *Holocene Vegetation History and Human Impact in the Western Lewis, Scotland*. Unpublished PhD thesis, University of Birmingham

Moore, P.D., Webb, J.A. & Collinson, M.A. 1991. *Pollen Analysis* (2nd edn). London: Blackwell Science

Munsell Color. 1975. *Munsell Soil Color Charts*. Baltimore ML: Munsell Color

Nesbitt, C., Church, M.J. & Gilmour, S.M.D. 2011. Domestic, industrial, (en)closed? Survey and excavation of a Late Bronze Age/Early Iron Age promontory enclosure at Gob Eirer, Lewis, Western Isles. *Proceedings of the Society of Antiquaries of Scotland* 141, 31–74

Rees, T. & Church, M. 2000. Bronze Age Timbers from Creag Ruaidh, Achmore, Isle of Lewis. *Northern Studies* 35, 133–50

Reimer, P. J., Bard, E., Bayliss, A., Beck, J. W., Blackwell, P. G., Bronk Ramsey, C., Grootes, P. M., Guilderson, T. P., Haflidason, H., Hajdas, I., HattŽ, C., Heaton, T. J., Hoffmann, D. L., Hogg, A. G., Hughen, K. A., Kaiser, K. F., Kromer, B., Manning, S. W., Niu, M., Reimer, R. W., Richards, D. A., Scott, E. M., Southon, J. R., Staff, R. A., Turney, C. S. M., & Plicht, J. van der. 2013. IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP. *Radiocarbon* 55, 1869–187

Rull, V. 1987. A note on pollen counting in palaeoecology. *Pollen and Spores* 29, 471–80

Rural Development Service. 2006. *Technical Advice Note 53: Soil texture*. Report, Department for Environment, Food and Rural Affairs (DEFRA). London: UK Government

Schweingruber, F.H. 1990. *Microscopic Wood Anatomy: Structural variability of stems and twigs in recent and subfossil woods from Central Europe*. Geneva: Swiss Federal Institute for Forest, Snow & Landscape Research

Stace, C.A. 2010. *New Flora of the British Isles*. Cambridge: Cambridge University Press

van Geel, B., Buurman, J., Brinkkemper, O., Schelvis, J., Aptroot, A., van Reenen, G. & Hakbijl, T. 2003. Environmental reconstruction of a Roman Period settlement site in Uitgeest (The Netherlands), with special reference to coprophilous fungi. *Journal of Archaeological Science* 30, 873–83

Wilkins, D.A. 1984. The Flandrian woods of Lewis (Scotland). *Journal of Ecology* 72, 251–8

Wilmshurst, J.M. & McGlone, M.S. 2005. Corroded pollen and spores as indicators of changing lake sediment sources and catchment disturbance. *Journal of Paleolimnology* 34(4), 503–17