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Later Prehistoric and Norse Communities in the Northern Isles: multi-proxy environmental investigations on Orkney

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Abstract

Despite being an important location in the Viking world, and containing a wealth of archaeological remains, little is known about the impact that Norse communities had on the landscape of Orkney. To redress this, a palaeoenvironmental investigation was conducted from the infilled Loch of Tuquoy, a basin located within 500 m of the high-status Norse farmstead and Crosskirk at Tuquoy on Westray, Orkney, Scotland. Pollen, non-pollen palynomorphs (NPPs), microscopic charcoal, sediment geochemistry and mineral magnetic measurements were performed on a 2.25 m core. The results suggest that a cultural landscape had already been established before the Loch of Tuquoy record commenced. The landscape was subsequently characterised by the near-continuous activity of a mixed agrarian economy that intensified during two periods: c. 900 to 150 cal. BC, and between cal. AD 700 and 1550, the latter being a timeframe which encompasses the Norse occupation of the Tuquoy farmstead. Palynological evidence suggests that during both periods the land was used to cultivate cereals, as well as for pasture. While the landscape was largely treeless from 900 cal. BC onwards, minor woodland/scrub clearance occurred in both periods. The Norse palaeoeconomy seems to have been a continuation of earlier practices but caused a significant change in the source of sediments deposited into the loch, switching from a siliceous to a more calcareous component as human activity became less intensive. Whilst the sediment geochemistry revealed little possible

evidence for ironworking, lead concentrations show a series of peaks during the Iron Age on Orkney (and encompassing the Roman period as used elsewhere in Britain and Europe) indicative of regional-scale pollution signals.

Introduction

Numerous pollen-analytical studies have been conducted on Orkney, with research focussing upon the development of vegetation since the start of the Holocene (e.g. Moar, 1969; Bunting, 1996) and reconstructing the impact of Neolithic and later prehistoric peoples (e.g. Davidson et al., 1976; Keatinge et al., 1979; Bartlett, 1983; Bunting, 1994; Dickson, 2000; Bunting & Tipping, 2001; Bunting et al., 2001; Tisdall et al., 2013; Farrell et al., 2014; Farrell, 2015; Whittington et al., 2015; Timpany et al., 2017). While the Norse colonisation, economy and resultant environmental impact of settlement upon the North Atlantic Islands has received a great deal of attention (e.g. McGovern et al., 1988; Dugmore et al., 2005; Lawson et al., 2008; Schofield et al., 2008, 2010; Gauthier et al., 2010; Silva Sanchez et al., 2015), few palaeoenvironmental studies have assessed the environmental impact of Norse societies on the Orkney islands (Edwards et al., [2016] being one example). Davidson and Jones (1985) describe the Orcadian pre-Norse and Norse landscape as essentially treeless, with mixed agricultural activity and expanding heathland. Pollen data from Maeshowe suggests that this landscape became established by AD 300 at the latest, and persisted into the Viking/Norse Period (Davidson et al., 1976), but Davidson and Jones (1985) lament the paucity of data available to make any detailed inferences about those periods. Edwards et al. (2016) summarise the palynological studies from the Northern Isles that currently provide the most detailed vegetational information for the immediate pre-Norse and Norse periods. Sites on the islands of Mainland and Unst (Shetland) and at Rousay (Orkney), generally show further reductions in already depleted woody taxa such as birch and heather, coincident with enhanced evidence for grassland/grazing indicators from around AD 800.

To assess the extent of the Norse impact more widely, and especially given the wealth of archaeology from that era on Orkney, this paper examines the landscape impacts that were associated with a high-status Norse farmstead at Tuquoy on Westray (Figure 1). We present data from multiple proxies – pollen, non-pollen palynomorphs (NPPs), micro-charcoal, sediment geochemistry and mineral magnetics – from the Loch of Tuquoy (LoT) to place the farmstead into an environmental context, and provide additional evidence as to the impact and palaeoeconomy of Norse people on Orkney between c. AD 800 and the 15th century AD, thereby widening this information base for the North Atlantic islands. In particular, we consider evidence for earlier human activity at Tuquoy, we aim to ascertain the longevity and nature of the palaeoeconomy of the Norse and of medieval settlement at this location, and discuss how such activities impacted upon the sources and supply of sediment to the loch, and its water quality.

Archaeological context

The site at Tuquoy, Westray, Orkney, has been the subject of archaeological investigation since the early 1980s (Owen & McKinnell, 1989) and is considered to be a high-status late Norse farmstead (Owen, 1993). It is located on the southern shore of the Ness of Tuquoy (NGR HY 454 431) as shown in Figure 1. Stone walls with lime-plastered masonry were exposed in a coastal section as a result of storms in 1981. These suggest the presence of a 12th century farmstead of significant size and status, leading to trial excavations in 1982-83 that revealed the remains of a rectilinear 'Hall' (Owen, 1993). The 'Hall' passed through three known stages of remodelling including the addition of a rectilinear structure. This later building was found to contain a large volume of waste, including iron hammerscale, suggestive of on-site metalworking and possibly the presence of a smithy (Owen, 1993). Further investigation of the site in 1988 led to the discovery of a deposit rich in palaeoenvironmental material including insects, charred and waterlogged plant remains, worked wooden objects and off-cuts that are suggested to have been the remnants of a possible byre floor (Owen, 1993).

Bayesian analysis of the radiocarbon dates obtained from Tuquoy suggest that construction of the byre was part of the earliest known phase of activity, which dated to the start of the 11th century AD and ended by the beginning of the 12th century AD, with the use of the 'Hall' commencing in the 12th century AD and continuing into the 14th century AD (Krus, 2017). A runic inscription found on a secondary partition slab within the 'Hall' that translates as, 'Þorstein Einarsson carved these runes' (Owen and McKinnell, 1989), further supports a 12th century date for that building. To the east of the farm lies the c. 12th century church of Crosskirk, a stone construction that may have been preceded by an earlier timber structure (Owen, 1993). The presence of the church suggests that the farmstead at Tuquoy was of significant size and status, and as such, can provide further insights into Norse communities during an important period in the early history of Orkney covering the transition from late Norse to medieval times.

The island of Westray as a whole, like much of Orkney, is rich in archaeological remains (Figure 1b). A substantial early settlement has been uncovered at the Links of Noltland comprising a Neolithic farmstead, field walls, cultivation remains and artefact-rich midden deposits, together with six Bronze Age buildings and a cemetery that dates to the third and second millennium BC (Moore and Wilson, 2011). A number of coastal brochs have been tentatively dated to the Early Iron Age, while a roundhouse excavated at Pierowall by Sharples (1984) has been dated to 500-600 BC. On a coastal promontory c. 2 km southwest of Tuquoy at Knowe of Skea, a Late Iron Age burial complex exists. More than 100 burials have been identified, 60% of which are either children or new-borns (Moore and Wilson, 2005). A number of Viking burials have also been discovered between Links of Noltland, Rackwick Bay and Pierowall (Moore and Wilson, 2011). The latter is considered to be the largest pagan Norse cemetery found in Britain (Graham-Campbell and Batey, 1998). At Quoygrew, north Westray, a Late Norse farming site of comparable age to Tuquoy, with activity beginning in the 10th century AD, has also been excavated (Barrett, 2012).

Methods

Loch of Tuquoy

A 2.25 m core was taken from the infilled former Loch of Tuquoy (HY 45192 43374) approximately 450 m from the Norse farmstead (Figure 1c). The core was collected using a Russian corer, and the sediments were described based upon a visual assessment and aided by reference to the Troels-Smith scheme (1955). Core sections were wrapped in polythene, sealed and taken back to the laboratory in the Archaeology Institute, UHI, where they were sub-sampled for microfossil and physical analyses, and radiocarbon dating. The infilled loch and surrounding catchment are today dominated by grassland, mainly used for pasture.

Microfossils

A total of 50 sub-samples of *c*. 2 g wet weight and 0.5 cm thickness were prepared for pollen, NPP and microscopic charcoal analyses using the procedure described by Barber (1976) incorporating a density flotation method in order to remove mineral matter and concentrate the pollen (Nakagawa et al., 1998). At least 500 total land pollen (TLP) grains were counted for each sub-sample and identified using keys in Fægri et al. (1989), Moore et al. (1991), and through reference to type slide collections housed in the Archaeology Institute, University of the Highlands and Islands (UHI), and the University of Aberdeen. Cereal-type pollen was differentiated from wild grass pollen based on grain size, pore and annulus diameter and surface sculpturing (Andersen, 1979). Pollen preservation was recorded following Cushing (1967) with damaged pollen grains classified as either broken, corroded, crumpled or degraded. Damaged or deteriorated pollen grains that had no remaining distinguishing features were categorised as unidentified. NPPs were recorded during routine pollen counting and these were identified using the descriptions and photomicrographs in van Geel (1978, 2001), van Geel and Middledorp (1988), van Geel et al. (1989; 2003), and van Geel and Aptroot (2006). A variety of NPPs are considered to be coprophilous and their presence in sedimentary archives is often used as evidence for the presence of herbivores. Baker et al. (2013) provide a list of these coprophilous taxa with *Sporormiella*-type (HdV-113), *Sordaria*-type (HdV-55A) and *Podospora*-type (HdV-368) considered to be the most reliable indicators in this respect. These microfossils, plus *Cercophora*-type (HdV-112) and *Tripterospora*-type (HdV-169, *aka Apiosordaira*-type), are here interpreted to be indicative of herbivores. Microscopic charcoal was routinely counted during pollen analysis. The fragments were divided into three size categories (longest axis <21 µm; 21-50 µm; and >50 µm) in order to attempt to distinguish between fires that may have taken place close to, as opposed to some distance, from the site. Notwithstanding complicating taphonomic issues such as breakage, post-depositional transport by water, and uncertainty with regards to modelling charcoal dispersal, the larger microscopic charcoal fragments can be considered to originate from closer to the sampling site (Patterson et al., 1987; Remy et al., 2018).

Magnetic Measurements

Low and high frequency magnetic susceptibility measurements (Xlf and Xhf respectively) were made on c. 10 ml samples every 4 cm down the core using a Bartington MS2B magnetic susceptibility meter, while whole core logging of low frequency susceptibility used an MS2E probe. Anhysteretic remanence magnetism (ARM) was measured on a Molspin fluxgate magnetometer after an anhysteretic remanence was imparted by smoothly ramping down a mains frequency alternating field of 0.1 T while the samples were subjected to a steady field of 40 mT. Other remanence measurements (saturation isothermal remanence [SIRM] and hard isothermal remanence [HIRM]) were also made on a Molspin fluxgate magnetometer after subjecting samples to a forward magnetic field of 0.88 T and a reverse field of 0.1 T in a Molspin pulse magnetiser. ARM and remanence were measured in a Molspin rotating magnetometer. These measurements allowed the derivation of IRM (0.88T and -0.1T), the S-ratio and HIRM values. Where relevant, all concentration parameters were corrected for organic matter content (determined through loss-on-ignition, LOI, at 550°C) following procedures and calculations outlined by Walling and Foster (2016).

Geochemistry

The elemental composition of the sediments was determined for dried, milled and homogenized samples at 4 cm intervals for the whole core. Carbon content was measured using a Leco-Truspec CHNS analyser. Concentrations of major, minor and trace lithogenic elements (e.g. Si, Al, Fe, Ti, Ga, Rb, Y, Zr, Nb, Th) and trace metals and metalloids (e.g. Pb, Mn, Ni, Cu and As) were obtained using X-ray fluorescence dispersive EMMA-XRF analysers (Cheburkin and Shotyk, 1996; Weiss et al., 1998).

The instruments are hosted at the RIAIDT (Infrastructure Network for the Support of Research and Technological Development) facility of the University of Santiago de Compostela, Spain. Standard reference materials were used for the calibration of the instruments. Quantification limits were: 0.01% for Al, Fe, and Ti; 0.05% for Si; 0.5 $\mu g \cdot g^{-1}$ for Pb and Th; and 1 $\mu g \cdot g^{-1}$ for the other trace elements. Replicate measurements were taken for one of every five samples to ensure reproducibility; all replicates agreed within 5%. Certified reference materials were used to test the accuracy of the results.

Statistical analyses

Principal Components Analysis (PCA) was performed on the elemental composition of the samples, using the lithogenic and metal tracers. Before PCA was performed, the data were transformed to z-scores (calculated as: $[X_i-X_{avg}]/STD$, where: X_i is the percentage of a given type in a given sample; X_{avg} is the average of the population; and STD is the standard deviation) to avoid the scaling effect and to obtain average-centered distributions (Eriksson et al., 1999). PCA was undertaken using the SPSS 15.0 software package.

To determine the probability of discrete changes having occur in the depth/age records, we used the change point modelling (CP) routine and software developed by Gallagher et al. (2011), as applied in previous investigations on peat records (e.g. Kylander et al. 2013). Changepoint modelling was applied to selected parameters (total tree pollen, Poaceae, *Plantago lanceolata*, *Gloeotrichia*-type, SIRM [minero], S-ratio and Cp's 1-5) to detect significant changes in the records. The approach uses transdimensional Markov chain Monte Carlo to sample thousands of possible solutions in a Bayesian context, balancing the requirement of fitting the data and avoiding unjustified complexity on the changepoint structure.

Results and interpretation

Stratigraphy

The stratigraphy of the Loch core is described in Table 1. At their deepest, deposits reached up to 2.25 m thickness and four major stratigraphic units could be identified: a basal clay, overlain by a marl (a light grey calcareous silty loam with occasional gastropods shells; Dry & Sinclair, 1985), covered by a shelly gyttja, with a cap of peat extending to the surface. This sequence represents the progressive infilling of the loch and its eventual terrestrialisation culminating in peat formation.

Radiocarbon dating

Six samples were selected for ^{14}C AMS dating. Bulk sediment (peat, gyjtta or organic silt) was used as no suitable terrestrial macrofossils were identified. Measurement was undertaken at the Scottish Universities Environmental Research Centre (SUERC) (Table 2). The ^{14}C dates were calibrated using the IntCal13 calibration curve (Reimer et al., 2013). The age-depth model was constructed using a cubic spline (Figure 2) applied using the Clam software developed by Blaauw (2010). All radiocarbon dates are presented in the text on a calibrated calendar (BC/AD) timescale and are cited using the 2σ calibrated age ranges (unless otherwise stated). Estimated ages are taken from the age-depth model as the 'best fit', rounded to the nearest half decade. The designated archaeological periods in this paper follow the Scottish Archaeological Research Framework (ScARF).

There are uncertainties with all radiocarbon dates (Telford et al., 2004; Piotrowska et al., 2011) and some of these might apply to this study. For example, radiocarbon dates from the more calcareous-rich sediment may incorporate a reservoir effect (cf. Reimer & Reimer, 2007). Notwithstanding these limitations, in most cases radiocarbon dating can provide robust and accurate chronologies for lake sediment records and individual dates can be accurate on a decadal scale. The radiocarbon dates obtained from the six samples show a progressive chronological sequence of loch sedimentation. The age-depth model estimates that the loch sediments started to accumulate from c. 915 cal BC and that sedimentation then proceeded in a linear fashion until c. cal AD 1450, after which the accumulation rate slowed. The radiocarbon dates reveal that the palaeoenvironmental record spans the timeframe from the Late Bronze Age/Early Iron Age through to the post-medieval ('modern') period; an interval of approximately 3000 years.

Magnetic measurements

Plots for LOI (Figure 3a), Xlf (minero), HIRM, SIRM (minero) and the S-ratio are shown in Figures 3b-e. LOI values show a remarkably wide range from almost 60% in the uppermost two samples to under 10% in samples between AD 800 and 1300, thereby justifying the correction of magnetic concentration parameters for LOI.

Xlf (minero) is a measure of the concentration of ferrimagnetic minerals (magnetite, maghemite) in the sample, but it is also a function of magnetic particle size and magnetic mineralogy (Mooney et al., 2003). Values remain below 0.06 10^{-6} m^3 kg^{-1} except for small peaks at 515 and 375 BC, and between AD 100 and 500. In the upper part of the core the values peak after c. AD 1745 (note: these data are not shown on the diagram because of their high values; the missing values are 0.678 and 0.414 at c.

AD 1745 and 1888 respectively). Raw measurements of high field magnetic susceptibility (Xhf) were too low (<20) for the reliable calculation of the frequency dependent susceptibility (Xfd and Xfd%).

HIRM and SIRM (minero) – the maximum obtainable Isothermal Remanent Magnetization, dependent upon the concentration and particle size of the magnetic mineral — show similar trends to Xlf, although the peaks at around AD 105 and 1120 are of significantly different magnitude (cf. Figure 3c and d). HIRM values are below 0.16 10^{-3} Am^2 kg^{-1} except for a small peak at AD 105 and a more sizeable one at AD 1120. SIRM, a measure of the concentration and particle size of magnetic minerals (Mooney et al., 2003), displays a series of peaks coincident with those recorded by Xlf.

In cases where the S-ratio (a measure of the relative abundance variations of ferrimagnetic and antiferromagnetic minerals) is above 0.6, this indicates the presence of ferromagnetic minerals, most likely dominated by magnetite rather than hematite (Mighall et al., 2009), although this parameter can also be influenced by particle size (Mooney et al., 2003). S-ratio increases above 0.6 from the base of the core until c. 515 BC, when values reached a plateau. At AD 405 values started to decrease gradually until AD 1070 where a fall to almost 0.1 was recorded, most probably as a result of the increased presence of anti-ferromagnetic minerals such as haematite and goethite (Bloemendal et al., 1992). A sharp drop in the S-ratio took place at AD 1120 before returning to previous values and a switch back to ferromagnetic minerals. A further rise in the S-ratio occurred at AD 1540 (to pre-500 BC values). Although less prominent, there was also a reduction in the S-ratio at c. AD 110.

The mineral magnetic data suggest that either significant changes in particle size occurred, or that there was a change in sediment source. Concentrating on the two periods centred on AD 110 and AD 1120, the former had a more significant increase in SIRM (minero) than HIRM (cf. Figure 3d and c). This pattern is reversed in the peak at AD 1120. If the signatures are dominated by source changes rather than particle size, it would suggest that the two periods represent different types of environmental disturbance; the earliest more likely to have been associated with agriculture, and the latter more probably linked to ironworking at the site. Sampling of local rocks and soils would help to confirm these tentative conclusions (cf. Mighall et al., 2009).

Geochemistry

Five principal components (Cp1-5) were deemed to be of importance (Figure 4a). Cp1 is characterised by high positive loadings of Si, Al, K, Ti and Cr and negative loadings of Ca, Mn and Sr. These appear to reflect changes in siliceous (positive loadings) versus carbonate-dominated (negative loadings) sediments. The carbonates are most probably of biogenic origin, so they may be related to lake bioproductivity (as a proportion of the sediment core contained molluscs) or the local geology. There are several fluctuations between these sediment types (revealed in the Cp1 scores) throughout the LoT record (Figure 4bi). These changes may reflect the contribution of sediments derived from different local lithologies. The geology of Westray comprises sandstones, locally named as 'Rousay Flags', which form part of a series of sedimentary rocks of the Middle Old Red Sandstone, which produce fertile soils. The grey coloured Flags suggest that their carbonate content is mainly calcite and some are rich enough in lime to be considered impure limestones. A moderately fine textured till containing shell fragments overlies extensive parts of Westray (Dry, 2016).

Cp2 is characterised by high positive loadings of S, Fe, Zn and Br (Figure 4a). These are a group of biophylic and organically-bound elements/metals. They appear to be responding to changes in organic matter content, which is reinforced by the correlation between LOI and the Cp2 scores (Figure 3 and Figure 4bii). Cp2 scores are generally positive between 900 cal BC and 405 cal BC and negative thereafter until a switch back to positive values at c. cal AD 1750.

Cp3 is characterised by high loadings (Zr, Nb, Y, Rb) or moderate loadings (Ti, Fe and Th) of elements that are preferentially enriched in fine particles (Figure 4a). This component seems to reflect grain size changes in the sediments (cf. Taboada et al., 2006). Three major phases are shown in Figure 4biii: (1) a shift from negative to positive values from 915 cal BC to 620 BC; (2) values fluctuating between slightly negative to (mainly) positive values until AD 1425; (3) values becoming increasingly negative thereafter.

Cp4 is dominated by Pb, but shows some variance of Cr, Zn, As, Br and P, and represents a metal pollution signal (Figure 4a). Figure 4biv shows a gradual increase in values throughout the record, with a big shift from cal AD 1500 marking the recent rise in industrial pollution. Cp5 is dominated by Ni, but also reflects a significant part of the variance of Cu (Figure 4a). This is another metal pollution signal. Positive values dominate the profile between 780 and 390 cal BC, and from AD 900 to AD 1400 (Figure 4bv).

Microfossils

The pollen and NPP data are shown in Figures 5 and 6. Plant nomenclature follows Stace (2010). Summary curves for trees, shrubs (constituting arboreal pollen, AP), dwarf shrubs and herbs (non-arboreal pollen, NAP) are shown. NPP terminology follows the type system devised by van Geel (1978) and uses the laboratory code as a prefix (HdV), followed by the type number (cf. Feeser and O'Connell, 2009; Miola, 2012). The pollen data are expressed as percentages of total land pollen (TLP). NPPs are expressed as percentages of total land pollen plus NPPs. The pollen diagram was constructed using the Tilia and Tilia.graph version 1.7.16 software package (Grimm, 2011) with CONISS (Constrained Incremental Sum of Squares) used to assist diagram zonation.

The interpretation of any palynomorph assemblage derived from lake sediment can be affected by several processes which can influence the fidelity of the microfossil record (Wilmshurst and McGlone, 2005a, b). These include, for example, changes in the sources of sediment entering a lake (Pittam et al., 2006). At present, the Loch of Tuquoy has no visible inlet or outlet, although Owen (1993) speculates that a stream may once have run from the loch to the coast. Given there is no clear evidence of this stream, we assume that the majority of the palynomorphs/sediment deposited in the loch were either derived directly through atmospheric deposition or via overland flow from the catchment. Catchment connectivity can also change through time as a result of human activity and this can lead to a non-linear response in sediment (and presumably pollen) delivery from source areas to a water body (Turnbull et al., 2008). There are no sharp changes in the microfossil record corresponding with changes in the stratigraphy that might suggest these issues have compromised the pollen assemblages. Whilst palynomorphs do show signs of deterioration, identifiable pollen counts of 500 TLP were achieved throughout the sequence (Delcourt and Delcourt 1980; Jones *et al.* 2007). Pollen grain damage (breakage, folding, and/or corrosion) was possibly due to soil maturation and peat development around the loch margins (e.g. Tipping, 1987), with crumpling and degradation most likely caused during transportation by water. Some of the corroded, crumpled and broken grains will reflect in-wash and possible reworking of the palynomorphs contained within eroded material (cf. Tipping, 1987; Wilmhurst & McGlone, 2005a). Degraded grains are commonly crushed or crumpled which also indicates that they are likely to have been transported and then redeposited (Cushing, 1967; Lowe and Walker, 1997). The proportion of unidentifiable grains is below thresholds beyond which it has been suggested that data may become biased or unrepresentative (Bunting et al., 2001; Tipping et al., 1994), and therefore we suggest that the Loch of Tuquoy microfossil record is a reliable proxy for vegetation change at the site.

Zone LoT1 – 915-675 BC, Late Bronze Age to Early Iron Age

The zone is dominated by Poaceae (grasses) and Cyperaceae (sedges) (Figure 5). Several of the herbaceous taxa are indicative of pasture, such as Ranunculaceae (buttercup family), Lactuceae (dandelion family), *Plantago lanceolata* (ribwort plantain), *Rumex acetosa*/*acetosella* (common sorrel/sheep's sorrel), *Aster*-type (daisies), *Potentilla*-type (tormentils/cinquefoils) and *Trifolium*-type (clover). Rough, wet pasture and/or fen are inferred from the presence of Apiaceae (carrot family), Caryophyllaceae (pinks), Cyperaceae, *Filipendula* (meadowsweet), Rubiaceae (bedstraws) and

Equisetum (horsetail) (Brown et al. 2007; Stace 2010). NPPs associated with animal dung are recorded, most notably HdV-112 (*Cercophora*), HdV-113 (*Sporormiella*) and HdV-55A/B (*Sordaria* sp.; which can also grow on dead wood; van Geel, 1979), suggesting that herbivores grazed nearby (Mighall *et al.* 2008) (Figure 6). Arable cultivation appears to have been practiced with *Hordeum*-type (barley) pollen consistently present throughout the zone from c. 750 BC. A rare occurrence of *Avena/Triticum*-type (oat/wheat) pollen is also noted. The presence of *Glomus* cf. *fasciculatum* chlamydospores (HdV-207) suggests that arable and pastoral agriculture may have been responsible for soil erosion as this microfossil is considered to be a marker for erosion in fluvial/lacustrine contexts (van Geel et al., 1983, 2003).

Deciduous woodland or scrub probably formed a minor constituent of the vegetation community as *Betula* (birch) and *Corylus* (hazel) are relatively well represented. Pteropsida monolete undiff. (ferns) were likely to have been components of the understorey. Whether *Quercus* (oak) and *Ulmus* (elm) were locally present as part of these woodlands is more difficult to determine. It has been suggested by some that oak grew locally on Orkney (Bartlett, 1983; Bunting, 1994; De la Vega-Leinart et al., 2007), but Farrell (2015) has argued that *Quercus* was probably not present at Hobbister even though the percentages of oak pollen recorded at that location are similar to those found at Tuquoy. Woodland cover appears to have decreased slightly mid-zone (c. 750 BC) before recovering between 700-650 BC, to fall once more towards the end of the zone. Fire may have played a role in suppressing tree growth as sustained high values of microscopic charcoal occur when arboreal pollen percentages are low. The observed patterns may also partly reflect changes in microfossil source areas. For example, a larger charcoal source area might result from a reduction or thinning of any woodland canopy fringing the loch, which would otherwise act as a filter to pollen transport and/or dominate the palynological signal from the surrounding landscape. As dryland tree percentages fall, *Alnus* (alder) increases in representation along with *Salix* (willow). Both these taxa are typical of wet woodlands, which was possibly growing around the fringes of the loch. Heathland supporting *Calluna* (heather), *Empetrum* (crowberry) and *Juniperus* (juniper), was also present in the landscape.

There was enough open water in the loch to support submerged and/or floating aquatics such as *Potamogeton*/*Callitriche* (pondweed/starworts) and *Myriophyllum alterniflorum* (alternate-leaved milfoil), and *M. spicatum* (spiked milfoil) and/or *M. verticillatum* (whorl-leaf watermilfoil), which increase in the second half of the zone. Frequencies of *Gloeotrichia*-type (HdV-146) rise steadily through this zone. This is an aquatic pioneer indicative of nutrient poor conditions, which has the ability to fix nitrogen (van Geel, 2001). Initially, high values of HdV-900 (*Pediastrum* – a genus of green algae) decrease sharply and then remain at a consistent value through the rest of the zone. Other wet indicators present in the NPP assemblage include *Alona rustica* (HdV-72A), *Valsaria variospora* (HdV-140) and HdV-731.

Zone LoT2 – 675-240 BC, Early to Middle Iron Age

An increase in the extent of rough, wet pasture and/or marsh/fen is suggested as Cyperaceae percentages rise dramatically and are combined with the continued presence of *Filipendula*, *Succisa pratensis* (Devil's-bit scabious), Apiaceae, Caryophyllaceae, Rubiaceae, *Selaginella* (spikemoss), *Botrychium lunaria* (moonwort) and *Sphagnum*. *Gaeumannomyces* (HdV-126) also increases. This fungus is associated with *Carex* (Pals et al., 1980). Evidence for arable and pastoral activities in the pollen record includes significant amounts of pollen of Poaceae, *Plantago lanceolata*, Lactuceae, Ranunculaceae, *Aster*-type, *Trifolium* and Brassicaceae (Mustard family), and trace amounts of *Anthemis*-type (chamomile), *Centaurea*-type (cornflowers), *Lotus*-type (trefoils), *Polygonum aviculare*-type (knotgrasses), *Hordeum*-type and miscellaneous cereal-type pollen. Coprophilous fungi (*Sporormiella*-type, *Podospora*-type, and possibly *Sordaria*-type, *Rivularia*-type (HdV-170) and *Coniochaeta* cf. *ligniaria* (HdV-172)), indicative of herbivores, are also well represented. Disturbed ground is indicated by low amounts of Chenopodiaceae (goosefoots), *Artemisia*-type (mugworts) and *Urtica*-type (nettles). *Plantago coronopus* (buck's-horn plantain) seems likely to have been growing on sand/gravel or cracks in rocks close to the sea (Stace, 2010).

Deciduous woodland cover remained fairly stable through this period, with consistent arboreal pollen percentages registered during this zone. Isolated records of *Tilia* (lime) and *Pinus* pollen are most likely to have been derived through long distance transport, whereas *Fraxinus* (ash), *Sorbus*-type (rowan) and Pteropsida monolete undiff. might have been under-represented constituents of local deciduous woodland. Some heathland or moorland cover existed as *Calluna* percentages are relatively stable, culminating in a small peak at the top of the zone. Fire may have influenced both environments. Three peaks in wood micro-charcoal are recorded (Figure 6) and microscopic charcoal values (both the <21 µm and 21-50 µm fractions) fluctuate through this zone, whilst there is a decline in fragments in the >50 µm size category (Figure 5) relative to the previous zone, possibly implying more frequent fires at a regional scale. However, small peaks are also present in identifiable microscopic wood charcoal and these suggest fires also occurred in more local settings.

Internal changes to habitats within the loch also occurred at this time. There is a sharp decline in *Myriophyllum spicatum/verticillatum* in this zone, accompanied by a more gradual decline in *M.*

alterniflorum, and a very slight increase in *Callitriche/Potamogeton* (pondweed) and a peak in *Pediastrum*. Species of *Pediastrum* are known to respond to a wide range of environmental factors, including catchment erosion, turbidity, water chemistry, nutrient status and pH (van Geel, 2001) and could have been driving competition between the loch constituents. *Gloeotrichia*-type remains high throughout the zone, with a notable, short-lived mid-zone decline corresponding with small peaks in HdV-901 (*Botryococcus*, a colonial green algae) and *Aphanizomenon* (HdV-600, a cyanobacteria). Other NPP 'wet' indicators are also present in this zone (Figure 6) including *Closterium idiosporum* (HdV-60), which is representative of open water (van Geel, 1978), and *Valsaria variospora*-type, which is often found in wet, eutrophic settings (van Geel et al., 2003). The occurrence of an intestinal parasite egg of *Trichuris*-type (whipworm) in this zone (Figure 6) indicates the potential pollution of the loch waters with faecal material. Measurement of the egg (42 µm x 25 µm) suggests it is likely to represent *T. trichiura* (which has a human host) or *T. suis* (pig host) (Dark 2004).

Zone LoT3 – 240 BC – AD 1020, Middle Iron Age to Medieval

Subzone LoT3a: 240 BC - AD 90

This period witnessed an initial increase in woodland with *Quercus*, *Betula* and *Salix* percentages all rising. This was short-lived as tree and shrub pollen gradually decreases towards the subzone (3a/b) boundary. A reduction in burning may well have facilitated the recovery of woodland as levels of microscopic charcoal in this zone are initially low but increase rapidly as tree pollen declines towards the end of the subzone, where grass microcharcoal is also recorded (Figure 6). Areas of heath or moorland persisted as *Calluna* percentages are constantly recorded and follow a similar pattern to arboreal pollen percentages. These changes in woodland and heathland coincided with a lower intensity of cultivation as only trace amounts of *Hordeum*-type are intermittently recorded (Figure 5). Pastoral activity continued, implied by the near-continuous presence of the coprophilous fungi *Chaetomium* sp. (HdV-7A), *Sporormiella*-type and *Sordaria*-type, and pollen records for a range of herbs commonly found in grazed fields, such as Poaceae, *Plantago lanceolata*, Caryophyllaceae, Lactuceae, *Rumex acetosa/acetosella*, *Plantago media/major* (hoary/broadleaf plantain), *Aster*-type and *Potentilla*-type. Disturbance indicators (e.g. *Artemisia*-type, Chenopodiaceae, Apiaceae and Brassicaceae) are also present but in lower values (Brown et al., 2007). If erosion of catchment soils took place, it was probably of lower intensity than previously as *Glomus* cf. *fasciculatum* chlamydospores do not feature much in this subzone (Figure 6).

Areas of marsh or fen persisted in the catchment, albeit it with lower Cyperaceae percentages midzone. *Filipendula* – a common component of fen communities – peaks at around 15% TLP. Within the loch, *Gloeotrichia*-type values declined, whilst *Pediastrum* (Figure 6) was relatively abundant. Aquatics (*Myriophyllum alterniflorum* and *M. spicatum/verticillatum*) are recorded in low percentages whilst *Callitriche/Potamogeton* increased at the top of the subzone (Figure 5).

Subzone LoT3b: AD 90-540

Initially, this zone witnessed a recovery in the extent of deciduous woodland, with increased frequencies of *Quercus*, *Betula* and *Ulmus* recorded. *Corylus* pollen falls to much lower percentages than previously, suggesting the abundance of this shrub declined. It then recorded a sharp decline c. AD 25 before partly increasing again by AD 100. From c. AD 100 to AD 250 the amount of woodland appears to have remained fairly stable before gradually contracting at the end of the subzone, c. AD 540.

Evidence for cultivation at the start of LoT3b is muted and of low intensity, with trace amounts of *Hordeum*-type only recorded in the latter part of the subzone. In contrast, evidence for grazing/pasture is more forthcoming, especially between c. AD 90-250. Coprophilous fungi are limited to very low amounts of *Sporormiella*-type and *Cercophora*-type, while *Sordaria*-type is more abundant, but subsequently all three fade in numbers. Poaceae and *Plantago lanceolata* percentages are relatively high and stable. *Potentilla*-type, and other herbaceous pollen types indicative of pasture and disturbance (e.g. *Artemisia*-type, *Cirsium*-type, Brassicaceae) are still recorded, albeit less frequently and/or in trace amounts (Figure 5).

Increased pollen from *Calluna* and Ericaceae suggest that heath or moorland expanded. Marsh or fen communities, which probably surrounded the loch, are well represented by Cyperaceae and *Filipendula*, along with Rubiaceae and *Succisa pratensis*. Small peaks in *Menyanthes trifoliata* (bog bean; considered to be an 'indicator' species for fen [Shotyk, 1988]) and *Typha latifolia* (bulrush), also occur.

Subzone LoT3c: AD 540-1020

Mixed woodland cover diminished in this subzone as *Alnus*, *Betula*, *Quercus*, *Pinus* and *Corylus* percentages all decrease at the 3b/c zone boundary. Fire was possibly one cause of the reduction in woodland cover as falls in AP coincide with peaks in microscopic charcoal, with trees likely to have been felled to provide fuel and construction materials, etc. Locally, the severity of fires may well have been reduced as fewer large fragments (≥ 50 µm) of microscopic charcoal were deposited. Based on arboreal pollen percentages, woodland failed to recover back to its previous level, probably suppressed by renewed arable activity as *Hordeum*-type and, to a lesser extent *Avena*/*Triticum*-type and undifferentiated cereal-type pollen, are recorded more regularly. Pasture/disturbance indicators are also well represented and the presence of a suite of coprophilous fungi, including *Podospora*-type/*Zopfiella* (HdV-466), suggest grazing and arable cultivation were practised in the catchment from c. AD 540 through to the tenth century AD, the latter being broadly the point at which the Norse farm at Tuquoy was established.

Zone LoT4 – AD 1020-1325, Medieval

Palynological assemblages recorded during this LPAZ are broadly contemporary with the period that

The pollen record in LoT4 suggests that more intense arable and pastoral activity, especially barley cultivation, commenced during this time: undifferentiated cereal-type and *Hordeum*-type pollen are recorded. High Poaceae percentages and the presence of herbaceous pollen types indicative of pasture and disturbance increase and/or are recorded more regularly (e.g. Brassicaceae, Lactuceae, Ranunculaceae, *Artemisia*-type, *Aster*-type, *Plantago lanceolata*, *Plantago media/major*, *Rumex acetosa/acetosella*) (Edwards et al., 2013). This is especially the case from c. AD 1150-1250, encompassing the known period of occupation of the hall at Tuquoy. Coprophilous fungi indicative of grazing animals (*Sporormiella*-type, *Podospora*-type, *Tripterospora*-type, *Cercophora*-type and *Sordaria*-type) increase from c. AD 1000 and are more abundant from cal AD 1250 forwards, and this suggests that mixed land-use remained in place until c. AD 1450 (Figure 6). Indeed, the continuous curve for *Hordeum*-type pollen throughout the zone and a near-continuous curve for *Avena/Triticum*-type from c. AD 1100-1400, suggest that increased cultivation of oats and/or wheat occurred alongside barley during the Norse period.

Glomus cf. *fasciculatum* chlamydospores continue to be recorded and may be associated with the inwash of eroded soils into the loch as a result of increased disturbance in the catchment. Heath and/or moorland, and marsh and/or fen, continued to be parts of the vegetation communities of Westray at this time. Changes in the loch ecosystem also took place. Frequencies of green algae (*Pediastrum*) fell, replaced at first by *Botryococcus* – which is commonly found in fens, temporary pools, ponds and lakes (van Geel, 2001) – and then *Gloeotrichia*-type and (subsequently) *Myriophyllum alterniflorum* and *M. spicatum*. An increase is also observed in the presence of HdV-72A (aquatic insect jaws), suggestive of open water conditions, while small peaks in HdV-128 are suggestive of eu- to mesotrophic water (Pals et al., 1980).

Zone LoT5 – AD 1325 to present, Medieval to Modern

Subzone LoT5a: AD 1325-1550, Norse to Post-medieval

Following the abandonment of the farm c. AD 1350, the palynological data suggests that some disturbance continued in the catchment for a time. After an initial short-lived increase, total arboreal pollen declines (an event dated c. AD 1400), with decreases in *Betula*, *Alnus* and *Quercus* particularly evident, and these frequencies then remaining at a lower level. Poaceae increases in this subzone, along with *Plantago lanceolata*, *Plantago media/major*, *Aster*-type, *Rumex acetosa/acetosella* and Lactuceae pollen. In contrast, many of the anthropogenic indicators decrease in value. These include the suite of coprophilous fungi (*Cercophora*-type, *Sporormiella*-type and *Sordaria*-type), and *Potentilla*-type, Chenopodiaceae and Brassicaceae. Cereal-type and *Hordeum*-type pollen percentages also fall during this subzone with *Avena/Triticum*-type occurring only rarely. This period, therefore, appears to have witnessed a downturn in arable and pastoral activity as by the end of the sub-zone nearly all of the aforementioned NAP taxa are much reduced in value. A reduction in *Glomus* cf. *fasciculatum* chlamydospores indicates any remaining disturbance did not produce much soil erosion.

Microscopic charcoal values in the categories <21 µm and 21-50 µm fluctuate through this zone with peaks and troughs evident, suggesting periodic burning. The >50 µm fraction is significantly reduced relative to the previous zone suggesting that there were not many fires occurring locally. Fire could have facilitated the increase in heather moorland across the wider landscape. By the end of the known period of Norse occupation of Tuquoy, a clear reduction in *Gloeotrichia*-type spores are recorded. This is an aquatic pioneer indicative of nutrient poor conditions. The limited presence and decline of other NPP and aquatic pollen types implies that the water in the loch was very shallow. Other features of this subzone include high but fluctuating *Pediastrum* values, reductions in *Botryococcus*, *Myriophyllum alterniflorum* and *Menyanthes trifoliata*, and a small peak in HdV-174, which is indicative of shallow, stagnant open water and eutrophic conditions (van Geel et al., 1983). *Aphanizomenon* cf. *gracile* is recorded and this microfossil has also been associated with eutrophic water (van Geel, 2001).

Subzone LoT5b: AD 1550-1850, Medieval to Modern

Rough/wet grassland and pasture form one of the dominant land uses around Loch of Tuquoy in the recent past. A peak in Poaceae pollen percentages is recorded and dated c. AD 1750, and Cyperaceae pollen is abundant. A slight recovery in woodland seems to have occurred at c. AD 1650, as suggested by an increase in *Pinus* and *Quercus* pollen, concomitant with a reduction in heathland as recorded by the sharp decline in *Calluna* pollen. Microscopic charcoal values are much lower compared with LoT5a, suggestive of fewer fires, although a small peak in values across all fractions at c. AD 1750 corresponds with the last recorded decline in arboreal pollen, which may suggest clearance through burning.

Grazing was slightly revitalised during LoT5b as indicated by an increase in coprophilous fungi including *Cercophora*-type, *Sporormiella*-type, *Sordaria*-type and *Tripterospora*-type. *Plantago lanceolata*, Brassicaceae, *Cirsium*-type (thistles), Lactuceae and Ranunculaceae are common plants of pastures (Brown et al., 2007), and all are present in this subzone. Limited cultivation appears to have occurred as there are sporadic records of *Hordeum*-type and a small peak in cereal-type pollen dated c. AD 1650. *Gloeotrichia*-type persists indicating any standing water was eutrophic, but aquatic taxa are much reduced in this subzone, probably as a consequence of the reduction in the area of open water as the loch entered its final stages of terrestrialisation (indicated, lithologically, by the transition from marl/gyttja to a peaty soil).

Discussion

Human impact on Orkney during the Atlantic Iron Age

In common with other pollen diagrams from Orkney and Shetland, the landscape of Tuquoy was

Numerous prehistoric sites lie in close proximity to the Loch at Tuquoy that confirm an Early Iron Age human presence in this area. Arable and pastoral agriculture took place during the Atlantic Iron Age in the Northern Isles although the balance between the two modes of farming has been questioned (Bond, 2002). Based upon pollen assemblages from Underhoull, Shetland, Edwards et al. (2013) suggested that pastoral agriculture was mostly favoured at that location. However, unless cereal-type pollen is found, palynological evidence for arable agriculture can be difficult to separate from signatures derived from coastal plant communities as both share similar suites of taxa (e.g. *Artemisia*-type, *Rumex* sp. and Asteraceae). At Underhoull, only three samples contained traces of cereal pollen suggesting that arable cultivation was practised, but possibly at low intensity. However, the cereal-type record in this instance many not necessarily be indicative of the situation at a wider spatial (e.g. island) scale. It may be a taphonomic effect (Hall, 1989) rather than a true record of the level of activity as cereal pollen is not dispersed far from its source plant. The palaeoenvironmental record at Tuquoy suggests that a previously unrecognised period of arable activity also occurred during the Early Iron

Age, from c. 800-100 BC, featuring primarily the cultivation of barley. This is generally considered to have been the dominant cereal crop in the northern latitudes of Scotland at this time (Armit and Ralston, 1997). *Hordeum*-type pollen was encountered more frequently and at higher percentages between c. 800 BC and 500 BC, suggesting that arable activity was possibly most intense at Tuquoy at that time. *Avena*/*Triticum*-type pollen is also present at trace values and is suggestive of some cultivation of wheat and /or oats. This interpretation is strengthened as significant changepoints occur that are dated c. 815 and 535 BC (Figure 7A). Given the Early Iron Age date for the cultivation, it is more likely that this represents evidence for wheat cultivation based on the reasoning outlined above by Armit & Ralston (1997), although the occurrence of large grass grains (Poaceae >35 µm; Figure 5) could conceivably be wild oat (*Avena fatua*), a common arable weed (Stace, 2010). Utilising rapid scanning techniques to optimise cereal pollen detection may perhaps reveal further insights into the extent and duration of cereal cultivation at the site (Edwards et al., 2005).

Cultivation of cereals was clearly part of a mixed agrarian economy at Tuquoy. Pastoral farming also seems to have occurred alongside cultivation until at least c. AD 100, after which date cereal pollen is less common in the pollen record. Evidence for grazing herbivores is provided by the presence of the coprophilous fungi *Cercophora*-type and *Sporormiella*-type, together with spores of *Sordaria*-type (HdV-55A/B) – which are commonly recorded in the heavily-grazed landscapes of the North Atlantic islands (e.g. Schofield & Edwards, 2011) – and (notwithstanding the caveats outlined above) the occurrence of NAP types with pastoral affinities (e.g. Lactuceae, Brassicaceae, *Rumex acetosa* and *Potentilla*-type). This may signal that there was a switch in economy to one that was more livestock intensive during the Middle Iron Age.

Early human activity at Tuquoy appears to have driven a shift in sediment source within the loch from more siliceous material (i.e. sediment with more positive values in Cp1) to more calcareous (more negative values) which lasted until 250 BC. An increase in the S-ratio to higher, positive values which continued until c. 515 BC, also records this shift, and these changes are also reflected in the early dominance of Si and Ti, which are later replaced by Ca, especially between 900 and 200 BC (Figure 7). Alternatively, a proportion of the calcium content could represent fragments of shells from molluscs, which are visible in the sediment. A long-term change in Cp3, which implies a coarsening of particles entering the loch (and is signified by the high positive loading of Zr), is coincident with the change in sediment source. This shift was quite rapid between 900 and 600 cal BC and it lasted until c. AD 1300. During this time Cp1 was again dominated by more calcareous material, and along with changes in all the other Cp's, this is coincident with the start of decreased representation of arable and pastoral pollen and coprophilous fungi. It is plausible that changes that took place in the catchment influenced the loch water quality as evidenced by an increase in *Gloeotrichia* (the changepoint at 535 BC coincides with its highest abundance) and the decline in *M. alterniflorum*, which is mostly present in base-poor lakes, in favour of *M. spicatum/verticillatum* common in base-rich water bodies (Clapham et al., 1987; Stace, 2010).

There appears to have been a lull in cultivation during the Late Iron Age into the Medieval period, between c. 400 BC and AD 550, which coincides with a slight recovery in deciduous woodland/scrub, especially *Betula* and *Corylus*, suggesting that some land may have been abandoned (as reflected by microfossil assemblages in the lower half of subzone 3b). The changepoint at 110 BC (Figure 7A) coincides with the first peak in *Betula* in the pollen record and the highest frequency registered for this taxon since the loch sediment started to accumulate. Some human presence throughout this period is still suggested by the occasional appearance of cereal pollen, and indicators for grazing (*Sporormiella*-type, and *Sordaria*-type) and disturbance (e.g. *Plantago lanceolata*, Lactuceae, *Rumex acetosa/acetosella*). Reduced levels of human disturbance and renewed tree/shrub growth coincided with a reversal in the trends of Cp1 and, to a lesser extent, Cp2, which shift around 250 BC (Figure 7). The changepoint at c. AD 215 also marks a rise in tree pollen and lower frequencies of *Gloeotrichia*-type. The S-ratio also shifts towards anti-ferromagnetic minerals and probably represents a change in the sources of sediment entering the loch. This downturn in human activity might have been caused by economic stress through a deterioration in soil quality, comparable with that recorded at Lairg in Sutherland (McCullagh, 1992), although any evidence for such in the palaeoenvironmental record from Tuquoy is equivocal. Notwithstanding regional variations in climate, a wet shift has been reconstructed from bogs across Scotland as having occurred between 600-200 cal BC, followed by a drier phase between 400 BC - AD 200 (Langdon and Barber, 2005), which may have been more beneficial for agriculture.

Into the Medieval period

The lower intensity in human activity suggested in the Tuquoy pollen record between the Late Iron Age and into the early Medieval period, c. 200 BC to AD 550, is perhaps more compatible with the idea of land use continuity (cf. Sharples & Parker-Pearson, 1999) for the Outer Hebrides rather than the suggestion of a hiatus between Norse settlements and their pre-Viking precursors (cf. Barrett, 2008; 2012). Evidence for human activity is more prominent once again after c. AD 550 with a strong agricultural signal recorded in the herbaceous pollen, and especially the NPPs, immediately before and during the Norse period (the latter stages of zones 3b and LoT4). This is marked by another changepoint at c. AD 620 and coincides with a shift in the S-ratio and Cp1 indicating a change in the sediment source (Figure 7A, C) and a decline in tree pollen and a higher representation of cereal-type pollen (Figure 7B). In common with Tuquoy, pollen evidence from other sites across the Northern Isles including Belmont on Unst, Loch of Clickimin on Mainland (Shetland), and Westness on Rousay (Orkney), shows increased human activity from c. AD 800 suggesting Norse impacts on landscape and vegetation were widely felt across the Northern Isles (Edwards et al., 2013; Edwards et al., 2016). Similarities exist across these sites including pre-existing low amounts of oak-birch-hazel woodland, a landscape dominated by grasses and sedges, and an increase in agricultural weeds, both arable and pastoral. Notwithstanding the gradual general cooling trend that has occurred since c. 1500 BC, temperatures during the Roman period in Britain were warm, whereas the extent of warmth during medieval times showed considerable variation (e.g. Kerr et al., 2009; Esper et al., 2012) but was still conducive to agricultural activity. An upturn occurred at Tuquoy c. AD 500 coincident with a period of warmer temperatures (Esper et al., 2012; Marcott et al., 2013). Trends in temperature reconstructions by Esper et al. (2012) show a warming trend until around AD 900, after which temperatures began to gradually fall (cf. Marcott et al., 2013; Figure 7). This downturn in temperatures does not appear to have had a detrimental impact on cultivation at Tuquoy until c. AD 1250. There were also important political events occurring around this time which could have impacted on agricultural activity. Norse influence in Scotland was fading and around this time (AD 1266), for example, Norway ceded Man and the Hebrides to Scotland, although the Northern Isles remained under Scandinavian control until the mid-15th century AD (Hayward, 1995).

The earliest Norse archaeological structure at Tuquoy appears to be a byre, which is dated to the 11^{th} to 12^{th} century AD. Its infill was rich in organic remains, including waterlogged and charred plant remains, charcoal, worked wood, insects and pollen (Owen, 1993). Analysis of materials showed the worked wood to be a mixture of resources that could probably have been gathered locally (e.g. willow and birch), together with imported materials such as pine, larch and spruce, with some fragments also containing runic inscriptions (Crone nd.). Charcoal evidence also suggests use of local copses of alder, willow, oak, hazel and ash woodland for fuel resources, together with the cutting or gathering of heathland/turf in which heather was abundant (Nye and Boardman, 2012). While the likely presence of some woodland is evident in the pollen diagram from Tuquoy, percentages generally fall throughout the Norse period with only very small, short-lived recoveries recorded. All of the woody taxa found as charcoal in the infill are recorded in the pollen diagram. The small dips in the total amount of tree and shrub pollen during the occupation of the farmstead suggest that whatever trees were locally present, they were likely to have been exploited, even ash and willow. *Salix* is only present in trace amounts and is most likely to be under-represented in the pollen diagram given that plants of this genus are insect-pollinated. *Fraxinus* is anomalous as no ash pollen was recorded during the known tenure of the farmstead and thus appears to be under-represented when compared to the wood assemblage (cf. Mighall *et al*., 2018). The presence of pine in the charcoal assemblages may indicate imported wood or the use of driftwood (Nye and Boardman, 2012), while pine off-cuts in the waterlogged wood assemblage imply import of timbers (Owen, 1993). The Loch of Tuquoy pollen record supports the suggestion that pine was unlikely to have been sourced locally. Only irregular, trace amounts of *Pinus* pollen were recorded throughout the 11th and 12th centuries AD. Bennett (1984) initially suggested that pine percentages must exceed 20% of total tree and shrub pollen to infer a local presence for the tree, before refining this threshold to 5% total pollen (Bennett, 1995). Lageard et al. (1999) suggest that even lower frequencies of *Pinus* pollen (3% TLP) may indicate that the tree was growing locally around the sampling location. *Pinus* pollen does not reach any of these suggested target values for local presence in zone LoT4.

High frequencies of oats/wheat and barley pollen indicative of an agricultural landscape are commonly found on similar sites to Tuquoy, including Buckquoy on Orkney (Driscoll, 2002), and are dominant in early Medieval cereal assemblages from further afield, e.g. Ireland (McCormick, 2014; McClatchie et al., 2015). Finds of charred cereal grains of six-row hulled barley and oats found in the byre compliment the Loch of Tuquoy pollen record (zone LoT4) and suggest these were the two main cultivars, with flax seeds also recovered. Cultivation of oats began prior to the activity at the Tuquoy Norse farmstead c. cal AD 1100. The dominance of barley and oats is probably unsurprising given their tolerance of both rich and poor-quality soils and the fact that each are suited to wet climatic conditions (McCormick, 2014). Coprophilous fungal spores also suggest the presence of grazing animals around the loch during the period of farmstead activity with increased values of *Sordaria*-type and *Sporormiella*-type, and trace amounts of *Cercophora*-type, recorded between approximately AD 1200 and 1550. This is compatible with assemblages of animal bones found on similar farms such as Buckquoy (Ritchie, 1976). There was a slight downturn in cultivation and reduced presence of coprophilous fungi c. AD 1250, coincident with a drop in temperatures (Esper et al., 2012), before spores regained their former values by AD 1350 during a period of increasing temperatures.

Localised erosion associated with Norse activity is also evident in palaeoenvironmental records at Tuquoy (as it is at Belmont on Unst) but the timing is variable and most likely reflects differences in the dates of occupation of the sites. From c. AD 1000 up until around AD 1220 land surfaces became destabilised, resulting in erosion at Belmont (Edwards et al., 2013). Changes in the S-ratio and geochemistry suggest a change in sediment sources feeding into the loch at Tuquoy. This is marked by some less significant changepoints between cal AD 1000 and 1130. According to the S-ratio, a change commenced around c. cal AD 500 (uncorrelated, low S-ratio [0.5-0.7] with positive Cp1 scores) and was particularly strongly registered by cal AD 1120 to 1245 (Figure 7). This very noticeable decline in the S-ratio, probably signifies a shift in sediment source, from soft remanence carrying minerals to hard remanence-carrying minerals, and coincides with an increase in cereal cultivation and ruderal/pastoral pollen indicators (from the start of Zone LoT4) between c. AD 500–1000 (Figure 5). A detectable shift was also identified at c. cal AD 1000 to AD 1200 (uncorrelated, very low S-ratio (>0.4) and positive Cp1 scores; Figure 7). High Si and Ti concentrations throughout the medieval also reflect increased erosion. Whereas the disturbance faded from c. AD 1220 and was not renewed until AD 1680 at Belmont, arable and pastoral activity continued seemingly relatively continuously at Tuquoy from c. cal AD 550 to until at least AD 1600 despite a decline in Si and Ti and increase in Ca concentrations.

A changepoint occurs at c. AD 1320. Pollen evidence suggests that agricultural activity diminished

Modern

Pastoral and disturbance indicators decline further in the post-medieval period, c. AD 1500, as *Calluna* (in zone LoT5a), then Poaceae and Cyperaceae percentages increase (in subzone LoT5b), suggesting there was an expansion of wet grassland and heathland. This is coincident with another changepoint (Figure 7A). Apart from a small spike in *Pinus*, arboreal pollen percentages remain low and woodland does not appear to have regenerated. Similar to the earlier reduction in the intensity of human activity (recorded between cal AD 100 and 550), this more recent cessation of agricultural activities coincides with lower rates of soil erosion signalled by a trend towards negative values in Cp1 and positive values in Cp2 (Figure 4), a pattern that is shown quite clearly in Figure 7C. Finer-grained material entered the loch, as attested to by the shift of Cp3 scores towards negative values. The S-ratio at this time is greater than 0.6, indicating increased presence of ferromagnetic minerals and SIRM(minero) increased. Xlf(minero) also increased from c. AD 1630 onwards. This is indicative of an atmospheric pollution signal and is reflected by changepoints between c. cal AD 1695 and 1735 (Figure 3). These trends in land use may have been exacerbated by a deteriorating climate from AD 1550 forwards (Lamb, 1964) – the conventional date for the onset of the 'Little Ice Age' (Matthews and Briffa, 2005). This was characterised by an extended period of cold, particularly between the late sixteenth and early eighteenth centuries according to dendroclimatological evidence from the Cairngorms (Rvydal et al., 2017). The seventeenth century was marked by three of the coldest decades of the LIA, and the occurrence of famine (Dawson, 2009).

Evidence for metal pollution and metalworking

Cp4 seems to primarily represent a signature for lead pollution (Figure 4), and values gradually

The Pb/Ti ratio helps to separate the anthropogenic lead fraction from the geogenic fraction (the latter being the Pb contained within the local bedrock; Boës et al. 2011). This ratio also peaks during the Iron Age, c. 340 BC (not clearly seen in Cp4 but more evident in the Pb record), pointing towards an anthropogenic source. Only very minor peaks are seen between the Late Iron Age until the post-medieval period, beyond which Pb pollution increases through the Early Modern Period and into the time of the Industrial Revolution. These latter peaks probably represent long-distance lead pollution, but the peak at c. AD 1190 might be a local source linked to the farmstead at Tuquoy. Comparing Cp4 against SIRM further supports this idea as the two parameters behave roughly inversely until c. AD 1055 when their trends become similar (Figure 7f). This suggests that lead was probably derived from different sources. The near-surface peaks coincide with the most recent changepoints in the last few centuries.

Amongst the archaeological features discovered at Tuquoy is a possible smithy (Owen, 1993). Ironworking is widely known to have been practiced on Orkney, with rich deposits of iron ore present on Hoy (Dickson, 2000), and evidence for ironworking appearing at other sites (e.g. Howe) from mid to late Iron Age contexts, although the scale of iron production has yet to be fully established (McDonnell, 1994). Evidence for ironworking in the sediments from Loch of Tuquoy is not clear. There are several iron (Fe) peaks in the record including one that coincides (in part) with the occupation of the Norse farm (AD 1290 to 1330), but Fe is ubiquitous in the environment and sensitive to many environmental factors (Davison, 1993), so to ascribe this peak to ironworking is clearly problematic when the data are examined in a wider temporal context. Mighall et al. (2009) demonstrated it is possible to identify ironworking in bogs using mineral magnetism. Peaks in SIRM and HIRM were measured in a bog at the Llwyn Du (North Wales) and appear to correlate with a time when the medieval bloomery was operational. However, at Tuquoy, HIRM and SIRM peak at c. AD 1020 but then fall back to lower values (Figure 3). Neither parameter shows any obvious trend that could be associated with ironworking during the occupation of the farmstead, suggesting the ironworking that did take place at the site (based upon the presence of hammerscale), then it was not of sufficient intensity to register a clear signal in the loch sediments that can detected using these mineral magnetic parameters.

Conclusions

Human activity has acted to modify the landscape surrounding the Loch of Tuquoy for at least the last three thousand years, primarily through arable and pastoral agriculture: a narrative that has also been described from other North Atlantic islands especially during their Norse occupation. The pollen and non-pollen palynomorph records from Tuquoy suggests that a mixed agrarian economy was possibly practiced near-continuously over this timeframe, but intensified during two distinct periods: at first from c. 900 to 150 BC, and secondly between AD 700 and 1550 – a timeframe which encompasses the Norse occupation of the farmstead. The landscape modification associated with this activity took various forms and changepoint analysis marks them as significant. There was modest vegetation change, primarily the loss of woodland/scrub, commencing during the Iron Age (c. 50 cal BC) and continuing into the early Medieval period (c. 550 AD), which was mainly replaced by heather-dominated moorland. A change in the source of sediment being delivered to the loch was most likely caused by agricultural manipulation of the catchment, as attested to by measures of sediment geochemistry and mineral magnetics. Eroded material entering the loch switched sources several times during the Late Holocene, notably at c. 500 cal BC, AD 600, AD 1300 and AD 1500. These pulses of erosion appear to be driven by the increased intensity of human activity. The ecology, water chemistry and character of habitats within the loch also changed, as indicated by the varying percentages of *Gloeotrichia*-type indicative of nutrient poor water, which were replaced by *Pediastrum* and, to a lesser extent, *Botryococcus*, the timing of which were coincident with changes in sediment source and the intensity of human activity. These switches appear to be largely influenced by human activity although climate changes cannot be ruled out as having had some contribution. The catchment appears to have been very sensitive to human pressure, but many of the measured parameters returned to levels closer to a pre-intensification state once human activity was reduced. Evidence for localised pollution is less forthcoming despite the lead (Pb) deposition record being consistent with the common narrative across Europe, but there is insufficient evidence to determine whether suspected metalworking by the Norse at Tuquoy has left any detectable signature within the palaeoenvironmental record.

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FIGURE CAPTIONS

Figure 1: Location of Tuquoy within (a) Scotland and Orkney, and (b) Westray. (c) Location of the loch, Norse farmstead and Crosskirk. Sites numbered on the map: 1. Underhoull; 2. Marrister; 3 Law Ting Holm; 4. Gulberwick; 5. Oxna; 6. Cunningsburgh; &. St Ninian's Isle; 8. Garthsbank; 9. Jarlshof; 10. Pierowall; 11. Tuquoy; 12. Scar; 13. Pool; 14. Westness; 15. Brough of Birsay; 16. Point of Buckquoy; 17. Saevar Howe; 18; Burgar; 19. Gurness; 20. Tingwall; 21. Skaill, Deerness; 22. Stenness; 23. Caldale; 24. Skaill; 25. Burray; 26. Kirk o'Banks; 27. Reay; 28. Balnakeil. (Figure adapted from Ritchie, 1993).

Figure 2: Age-depth model for the Loch of Tuquoy developed using CLAM software.

Figure 3: LOI (a); mineral magnetic measurements (b); Xlf minero (c); HIRM (d); SIRM minero (e); and S-ratio for the Loch of Tuquoy sediments. Yellow shading represents the period of Norse occupation at Tuquoy farmstead.

Figure 4: Geochemical data from the Loch of Tuquoy. (a) Major principal components and the proportion of the explained variance in each component for each element from LoT sediment. (b) Five major principal component factor scores plotted by age (AD/BC). (c) Pb concentrations ($\mu g\ g^{-1}$) and Pb-Ti ratio.

Figure 5: Selected percentage pollen and spores diagram from Loch of Tuquoy. Rare pollen types are denoted by + (where + is one grain, ++ is two grains and +++ is three grains).

Figure 6: Selected percentage non-pollen palynomorph (NPP) diagram from Loch of Tuquoy. Rare types are denoted by + (where + is one palynomorph, ++ is two palynomorphs and +++ is three palynomorphs).

Figure 7: Key trends in the Tuquoy environmental data and proxy climate records: (a) Changepoint analysis on selected parameters. Significant changepoints occur at 815 cal BC, 535 cal BC, 110 cal BC and cal AD 215, 620, 1006, 1044, 1130, 1320, 1507-1539, and from 1695 to 1735. (b): Selected pollen (% TLP) and NPPs (% TLP + NPPs); (c): Cp1 scores (orange) and the S-ratio (blue) through time at LoT; (d) Composite records for bog surface wetness based on proxy data from peat mosses (peat humification, plant macrofossils, and mean water table depth transfer function) derived from testate amoebae from Ben Gorm (lower profile) and Craigmaud (upper profile), NE Scotland by Langdon &

Barber (2005); (e): Trends in N-scan JJA temperature reconstructions back to 138 BC by Esper et al. (2012; 2014). Extreme cool & warm summers (blue); cool and warm periods on decadal to centennial scales (black curve); a long-term cooling trend (dashed red curve); Uncertainty estimate (grey area). For full details refer to Esper et al. (2012) (f): Cp4 (blue) against SIRM minero (orange) through time (LoT).

Table 1: Stratigraphy of the Loch of Tuquoy core.

Table 2: Radiocarbon dates and calibrated ages from Loch of Tuquoy.

Table Supplementary 1: Factor loadings for the chemical data from the LoT core.