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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/Norse world, and containing a wealth of Norse archaeological remains, little is known about the impact that Norse communities had on the landscape of Orkney. To redress this, a palaeoenvironmental investigation of sediments was conducted from the infilled Loch of Tuquoy, located within 500m of the high-status Norse farmstead and Crosskirk at Tuquoy on Westray, Orkney. Pollen, non-pollen palynomorphs, microscopic charcoal, sediment geochemistry and mineral magnetic measurements were performed on a 2.25 metre-deep core. The results suggest that a cultural landscape was created before the Loch of Tuquoy record commenced and was 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, which encompasses the Norse occupation of the Tuquoy farmstead. Pollen evidence suggests that during both periods the land was used to cultivate barley and oats/wheat, 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 palaeoeconomy of the Norse seems to have been a continuation of earlier practices but caused a significant change in the source of sediments deposited into the loch. Whilst the sediment geochemistry found little evidence of possible ironworking, lead concentrations show a series of peaks during the Iron Age and Roman periods indicative of more regional-scale pollution.

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; Dickson, 1995; Bartlett, 1983; Bunting, 1994; 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 the North Atlantic Islands has received a great deal of attention (e.g. McGovern et al., 1988; Dugmore et al., 2005; Edwards et al., 2016; Lawson et al., 2008; Gauthier et al., 2010; Schofield et al., 2008, 2010; Silva Sanchez et al., 2015), few palaeoenvironmental studies have assessed the environmental impact of Norse societies (e.g. Edwards et al., 2016). 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 Maes Howe suggests that this landscape persisted from at least AD 300 (Davidson et al., 1976) but Davidson and Jones (1985) lament on the paucity of data available to make any detailed inferences about the vegetational landscape during those periods. To partly redress this, Edwards et al. (2016) examined the vegetation impacts associated with Norse peoples at Belmont on Unst and Rousay on Orkney with palynological evidence of clearance of woody taxa, such as birch and heather, coincident with evidence for grassland/grazing indicators from around AD 800. To assess the extent to which Norse people had on the landscape more widely, and especially given the wealth of Norse-Viking Age archaeology on Orkney, this paper examines the impact of a high-status Norse farmstead at Tuquoy on Westray on the landscape (Figure 1). We present a combination of pollen, non-pollen palynomorphs, micro-charcoal, sediment geochemistry and mineral magnetic data 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 and the wider North Atlantic Islands. In particular, we aimed to establish evidence of earlier human activity, to ascertain longevity and nature of the palaeoeconomy of the Norse and medieval settlement of Tuquoy, and how such activities impacted on the loch e.g. sediment sources and 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 and suggested the presence of a significant 12th century farmstead. This led to trial excavations in 1982-83 revealing the remains of a rectilinear 'Hall' (Owen, 1993). The 'Hall' went through three known stages of remodelling including the addition of a further rectilinear structure. This later building was found to contain a large volume of waste, including iron hammerscale, suggestive of on-site metalworking and possibly a smithy (Owen, 1993). Further investigation of the site in 1988 led to the discovery of a waterlogged deposit rich in palaeoenvironmental material including insects, charred and waterlogged plant remains, worked wood objects and off-cuts suggested to have been the remnants of a possible byre floor (Owen, 1993).

Bayesian analysis of the radiocarbon dates obtained from Tuquoy suggest that the byre feature was part of the earliest known phase of activity, which dates 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 to 'Þorstein Einarsson carved these runes' (Owen and McKinnell, 1989) may further support a 12th century date. 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 is significant as it 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), and this suggests a long and continued settlement history. A substantial early settlement has been uncovered at the Links of Noltland comprising of a Neolithic farmstead, field walls, cultivation remains and artefact-rich midden deposits, together with six Bronze Age buildings and a contemporary cemetery that dates to the third and second millennium BC (Moore and Wilson, 2011). A number of coastal broch sites, 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 considered to be the largest pagan Norse cemetery found in Britain (Graham-Campbell and Batey, 1998). At Quoygrew, in the north of Westray, a Late Norse farming site of comparable age to Tuquoy, has been excavated with activity beginning in the 10th century AD (Barrett, 2012).

Loch of Tuquoy

A 2.25 metre 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, then wrapped in polythene, sealed and taken back to the laboratory in the Archaeology Institute, UHI, where it was sub-sampled for microfossil and physical analyses, and radiocarbon dating.

The geology of Westray comprises sandstones, locally named 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).

Methods

Microfossils: A total of 50 sub-samples of *c*. 2 g wet weight and 0.5 cm thickness were prepared for pollen, non-pollen palynomorphs (NPPs) 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 pollen type slide collections housed in the Archaeology Institute, UHI, and the University of Aberdeen. Cereal-type pollen identification 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) and damaged pollen grains were classified as broken, corroded, crumpled or degraded. Pollen grains that had no remaining distinguishing features were categorised as unidentified. NPPs were recorded during routine pollen counting and they were identified using the descriptions and photomicrographs of van Geel (1976; 2001), van Geel *et al*. (1989; 2003) van Geel and Middledorp (1988) and van Geel and Aptroot (2006). Microscopic charcoal was routinely counted during pollen analysis. The fragments were divided into three size categories (<21 µm; 21-50 µm and >50 µm) in order to distinguish between fire events taking place close to and some distance from the site; and notwithstanding taphonomic issues, such as breakage, post-depositional transport by water and uncertainty with regards to modelling charcoal dispersal, the larger microscopic charcoal fragments are 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 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 up 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 (loss-on-ignition, LOI at 550°C) following procedures and calculations outlined by Walling and Foster (2016).

Geochemistry: Elemental composition of the sediments was determined for dried, milled and homogenized samples. Carbon content was determined using a Leco-Truspec CHNS analyzer. 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 by 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, 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 done in 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 analysis: We have performed Principal Components Analysis (PCA) on the chemical composition of the samples, using the lithogenic and metal tracers. Before PCA the data were transformed to Z-scores (calculated as: $[X_i-X_{avg}]/STD$, were 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 obtain average-centered distributions (Eriksson et al., 1999). PCA was done using the SPSS 15.0 software package.

To determine the probability of discrete changes occurring in the depth/age records we used the change point modelling (CP) routine developed by Gallagher et al. (2011), as applied in previous investigations on peat records (e.g. Kylander et al 2013). Changepoint (CP) modelling was applied on selected parameters (total tree pollen, Poaceae, *Plantago lanceolata*, *Gleotrichia*-type, SIRM (minero), s-ratio and Cp's 1-5) to detect significant changes in the microfossil records statistically. 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. In the deepest section, deposits reached up to 2.25 metres in depth and four major stratigraphic unit's infill the loch: a basal clay, overlain by a marl (a light grey calcareous silty loam with occasional gastropods shells (Dry & Sinclair, 1985), a shelly gyjtta and a surface peat.

Radiocarbon dating: Six samples were selected for ^{14}C dating using the AMS technique. Bulk sediment (peat, gyjtta or organic silt) was used as no definable macrofossils were identified. Radiocarbon dates for the loch sediments have been provided by the Radiocarbon Laboratory at the Scottish Universities Environmental Centre (SUERC) (Table 2). The ^{14}C dates were calibrated using the IntCaL13.14C calibration curve (Reimer et al., 2013). The age-depth model, using a cubic spline (Figure 2), was obtained using the Clam software developed by Blaauw (2010). All radiocarbon dates presented in the text are cited using the 2σ calibrated age ranges. Dates are cited in the text as calibrated BC/AD ages. Estimated ages are taken from the age-depth model as the best fit ages, rounded to the nearest half decade.

There are some uncertainties with any radiocarbon date (Telford *et al.* 2004; Piotrowska *et al.*, 2011) and some of these might apply to this study. For example, the uncertainty of the radiocarbon dates from the more calcareous-rich sediment may have been increased by a reservoir effect (Reimer & Reimer, 2007). Notwithstanding these limitations, 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 they accumulated in a linear fashion until c. cal AD 1450 when the accumulation rate slowed thereafter. Overall, the radiocarbon dates have provided a chronology for these deposits and an associated palaeoenvironmental record from the Late Bronze Age/Early Iron Age through to the post-medieval period; a sequence spanning approximately 3000 years.

Magnetic measurements:

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

Xlf (minero): values remain below 0.06 10^{-6} m^3 kg^{-1} except for small peaks at 515, 375 cal BC and between AD 100 to 500 until the upper part of the core when values peak from c. AD 1745 (data not shown because of high values; 0.678 and 0.414 at ~AD 1745 and 1888 respectively). Raw measurements of high field magnetic susceptibility (Xhf) were too low (<<20) for the reliable calculation the frequency dependent susceptibility (Xfd and Xfd%).

HIRM and SIRM (minero) show similar trends although the magnitude of 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 coincidental with those recorded by Xlf.

S-ratio values above 0.6 indicate the presence of ferromagnetic minerals most likely dominated by magnetite rather than hematite (Mighall et al., 2009) but can be influenced by particle size (Mooney et al., 2003). This accounts for most of the core with values increasing above 0.6 at the base of the core, until c. 515 BC when they plateau. At AD 405 values start to decrease gradually until AD 1070 and fall almost to 0.1, most likely the result of 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 return to previous values and a switch back to ferromagnetic minerals. A further rise at AD 1540 to pre-500 BC values occurred. Although less prominent, there is also a reduction in the S-ratio at ca AD 110.

The mineral magnetic data suggest that either significant changes in particle size have occurred or that there has been a significant change in sediment source. Concentrating on the two periods centred on AD 110 and AD 1120; the former has 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 be associated with agriculture and the latter more likely to be associated with ironworking at the site. Sampling local rocks and soils would help to confirm these tentative conclusions (cf Mighall et al., 2009).

Geochemistry: Five principal components were deemed to be of importance: Cp1-5 (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 and a proportion of the sediment core contained molluscs. There are several fluctuations between these sediment types in (Cp1 scores) throughout the LoT record (Figure 4bi). Cp2 is characterised by high positive loadings of S, Fe, Zn and Br (Figure 4a). The elements in this component are biophylic elements and organically-bound elements/metals. They appear to be responding to changes in organic matter content, which is reinforced this 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 c. cal AD 1750. Cp3 is characterised by high loadings of elements (Zr, Nb, Y, Rb) or moderate loadings (Ti, Fe and Th) 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 changes are shown in Figure 4biii: (1) a shift from negative to positive values from 915 cal BC to 620 cal BC; (2) values fluctuate between slightly negative to (and mainly) positive values until cal AD 1425; (3) values become 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 a rise in recent industrial pollution. Cp5 is dominated by Ni, but also 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 non-pollen palynomorph (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 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 and CONISS software as part of the Tilia and Tilia.graph version 1.7.16 package (Grimm, 2011) to assist in establishing zonation. Those grains that could not be identified are listed as unidentified in the pollen diagram.

The interpretation of any pollen assemblage derived from lake sediment is compromised by several processes which can affect the fidelity of the pollen record (Wilmshurst and McGlone, 2005a, b), including changes in sediment sources 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 have run from the loch to the coast. Given there is no clear evidence of this stream, we assume that the majority of the pollen/sediment deposited in the loch is either through the atmosphere 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 to sediment (and presumably pollen) delivery from source areas to a water body (Turnbull et al., 2008). There are no major or rapid changes in the pollen record as a result of a change in the stratigraphy to suggest these issues have compromised the pollen assemblages. Whilst the condition of pollen grains show signs of deterioration, identifiable counts of 500 TLP were achieved throughout the sequence (Delcourt and Delcourt 1980; Jones *et al.* 2007). Pollen grain damage (broken, folded and/or corrosion) was possibly due to rates of soil maturation and peat development around the Loch margins (e.g. Tipping, 1987), with crumpling and degradation most likely caused during transportation in water. Some of the corroded, crumpling and broken grains will reflect in-wash and possible reworking of pollen contained within eroded material (cf. Tipping, 1987; Wilmhurst & McGlone, 2005a). Degraded grains are commonly crushed or crumpled which also indicates that they have been transported and are then redeposited (Cushing, 1967; Lowe and Walker, 1997). The proportion of unidentifiable grains is below some of the thresholds suggested for data being unrepresentative (Bunting et al., 2001; Tipping et al., 1994) and therefore we suggest that the Loch of Tuquoy pollen record is a reliable proxy for vegetation change at the site.

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

The zone is dominated by Poaceae (grasses) and Cyperaceae (sedges) (Figure 5). A range of 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 by the representation of Apiaceae (carrot family), Caryophyllaceae (pinks), Cyperaceae, *Filipendula* (meadowsweet), Rubiaceae (bedstraws) and *Equisetum* (horsetail) (Brown et al. 2007; Stace 2010). Non-pollen palynomorphs (NPP) associated with animal dung are represented with 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 took place with *Hordeum*-type (barley) pollen consistently present throughout the zone from c. 750 BC and a rare occurrence of *Avena/Triticum*-type (oat/wheat) pollen. The presence of NPP *Glomus* cf. *fasciculatum* chlamydospores (HdV-207) suggest that arable and pastoral agriculture may have been responsible for soil erosion as this particular NPP is considered to be a marker for erosion in fluvial/lacustrine contexts (van Geel et al., 1983, 2003).

Deciduous woodland, possibly scrub, formed a minor constituent of the vegetation community with *Betula* (birch) and *Corylus avellana*-type (hazel) relatively well represented and *Pteropsida* monolete undiff. (ferns) most likely in the understorey. A local presence of *Quercus* (oak) and *Ulmus* (elm) is more difficult to determine. Others have suggested that oak grew locally on Orkney (Bartlett, 1983; Bunting, 1994; De la Vega-Leinart et al., 2007) but Farrell (2015) suggest *Quercus* was probably not present at Hobbister with similar percentages in the pollen record found at Tuquoy. Relict birch woodland can be found on Hoy (Prentice & Prentice, 1975). Woodland cover decreases slightly mid-zone c 750 BC, before recovering between 700-650 cal 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 occurred when arboreal pollen percentages are low. As dryland tree percentages fall, *Alnus* (alder) increases in representation and along with *Salix* (willow), both typical of wet woodland, possibly around the fringes of the loch. Heathland, possibly supporting some *Betula*, with *Calluna* (heather), Ericaceae (Erica family), *Empetrum* (crowberry) and *Juniperus* (juniper) is 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), *Myriophyllum alterniflorum* (alternate-leaved milfoil) and an increase in *Myriophyllum spicatum* (spiked milfoil) and/or *verticillatum* (whorl-leaf watermilfoil) in the second half of the zone. Values of HdV-146 rise steadily through this zone: *Gloeotrichia*-type (HdV-146), is an aquatic pioneer indicative of nutrient poor conditions, which has the ability to fix nitrogen (van Geel, 2005). Initially, high values of HdV-900 (*Pediastrum*) decreased sharply and then remained 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 (unknown).

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

An increase in rough, wet pasture and/or marsh/fens is suggested as Cyperaceae percentages rose dramatically and combined with the continued presence of *Filipendula*, *Succisa pratensis* (Devils bit scabious), Apiaceae, Caryophyllaceae, Rubiaceae, *Selaginella* (spikemoss) and *Sphagnum*. *Gaeumannomyces* (HdV-126) also increased and this fungus is known to be associated with *Carex* (Pals et al., 1980). Arable and pastoral activities continued with Poaceae, *Plantago lanceolata*, Lactuceae, Ranunculaceae, *Aster*-type, *Trifolium* and Brassicaceae (Mustard family) prominent, and with 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 (HdV-113, *Podospora*-type (HdV-368), and possibly *Sordaria*-type (HdV-55A/B), *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 (mugwort) and *Urtica*-type (nettle), with *Plantago coronopus* (buck's-horn plantain) likely to be growing on sand/gravel or cracks in rocks close to the sea (Stace, 2010).

Deciduous woodland cover remained fairly stable, with consistent arboreal pollen percentages during this zone. An isolated find of *Tilia* (lime) and *Pinus* pollen is most likely long distance transport but *Fraxinus* (ash), *Sorbus*-type (rowan) and *Pteropsida* monolete undiff. might have been under-represented constituents of local deciduous woodland. Some heath or peatland cover existed as *Calluna* relatively stable percentages occur, 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) microscopic charcoal values fluctuate through this zone but remain in both the <21 μm and 21-50 μm fractions while there is a decline in the >50 μm values (Figure 5) from the previous zone, implying more regional fires. However, small peaks are also present in identifiable microscopic wood charcoal and suggest fire occurred in more local settings as well.

Internal changes in the Loch also occurred at this time. There is a sharp decline in *Myriophyllum spicatum/verticillatum* in this zone, accompanying a more gradual decline in *Myriophyllum alternifolium*, and a very slight increase in *Callitriche/Potamogeton* (pondweed) and a peak in *Pediastrum*. Species of *Pediastrum* are known to have a wide range of environmental responses, including catchment erosion, turbidity, water chemistry nutrient status and pH (van Geel, 2001) and could be driving competition between the loch constituents. *Gleotrichia*-type (HdV-146) remains high throughout the zone, with a notable, short-lived decline midzone corresponding with small peaks in HdV-901 (*Botrycoccus* colonial green algae), *Botrychium lunaria* and *Aphanizomeron* (HdV-600: cyanobacteria). Other NPP wet indicators are also present in this zone (Figure 6) including HdV-60 (*Closterium idiosporum*) representative of open water (van Geel, 1978) and *Valsaria variospora*-type (HdV-140), which is often found in eutrophic wet conditions (van Geel et al., 2003). The occurrence of an intestinal parasite egg of *Trichuris*-type (whipworm) in this zone (Figure 6) indicates potential pollution of the loch waters from faecal material. Measurement of the egg (42 µm x 25 µm) suggests it is likely to represent *T. trichiura* (human host) and/or *T. suis* (pig host) (Dark 2004).

Zone LoT3 – 240 cal BC – cal AD 1200, Middle Iron Age – Norse

Subzone LoT3a: 240 cal BC - AD 90:

There is an initial increase in woodland with *Quercus*, *Betula* and *Salix* percentages all rising. This is short-lived as trees and shrubs gradually decrease until the subzone boundary. A reduction in burning may well have facilitated the recovery of woodland as levels of microscopic charcoal are initially low but increase rapidly as tree pollen declines towards the end of the subzone, as grass-microcharcoal is also recorded (Figure 6). Heath or peatland cover continued 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 recorded intermittently (Figure 5). Pastoral activity continued, implied by the near-continuous presence of *Chaetomium* sp (HdV-7A), *Sporormiella*-type (HdV-113) and *Sordaria*-type (HdV-55A/B), and a range of herbaceous pollen from plants commonly found in grazed fields such as Poaceae, *Plantago lanceolata*, Caryophyllaceae, Lactuceae, *Rumex aceotosa/acetosella*, *Plantago media/major* (hoary/broadleaf plantain), *Aster*-type and *Potentilla*-type. Disturbance indicators are also present but in lower values e.g. *Artemisia*-type, Chenopodiaceae, Apiaceae and Brassicaceae (Brown et al., 2007). If any erosion took place, it was probably of lower intensity as *Glomus cf. fasciculatum* chlamydospores (HdV-207) do not feature much in this subzone (Figure 6).

Marsh/fen persisted in the catchment, albeit it with lower Cyperaceae percentages midzone, however, *Filipendula* peaks at around 15% TLP. Within the loch, *Gleotrichia*-type values (HdV-146) declined, as *Pediastrum* (HdV-900) was relative abundant. Aquatics (*Myriophyllum alterniflorum* and *spicatum/verticillatum*) are recorded in low percentages while *Callitriche/Potamogeton* begin to increase at the top of the subzone (Figure 5).

Subzone LoT3b – cal AD 90-540

Initially deciduous woodland recovered, with increased presence of *Quercus*, *Betula* and *Ulmus*. *Corylus avellana*-type also falls to much lower percentages. It then has a sharp decline c. AD 25 before partly increasing again by cal. AD 100. From cal. AD 100 to AD 250 the amount of woodland remains fairly stable before gradually contracting at the end of the subzone, c. cal. AD 540.

Evidence for cultivation is muted and of low intensity, with only one record of *Hordeum*-type recorded. In contrast, evidence for grazing/pasture is more forthcoming, especially between c. cal AD 90-250. Coprophilous fungi are limited to very low amounts of *Sporormiella*-type (HdV-113) and *Cercophora*-type (HdV-112), while *Sordaria*-type (HdV-55A/B) is more abundant but then all three fade. 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 *Calluna* and Ericaceae suggest that heath/peatland expanded and marsh/fen, probably surrounding the loch is 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 – cal AD 540-1020

Mixed woodland cover diminishes across the sub-LPAZ boundary as *Alnus*, *Betula*, *Quercus*, *Pinus* and *Corylus avellana*-type percentages all decrease. Fire was possibly a cause of the reduction in woodland cover as falls in AP coincide with peaks in microscopic charcoal but trees were more likely to have been cleared for fuel wood and construction etc. Locally, the severity of fires may well have been reduced as fewer large fragments ($\geq$ 50 µm) of microscopic charcoal were deposited. Based on arboreal pollen percentages, woodland fails to recover back to previous levels, 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 suggest grazing and arable cultivation, including *Podospora* sp./*Zopfiella* (HdV-466), were practised in the catchment from c. cal AD 540 through to the tenth century AD when the Norse farm at Tuquoy was established.

Zone LoT4 – cal AD 1020-1325, Norse to Post-medieval

The Norse farm was occupied at Tuquoy during this zone. Deciduous woodland decreased at the very start of the zone: with *Quercus* and *Betula* most affected. *Alnus* also falls to much lower percentages implying clearance of wet woodland (Figure 5). This coincided with a rise in microscopic charcoal ($\leq$21 µm fraction). A short-lived recovery followed before woodland cover decreased again and total AP% never exceeds its pre-cal AD 750 value. This latter decline occurred as the 21-50 µm and >50 µm fractions of microscopic charcoal increased, implicating local and possibly natural fire in woodland, but more likely to be the result of settlement activities, with the charcoal derived from domestic and/or industrial purposes. Wood was probably used more practically.

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, such as trampling, 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), especially from c. cal AD 1150-1250, encompassing the known occupation of the hall at Tuquoy. Coprophilous dung fungi, indicative of grazing animals, (*Sporormiella*-type, HdV-113, *Podospora*-type, HdV-368, *Tripterospora*-type HdV-169, *Cercophora*-type HdV-112 and *Sordaria*-type, HdV-55A/B) increase from cal AD 1000 and are more abundant from cal AD 1250, and this mixed land use remains in place until c. cal AD 1450 (Figure 6). Indeed, the continuous curve for *Hordeum*-group throughout the zone and a near continuous curve for *Avena/Triticum*-group present from c. cal AD 1100-1400 suggest increased cultivation of oat/wheat during the Norse period.

Glomus cf. fasciculatum chlamydospores (HdV-207) may be associated with the inwash of eroded material as a result of increased disturbance in the catchment. Heath/peatlands and marsh/fens continued to be part of the vegetation community of Westray at this time. Changes in the loch ecosystem also took place. *Pediastrum* (HdV-900) values fell, replaced by first *Botrycoccus* (HdV-901), commonly found in fens, temporary pools, ponds and lakes (van Geel, 2001) then *Gleotrichia*-type (HdV-146) and subsequently *Myriophyllum alterniflorum* and *spicatum/verticillatum*. An increase is also observed in the presence of HdV-72A (aquatic insect jaws), suggesting open water, while small peaks in HdV-128 (unknown) also occur.

Zone LoT5 – cal AD 1325-present, Post-medieval-modern

Subzone LoT5a – cal AD 1325-1550, Norse to Post-medieval

Following the known abandonment of the farm, at c. cal AD 1350, the landscape is characterised by a rise in Poaceae, along with *Plantago lanceolata*, *Plantago media/major*, *Aster*-type, *Rumex acetosa/acetosella* and Lactuceae pollen, along with Cyperaceae, Apiaceae, Ranunuculaceae and *Filipendula* suggestive of rough, wet grassland/fen (Brown et al., 2007) and some continued disturbance in the catchment. Total arboreal pollen also declined at c. cal AD 1400, particularly *Betula*, *Alnus* and *Quercus*.

Many of the anthropogenic indicators also decreased in value including coprophilous fungi (*Cercophora*-type (HdV-112), *Sporormiella*-type (HdV-113), and possibly *Sordaria*-type HdV-55A/B), and *Potentilla*-type, Chenopodiaceae and Brassicaceae all decline. Cereal-type and *Hordeum*-type pollen percentages also fall during this subzone with *Avena/Triticum*-type occurring only as a rare type. This period, therefore, marks 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 (HdV-207) indicates any remaining disturbance did not produce much soil erosion.

Microscopic charcoal values at <1-21 µm and 21-50 µm fluctuate through this zone with peaks and troughs suggesting periodic burning activity; >50 µm fraction is significantly reduced from the previous zone suggesting these burning events were not taking place locally. Fire could have facilitated the increase in heather moorland in the wider landscape. By the end of the known Norse occupation of Tuquoy, there is visible reduction in *Gleotrichia*-type (HdV-146), an aquatic pioneer indicative of nutrient poor conditions in the remaining loch water, corresponding with a fall in arable and pastoral activity. The presence/decline of other NPPs and aquatic pollen infers that the water level of the loch water was shallowing. This includes high but fluctuating *Pediastrum* values, a reduction in *Botrycoccus*, *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* (HdV-600) has also been associated with eutrophic water (van Geel, 2001).

Subzone LoT5b – cal AD 1550-1850, Post-medieval to modern

Rough/wet grassland and/pasture forms one of the dominant land uses in the recent past. Poaceae pollen percentages peak c. cal AD 1750 and Cyperaceae is abundant. A slight recovery in woodland occurs at c. cal AD 1650, especially *Pinus* and *Quercus*, concomitant with a reduction in heathland as recorded by the sharp decline in *Calluna* pollen. Microscopic charcoal values are much lower compared with LoT5a, although a small peak in values across all fractions at c. cal AD 1750 corresponds with the last recorded decline in arboreal pollen.

Grazing is slightly revitalised with an increase in coprophilous fungi including *Cercophora*-type (HdV-112), *Sporormiella*-type (HdV-113), possibly *Sordaria*-type HdV-55A/B and *Tripterospora*-type (HdV-169). *Plantago lanceolata*, Brassicaceae, *Cirsium*-type (thistles), Lactuceae and Ranunculaceae are common on pasture (Brown et al., 2007). Limited cultivation appears to have occurred with sporadic *Hordeum*-type and a small peak in Cereal-type pollen taking place at around c. cal AD 1650. A large peak in *Vicia cracca*-type pollen (tufted vetch) occurs at c. cal AD 1850 and is likely to reflect this plant growing directly at the core location as it contributes to around 75% TLP (data not shown). *Vicia craccia* is found along woodland edges, in wasteland and scrubby grassland, abandoned fields, coastal cliffs and sand dunes (Stace, 2010). *Gleotrichia*-type (HdV-146) persists indicating any standing water is eutrophic but aquatic taxa are much reduced during this period as the loch terrestrialises from marl/gyttja to a peaty soil.

Discussion

Human impact during the Atlantic Iron Age

In common with other pollen diagrams on Orkney and Shetland, the landscape of Tuquoy was dominated by grasses and sedges by the Late Bronze Age/ Early Iron Age (cf. Edwards et al., 2013). Pollen evidence from both on-site and off-site contexts at Tuquoy reveals a largely treeless landscape with local heathland (cf. Tipping, 2012). Woodland cover varied between 10 and 15 %TLP up until the Norse presence on Tuquoy, characterised by small-scale, mostly short-lived woodland development, particularly from c. 100 cal BC to AD 600, both marking significant changepoints (Figure 7A). Some of the tree pollen could be derived from sources off-island or from the Scottish mainland (Tyldesey, 1973; Edwards and Whittington, 1998; Edwards et al., 2013). Thus, the landscape was predominantly cultural by the time sedimentation commenced in the loch with some peat/heathland development as suggested by the regular, albeit low, percentages of *Calluna* pollen with *Empetrum* and other Ericaceae (Figure 5). Bunting (1996) suggests that heathland vegetation started to develop around 5700 BP expanding by c. 5400 BP based upon pollen records from Rousay and Hoy. While the Tuquoy record does not extend back into the Neolithic, the *Calluna* pollen curve suggests that heath/blanket peat was present by the end of the Bronze Age and expanded from c. cal. AD 200, marking a significant changepoint (Figure 7A).

Numerous prehistoric sites lie in close proximity to the loch at Tuquoy, confirming an Early Iron Age human presence. Arable and pastoral agriculture took place during the Atlantic Iron Age in the Northern Isles although the balance between the two economies has been questioned (Bond, 2002). Edwards et al. (2013), based on pollen assemblages from Underhoull, Shetland, suggested that pastoral agriculture was most favoured on first inspection. Unless cereal-type pollen is found, palynological evidence for arable agriculture can be difficult to separate from coastal plant communities as both share similar plant taxa (e.g., *Artemisia*-type, *Rumex* spp. and Asteraceae). At Underhoull, only three samples contained traces of cereal pollen suggesting that arable cultivation was practised, possibly at low intensity, but as cereal pollen does not travel far this maybe a taphnomic effect (Hall, 1989) rather than a true record of the level of activity. The palaeoenvironmental record at Tuquoy suggests that a previously unknown period of arable activity also occurred during the Early Iron Age, from around 800 cal BC to 100 cal BC, with the cultivation of mainly barley; generally considered to be the dominant crop in northern latitudes of Scotland at this time (Armit and Ralston, 1997). *Hordeum*-type, was encountered more frequently and at higher percentages between c. 800 cal BC and 500 cal BC, suggesting that arable activity was possibly of increasing importance at Tuquoy. *Avena*/*Triticum*-type pollen is also present at rare values suggestive of some cultivation of wheat/oats. This interpretation is strengthened as significant changepoints occurred at c. 815 and 535 cal BC (Figure 7A). Given the Early Iron Age date for the cultivation, it is more likely this represents evidence for wheat cultivation (cf. Armit & Ralston, 1997), although the occurrence of large grass grains (Poaceae >35 µm; Figure 5) could be wild oat (*Avena fatua*), a common arable weed (Stace, 1991). Utilising rapid scanning techniques to optimise cereal pollen detection would reveal further insights on the extent and duration of cereal cultivation at the site (Edwards et al., 2005).

Cultivation was clearly part of a mixed agrarian economy at Tuquoy. A pastoral economy also seems to have occurred alongside cultivation until at least c. AD 100 when cereal pollen is less common in the pollen record. Evidence for grazing herbivores is provided by the presence of coprophilous fungi *Cercophora*-type (HdV-112) and *Sporormiella*-type (HdV-113), together with HdV-55A/B and *Sordaria* spp, which are commonly recorded in heavily grazed landscapes of the North Atlantic islands (e.g. Schofield & Edwards, 2011), and, notwithstanding the caveats outlined above, the occurrence of NAP pollen taxa with pastoral affinities (e.g., Lactuceae, Brassicaceae, *Rumex acetosa* and *Potentilla*-type). This may signal a switch in economy to one that is more livestock intensive during the Middle Iron Age.

This early activity at Tuquoy appears to drive a shift in sediment source from more siliceous material (more positive values in Cp1) to more calcareous (more negative values) which lasts until 250 cal BC. An increase in the S-ratio to higher, positive values which continued until c. 515 cal BC, also records this shift. It is seen in the early dominance of Si and Ti being replaced by Ca, especially between 900 and 200 cal BC (Figure 7). Alternatively, a proportion of this could represent fragments of shells from molluscs visible in the sediment. A long-term change in Cp3, implying a coarsening of particles entering the loch (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 lasts until c. cal AD 1300. During this time Cp1 shifts back to more calcareous material, along with shifts in all the other Cp's and is coincident with the start of decreased representation of arable and pastoral pollen and coprophilous fungi. It is plausible that changes incurred in the catchment also impacted on the loch, with increased *Gleotrichia*, indicative of poor water quality (the changepoint at 535 BC coincides with its highest abundance) and the decline in *M. alterniflorum*, present in mostly base-poor lakes in favour of *M. spicatum/verticillatum* common in base-rich water bodies (Clapham et al., 1987; Stace, 2010).

There appears to be a lull in cultivation activity during the Late Iron Age, between c. 400 cal BC to AD 550, which coincides with a slight recovery in deciduous woodland/scrub, especially *Betula* and *Corylus avellana*-type, suggesting that some land may have been abandoned (the first half of subzone 3b). The changepoint at 110 cal BC (Figure 7A) coincides with the first *Betula* peak in the pollen record and at that time its highest occurrence since the loch sediment started to accumulate. Some human presence throughout this period is still suggested by the occasional cereal pollen, grazing (*Sporormiella*-type, possibly *Sordaria*-type) and disturbance indicators in the pollen and NPP record (e.g. *Plantago lanceolata*, Lactuceae, *Rumex acetosa/acetosella*). This lessening in human disturbance and renewed tree/shrub growth coincides with a reversal in the trends of Cp1 and, to a lesser extent, Cp2, which shift around 250 cal BC (Figure 7). The changepoint at c. cal AD 215 also marks a rise in tree pollen and lower *Gleotrichia*-type. The S-ratio also shifts towards anti-ferromagnetic minerals and most likely represents a change in sediment source into 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) but there is little evidence forthcoming in the palaeoenvironmental data presented from Tuquoy to support this hypothesis. Notwithstanding regional variations, a wet shift has been reconstructed from bogs across Scotland between 2600 and 2200 cal BP (600 cal BC - 200 cal BC), followed by drier phases between 2400- 1800 cal BP (400 cal BC - AD 200) by Langdon et al. (2005) which suggests climatic conditions were conducive to agriculture rather than detrimental during this time.

The lower intensity in human activity suggested in the pollen record between the Late Iron Age and the Norse period, c. 200 cal BC to AD 550 is perhaps more compatible with the idea of land use continuity from the first millennium BC to the fourteenth century AD (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).

Viking-Late Norse periods (c. AD 800-1350)

Evidence for human activity is more prominent once again after c. cal AD 550 with a strong agricultural signal recorded in the herbaceous pollen and NPPs especially immediately before and during the Norse period (the latter stages of zones 3b and LoT4). This is marked by another changepoint at c. cal AD 620 and coincides with a shift in the s-ratio and Cp1 indicating a sediment source shift (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 across the Northern Isles including Belmont on Unst, Loch of Clickhimin, on mainland Shetland and Westness on Rousay, Orkney shows increased human activity from c. cal AD 800 suggesting impacts 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 years BC, temperatures during the Roman period were warm, whereas the extent of warmth during medieval times showed considerable variation (e.g. Kerr et al., 2009; Esper et al., 2012). The climate at the time appears to have been 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 N-scan JJA temperature reconstructions by Esper et al. (2012) suggest they show a warming trend until around AD 900 when temperatures begin to fall gradually (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. cal AD 1250 and probably coincident with the onset of the Little Ice Age (Miller et al., 2012).

The earliest archaeological evidence of Norse occupation from Tuquoy appears to be a byre, dated from the 11^{th} to 12^{th} century AD. Its infill was rich in organic remains, including waterlogged and charred plant remains, charcoal, worked wooden objects, insects and pollen (Owen, 1993). Analysis of materials showed the worked wood to be a mixture of possible local materials (willow and birch), together with imported materials such as pine, larch and spruce with fragments also containing runic inscription (Crone nd.). Charcoal evidence also suggests use of local copses of woodland for fuel resources of alder, willow, oak, hazel and ash, together with heathland/turf with heather abundant (Nye and Boardman, 2012). While the presence of some woodland is evident in the pollen diagram, percentages generally fall throughout the Norse period with only very small, short-lived recoveries recorded. All of the taxa found 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 would be most likely under-represented being insect-pollinated. *Fraxinus* is the exception 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 may indicate imported wood or 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, before refining it to 5% total pollen (Bennett, 1995) whilst Lageard et al. (1999) suggest it could be even lower at 3-9%TLP. *Pinus* pollen does not reach these suggested target values in zone LoT4.

Pollen evidence from both on-site and off-site contexts at Tuquoy reveals a largely treeless landscape with local heathland (Tipping, 2012; this study). Bunting (1996) suggests that heathland vegetation started to develop around 5700 BP expanding by c. 5400 BP based upon pollen records from Rousay and Hoy. While the Tuquoy record does not extend back into the Neolithic, the *Calluna* pollen curve suggests that heath/blanket peat was present by the end of the Bronze Age and expanded from c. cal AD 200. Heather was also abundant within the charcoal assemblage (Nye and Boardman, 2012), suggestive of a local presence and therefore turf/heath could have been exploited in the landscape close to the farmstead by Norse communities.

High values of oat/wheat and barley pollen indicative of an agricultural landscape is most commonly found on similar sites including Buckquoy on Orkney (Driscoll, 2002) and is dominant in early Medieval cereal assemblages further afield e.g. in Ireland (McCormick, 2014; McClatchie et al., 2015). Finds of charred cereal grains of 6-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. Oat cultivation 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 tolerant of rich and poor quality soils and are suited to wetter climatic conditions (McCormick, 2014). Coprophilous fungi indicators also suggest the presence of grazing animals around the loch during the period of farmstead activity with increased values of *Sordaria*-type (HdV-55A/B) *Sporormiella*-type (HdV-113) and trace amounts of *Cercophora*-type (HdV-112), between approximately cal AD 1200-1550, and is compatible with animal bones found on similar farms such as Buckquoy (Ritchie, 1976). There is a slight downturn in cultivation and the presence of coprophilous fungi c. AD 1250, coincident with a drop in temperatures (Esper et al., 2012) before regaining their former values by AD 1350 during a period of increasing temperatures.

Localised erosion associated with Norse activity is also evident at Tuquoy and Belmont but the timing is variable and most likely reflects differences in the dates of occupation. By c. AD 1000 until around AD 1220 land surfaces had become destabilised resulting in erosion at Belmont (Edwards et al., 2013). Changes in the S-ratio and geochemistry suggest a change in sediment sources being deposited 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 in c. cal AD 500 (uncorrelated, low S-ratio (0.5-0.7) with positive Cp1 scores) and was particularly strong by cal AD 1120 to 1245 (Figure 7). This very noticeable decline in the S-ratio at the very end of the Early Medieval period, which commenced more gradually from the Roman (Scottish Iron Age), 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 – AD 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 early medieval and medieval period 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. The sediment entering the loch does not reflect earlier prehistoric magnetic/geochemical signature until AD 1800 (the S-ratio negatively correlates to Cp1 for S-ratios >0.6).

Post Norse AD 1350-modern

Following the abandonment of the farmstead, agricultural activity diminishes between cal. AD 1350-1400, with only the odd occurrence of cereal-type pollen. A changepoint occurs at c. AD 1320. Although barley continued to be cultivated until around cal AD 1625, while oat cultivation appears to have mostly ceased around cal AD 1350 and is probably linked with the end of activity at the farmstead rather than the more severe decline in N-scan JJA temperatures during the AD 1400s. The 1440s being one of the coldest periods cautiously identified in the record (see Rydval et al., 2017) and it is around this time that a large proportion of agricultural indicators decline in the microfossil record at Tuquoy. Notwithstanding, the difficulties in matching historical events to radiocarbon-dated palaeoenvironmental records, the AD 1350s downturn in cultivation might have also been acerbated by the Black Death (Figure 7, vertical red line) which peaked in Europe around AD 1346 to 1351 (Ziegler, 2013) and it has been suggested that the impacts of the plague were long-lasting across Europe (e.g. Hamilton & Thomas, 2012; Thór, 2015; Riddell et al., 2018). Oram (2014) suggests that at least 130,000 of a total estimated Scottish population of 500,000 died. Interestingly Richards et al. (2006) suggest that there was an increased frequency of individuals with marine isotopic values implying a greater proportion of marine foods in their diets during the Viking and Medieval periods from data collated from Newark Bay on Orkney.

Pastoral and disturbance indicators also decline in the post-medieval period, c. AD 1500, as *Calluna* (in zone LoT5a), then Poaceae and Cyperaceae percentages increase (in subzone LoT5b) suggesting an expansion of wet grassland and heathland, coincident with another changepoint, Figure 7A). Apart from a small spike in *Pinus*, woodland does not regenerate. Similar to the earlier weakening of human activity (between cal AD 100-550), 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) and shown quite clearly in Figure 7C. Finer grain material enters the loch attested by the shift of Cp3 scores towards negative values. The S-ratio is greater than 0.6, and indicating increased presence of ferromagnetic minerals and $SIRM_{(minero)}$ and $Xlf_{(minero)}$ increase from c. AD 1630 onwards indicative of an industrial atmospheric pollution signal and changepoints between c. cal AD 1695 and 1735 (Figure 3). These changes coincide with a deteriorating climate from AD 1550 (Lamb, 1964), characterised by an extended period of cold, particularly in from the late sixteenth to early eighteenth century based on tree-ring evidence from the Cairngorms (Rvydal et al., 2017) and forms part of the so-called Little Ice Age (Matthews and Briffa, 2005). The seventeenth century is also marked by three of the coldest decades, and the occurrence of famine (Dawson, 2009).

Metal pollution and metalworking?

Cp4 seems to represent mostly lead pollution (Figure 4), and gradually increases throughout the record showing more distinctive peaks around 750-700 cal BC, 345 cal BC, 5 cal BC and cal AD 280 which encompasses the Iron Age to nearly the end of the Roman period. Further peaks are evident at c. AD 1190 (early medieval) and from AD 1490 (late medieval), with a more rapid increase from AD 1540 into the industrial period. Peaks of these ages are not inconsistent with lead pollution records across the British Isles and in Europe (e.g., Cloy et al., 2005; Kuttner et al., 2014). Lead pollution increased from the Late Iron Age, culminated during the Roman period, increased again from the early medieval period and reached its zenith during the industrial revolution (e.g., Mighall et al., 2002, 2009; De Vleeschouwer et al., 2010). At Tuquoy, the first peak in metal enrichment occurs in the Late Bronze Age/Early Iron Age in Cp4 and there is also an increase in Cp5 at the same time which is dominated by Ni. Copper shares some variance with this component which suggests a link to mining/metallurgy. Copper and lead are constituents of bronze, with lead being an important alloy introduced in bronze during the Late Bronze Age (Rohl & Needham, 1998). Arsenic concentrations also peak and its presence can be associated with certain copper ores (Ixer and Pattrick, 2003). However, there is no evidence on site of metallurgy involving these metals so at present the evidence is circumstantial and must be treated with caution.

The Pb/Ti ratio helps to separate the anthropogenic lead fraction from the geogenic fraction (Pb contained within the local bedrock) (Boës et al. 2011). This ratio confirms the peak during the Late Bronze Age /Early Iron Age transition, c. 340 cal BC (not clearly seen in Cp4 but more evident in the Pb record). 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 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.

The archaeological evidence for ironworking is more convincing with the discovery of a possible smithy (Owen, 1993). Ironworking is well known on Orkney, with rich deposits of iron ore present on Hoy (Dickson, 1995) and evidence for Iron Age working at sites like Howe from mid to late Iron Age contexts, although the scale of iron production is yet to be fully established (McDonnell, 1994). Evidence in the sediments at loch of Tuquoy for ironworking is not clear. There are several Fe peaks in the record including one that coincides with 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 is 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) but both parameters do not show any obvious trend that could be associated with ironworking throughout the occupation of the farmstead, suggesting that any ironworking that took place at the site was not of sufficient intensity to register a signal in the loch sediments using these parameters.

Conclusions

Human activity has modified the landscape surrounding the Loch of Tuquoy for at least three thousand years, primarily through arable and pastoral agriculture: a narrative that has also been described from other North Atlantic islands especially during the Norse occupation. The pollen and non-pollen palynomorph record suggests that this mixed agrarian economy was possibly practiced near continuously but intensified during two periods: the first from c. 900 to 150 cal BC and the second between AD 700 and 1550, which encompasses the Norse occupation of the Tuquoy 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 from c. 50 cal BC to c. 550 AD, which was mainly replaced by heather-dominated moorland. A change in the source of sediment most likely caused by agricultural manipulation of the catchment is attested from the sediment geochemistry and mineral magnetics. Eroded material entering the loch switched sources several times during the Late Holocene, especially at c. 500 cal BC, AD 600, AD 1300 and AD 1500. These appear to be driven by the increased intensity of (or lack of) human activity. Water ecology in the loch also changed, indicated by the varying percentages of *Gleotrichia*-type indicative of nutrient poor water replaced by *Pediastrum* and, to a lesser extent, *Botrycoccus*, the timing of which is 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 totally ruled out as a contributory factor. The catchment appears to have been very sensitive to human pressure but many of the measured parameters returned back to closer to a pre-intensification state once human activity 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 left a detectable impact.

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FIGURE CAPTIONS

Figure 1: Location of Tuquoy: (a) Scotland and Orkney; (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 Bukquoy; 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 (adapted from Ritchie, 1993).

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

Figure 3: LOI (a) and mineral magnetic measurements (b) Xlf minero (c) HIRM (d) SIRM minero (e) 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 a +, where + is one grain, ++ is two grains and +++ is three grains.

Figure 6: Selected percentage of non-pollen palynomorph diagram from Loch of Tuquoy. Rare types are denoted by a +, 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, mean water table depth transfer function derived from testate amoebae from Ben Gorm (lower profile) and Craigmaud (upper profile), N.E. 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.