LOCH NAN GABHAR, MACHRIE MOOR, ISLAY

Palaeoenvironmental Fieldwork Report

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1. INTRODUCTION

This report describes fieldwork and preliminary analysis of palaeoenvironmental samples collected from Loch nan Gabhar, Machrie Moor, Islay (grid ref. NR 33789 48198; site code: MM2016). The fieldwork was carried out by a team of specialists from the University of Reading (Dr Karen Wicks, Project Director; Dr Rob Fry, Surveyor) and University of Wales Trinity Saint David (Dr Roderick Bale, Dendrochronologist; Selina Ali and Miguel Martins, both Marie Curie Research Fellows). Fieldwork was initiated following the discovery of *in situ* sub-fossil tree stumps in peat at the shoreline of Loch nan Gabhar – these having been exposed during an exceptional period of lowered groundwater level that had enlarged an area of previously submerged shoreline at the edges of the loch in 2016.

An initial ^{14}C date was obtained from the outer growth rings of an exposed tree stump (subsequently allocated label MM16-18). This was identified as *Quercus* in April 2016, yielding a date of 6930±30 BP (Beta-435773) that calibrates to 7840-7680 cal BP (95% probability) using the IntCal13 atmospheric calibration curve (Reimer *et al.*, 2013). Falling as it does relatively soon after 8200 BP, this date is a significant result as it demonstrates that the exposed woodland and underlying peat at Loch nan Gabhar have the potential to provide new palaeoenvironmental records of significance to studies of abrupt episodes of climate cooling during the early Holocene such as the 8.2 ka event. The significance of such episodes on the Mesolithic of northwest Europe has been elevated recently, having been shown to have impacted severely on the size of the hunter-gatherer population occupying northern Britain at this time (Wicks & Mithen, 2014; Waddington & Wicks, under review).

Defining the characteristics of abrupt episodes of climate change (e.g. Thomas *et al.*, 2007; Fleitmann *et al.*, 2008) and their regional expressions during the Early Holocene is demanding, as is distinguishing their impacts on the environment and human communities particularly in regions where their effects are superimposed over longer-term episodes of climate change (e.g. Rohling & Pälike, 2005). In northern Britain, this is particularly challenging as well-dated climate change proxies - particularly pollen records of sufficient chronological resolution - are surprisingly scarce. Tephrochronology has the potential to overcome some of these challenges by placing palaeoenvironmental records contained in peat (such as those found at Loch nan Gabhar) in a high-resolution chronological framework that can be traced over a wide spatial area.

When coupled with robust ^{14}C and tephra chronologies, sub-fossil wood remains have the potential to provide palaeoclimate records based on stable isotopes (carbon and nitrogen) from individually-resolved tree rings for comparison with Greenland ice core records and other climate proxies preserved in peat. As such, by utilising pollen and tephra records, dendrochronological techniques and ^{14}C dating this project is provided with an opportunity to begin to address the following questions:

i. What is the chronology of the sub-fossil woodland and peat deposits at Loch nan Gabhar?
ii. Is pollen sufficiently preserved to allow for vegetation history reconstruction?
iii. If pollen is sufficiently well-preserved, what does this tell us about the composition of woodland at a local, extra-local and regional scale?
iv. Is tephra sufficiently preserved to establish a tephrochronology for the site?
v. If so, can the site tephrochronology be correlated with palaeoenvironmental records from elsewhere in the North Atlantic region?
vi. What do the sub-fossil wood remains indicate concerning the composition of the local woodland on Islay during the Early Holocene?
vii. Are peat deposits underlying the sub-fossil woodland coincident with the 8.2 ka event or earlier episodes of abrupt climate change?
viii. If so, are vegetation impacts discernible in pollen records, particularly with regards to lead-in and lag responses?

ix. Do high-resolution (annual) stable isotope records in tree rings correlate with Greenland ice core evidence for climate change? How do these accord with corresponding pollen records and evidence for vegetation perturbations?
x. Do peat deposits overlying the sub-fossil woodland provide climate proxy records corresponding with mid- to late Holocene episodes of climate change?
xi. If so, what do such records suggest about the severity of episodes of climate change both in the past and those predicted in the future?

Site investigation involved topographic survey, recording and sampling of the woodland exposed at the foreshore of Loch nan Gabhar and sampling of peat for palaeoenvironmental analysis.

2. SITE DESCRIPTION

Loch nan Gabhar is a large freshwater loch situated in moorland in the southwest of Islay (Figs 1-3). Its major tributary debouches into the Kintra River approximately 500 metres to the northwest of the loch's northern flank (Fig. 2). A c. 1.5 metre bank of peat surrounds the loch, whilst a reed bed encroaches into shallow water on its western flank (Figs 4 & 47-8). Brecciated cobbles and pebbles form the foreshore surface at the southern flank of the loch, this being overlain by increasing depths of peat up to c. 50 cm or more thickness at the southeast and eastern edges. Tree stumps and branches have recently been exposed growing in or embedded within peat exposed at the surface of the foreshore at the southern and northern edges of the loch.

3. SURVEY, SAMPLING AND PRELIMINARY EVALUATION

3.1 Topographic survey

A topographic survey was undertaken using a Leica Smartnet differential GNSS system (precise to approximately 0.02m), to record the position of the tree stumps and branches exposed on the foreshore in relation to the edge of the water body and surrounding habitats (Figs 4-7). This was cross-referenced with the site labelling system allocated to all *in situ* tree stumps and substantial branches examined at the foreshore (e.g. wood sample MM16-01, MM16-02… and so on). Woodland was photographed and sampled for AMS dating and wood identification, with a proportion of larger wood samples being selected for dendrochronological analysis. Our field observations indicated that in most cases these were rooted in peat or sitting immediately above a transgressive fine sand unit. A list of dendrochronology, wood identification and ^{14}C dating samples is provided in Table 1.

3.2 Wood identification and AMS samples

In total, thirty one samples of wood were collected from *in situ* tree stumps and branches for wood identification and ^{14}C dating (MM16-01 to MM16-31; Figs 6-36). Preliminary wood identifications (n=15; Table 1) indicate that oak woodland is predominant within the vicinity of the loch, with some birch at the time that the sub-fossil woodland was in growth. Further wood identifications will be undertaken at the University of Reading to select, wherever possible, the outermost growth rings from short-lived species of wood for AMS ^{14}C dating, in addition to providing information about the form and composition of local woodland. AMS samples will be obtained via an application submitted to the National Radiocarbon Facility (NRCF) dating platform hosted by the University of Oxford.

3.3 Dendrochronology samples

The largest samples of wood were assessed at the UWTSD Dendrochronology Laboratory for their suitability for dendrochronological growth ring matching, with a view to constructing at least a partial site-dendrochronology augmented by ^{14}C dating. Methods employed at the UWTSD Dendrochronology Laboratory in general follow those described in English Heritage guidance (English Heritage, 1998).

Eight samples were evaluated: MM16-01 (Fig. 8) MM16-02 (Fig. 9), MM16-04 (Fig. 11), MM16-20 (Fig. 27), MM16-21 (Fig. 28), MM16-23 (Fig. 30), MM16-25 (Fig. 32) and MM16-28 (Fig. 33), with those containing sufficient (>50) annual growth rings being subsequently subjected to cleaning and growth-ring measurement (MM16-01, Fig. 37; MM16-02, Fig. 38; MM16-04, Fig. 39; MM16-23, Fig. 40; MM16-25, Fig. 41 and MM16-28, Fig. 4; Table 2). Two samples (MM16-20 and MM16-21) proved to be non-oak, diffuse porous species unsuitable for dendrochronology, whilst two further samples of oak (MM16-04 and MM16-23) lacked sufficient growth ring numbers to warrant analysis (Table 2).

A clean surface on a cross-section of wood was achieved by hand, using razor blades (Figs 37-42). The complete sequence of growth rings in each sample was measured to an accuracy of 0.01mm using a micro-computer based travelling stage (Tyers, 2004). Cross-correlation algorithms (Baillie

& Pilcher, 1973; Munro, 1984) were employed to search for positions where the ring sequences are highly correlated against each other.

Dendrochronology

Table 2 provides information concerning dimensions of wood cross-sections analysed, the number and width of growth rings present and whether bark or sapwood could be identified (in terms of presence or absence). Interpreting the results of the analysis has been problematic as samples could not be cross-dated against each other or against external reference chronologies from the UK and Ireland for the following reasons: (i) A lack of dating against external chronologies is likely to be a consequence of the woodland pre-dating the earliest British and Irish reference chronologies, if the ^{14}C date provided above provides a general indication of the age of the woodland community as a whole rather than a single tree, and (ii) The relatively low number of suitable tree remains from the site itself limits the establishment of a dendrochronological site sequence as anomalous growth rings present in many of the samples prevented cross-matching even within individual samples. For instance, the sample that contained the highest number of rings (MM16-28) exhibited a considerable number of growth suppressions and unmeasurable rings (e.g. c. 50 narrow growth rings at its outer edge; Figs 42-43) that meant that it proved difficult to cross date individual radii against each other on the basis of growth ring thickness. Had this been possible, it would have provided an internal control for the replication – and hence the reliability - of relative thicknesses with which to match corresponding growth rings in the outer areas of the cross-section. A further complication occurs in this sample caused by a large scar evident in Figure 42 that may have been caused by lightning, flood damage or browsing. By contrast, Figure 43 also provides an example whereby three radii show good agreement in growth ring boundaries during earlier stages of growth in MM16-28. MM16-01 also provided a match between three measured radii (Figs 37 & 44; Table 3).

Further growth ring anomalies were observed in MM16-02 (growth suppressed after the inner 35 rings such that it's outer remaining rings, c. n=100, could not be measured with confidence; Fig. 38) and MM16-25 (c. 50 unmeasurable rings at its outer edge; Fig. 41). A deterioration in the quality of the outer growth rings was observed in all samples. Such desiccation of the outer rings is likely to have arisen from wet-dry cycles attributed to fluctuations in ground water level endured by samples situated close to the shoreline over several millennia. The consequence of this is that no sapwood or bark has survived in any of the samples, which will prevent a precise date for the senescence of the trees from being established.

Despite extensive prospecting for tree remains both at the loch edge and in the loch itself, insufficient remains of oak trees were recorded with which to create a site master ring width chronology. Coupled with the 'bog oak' nature of the trees, and inherent periodic growth reductions it is likely that even with further samples it would prove difficult to provide absolute tree-ring dates for the trees. As it has not proved possible through dendrochronology and wiggle-match dating to ascertain whether the trees are contemporary, a program of AMS dating should provide some clarity.

Dendrochemistry

Stable isotope analysis (carbon, oxygen) of absolutely dated British oak tree-rings is proving to be an effective method by which to reconstruct growing season temperatures and circulation patterns beyond the limits of instrumental weather data (e.g. Young *et al*., 2012a,b; 2015). When calibrated against instrumental weather data from the northern hemisphere, well replicated growth pattern sequences have the potential to provide millennial-length tree ring isotope climate reconstructions (e.g. Bale *et al.,* 2011; Loader *et al*., 2013; Young *et al*., 2012b). The techniques employed rely upon absolutely dated samples, and in order to understand tree to tree variability, replication of results through analysis of multiple trees from the same site.

In the case of the tree samples listed in Table 2, where it has not proved possible to cross date the samples using dendrochronology, there is potential to use AMS dating coupled with high precision 'wiggle match' dating of growth rings a known distance in time apart (e.g. every tenth ring) to provide a dating framework on which any isotope measurements could be undertaken (i.e. should AMS dating suggest contemporaneity, it might be possible to identify likely periods of overlap amongst the samples). Single tree analysis is not recommended as the results and subsequent interpretation could be spurious due to the variability observed in growth ring reductions in individual samples. Furthermore, decay was observed to vary through the wood samples from inner to outer areas of the cross-sections. Such variable decay suggests that should isotopic analysis be undertaken, it should be done on the cellulose component rather than whole wood digests as these would yield unreliable results.

Interpreting the results of isotope analysis would be dependent on comparison with the temporal stability observed in modern oak isotope data sets from the British Isles, though wiggle match dated common shifts could be compared to other proxy data (e.g. Greenland ice core records). Annually resolved isotope analysis could only be possible on rings that are microscopically discernible, though the significance of abrupt climate change could still be realised in lower resolution (e.g. pentad or decadal) measurements (cf Leavitt, 1994).

3.4 Pollen and tephra sampling

Peat deposits underlying the woodland were sampled using a Russian peat sampler (Figs. 4, 6 & 45-7) for pollen and tephra analysis, and to provide AMS dating evidence. The position of the pollen core was established approximately 17 metres due east of the MM16-11 wood sample, at the southern end of the loch. A 1-metre peat core was collected – the top of the core coinciding with the surface of the peat within which the fossil woodland is rooted.

A peat bank situated at the southern edge of the loch foreshore was also sampled using two steel monolith tins (10x10x50 cm) to provide palaeoecological records post-dating the sub-fossil woodland (Figs 47-9). The position of the base of the lower monolith tin was coincident with the woodland surface, whilst a second overlapping monolith of peat was collected to capture a further c. 0.5 metre of palynomorph deposition likely to span later prehistoric and historic periods. Using funds provided by the University of Reading, six rangefinder AMS dates derived from the peat deposits will be obtained from Beta-Analytic Ltd. These will be used to support an application to the NRCF for additional dates to establish a high-resolution chronology for peat accumulation and associated evidence at the site.

4. FUTURE RESEARCH

Fieldwork and preliminary evaluation have demonstrated that a substantial ^{14}C- and tephra dated palaeoenvironmental dataset may potentially be compiled from sub-fossil wood remains and peat sampled at Loch nan Gabhar. Using the results of this preliminary evaluation, a program of work consisting of the preparation of a research proposal tailored to NERC-funded awards, along with an application to the NRCF for AMS dates is underway.

Specifically, this program will comprise of five work packages:

- Work Package 1 - NRCF application to obtain high-resolution ^{14}C chronologies for woodland (c. 15 dates) and peat deposits (c. 12 dates) exposed at the foreshore at Loch nan Gabhar.
- Work Package 2 – Analysis of tephra in peat (1.5 metres) to establish a tephrochronology to augment the site chronology.
- Work Package 3 - Wood identifications (16 samples) to establish form and composition of local woodland.
- Work Package 4 – Dendrochronological analysis of MM16-01, MM16-02, MM16-04, MM16-23, MM16-25 and MM16-28 encompassing: (i) Wiggle match dating of individual growth rings at known intervals from the measured sections of individual trees, and (ii) Isotopic analysis (cf. Woodley *et al.,* 2012) ideally undertaken on pentad or decadal block samples, that cover the same time period, and on extracted alpha cellulose due to decayed nature of wood.
- Work Package 5 – High-resolution pollen and microscopic charcoal analysis of peat samples (c. 30 samples) to obtain a vegetation history.

5. ACKNOWLEDGEMENTS

We owe thanks to Niall Coulthart for bringing the site to our attention and for his invaluable assistance in establishing ownership of the land upon which the site is situated. We are also indebted to Bowmore Distillery for giving us permission to access the site.

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LIST OF TABLES

LIST OF FIGURES

Table 1. List of samples collected from tree stumps and branches for ^{14}C dating, wood identification and dendrochronology.

Sample no.	Sample Code	Form	Taxa	Dendro sample	Comments
1	MM16-01	Stump	*Quercus*	Yes	At least 0.5m of peat under roots
2	MM16-02	Trunk fragment	*Quercus*	Yes	
3	MM16-03	Branch fragment	*Quercus*	Yes	
4	MM16-04	Stump	*Quercus*	Yes	
5	MM16-05	Branch fragment	-	-	
6	MM16-06	Branch fragment	*Quercus*	-	
7	MM16-07	Branch fragment	*Quercus*	-	
8	MM16-08	Branch fragment	-	-	
9	MM16-09	Branch fragment	-	-	
10	MM16-10	Branch fragment	-	Yes	
11	MM16-11	Branch fragment	-	-	
12	MM16-12	Branch fragment	-	-	
13	MM16-13	Branch / trunk fragment	-	-	
14	MM16-14	Branch / trunk fragment	-	-	
15	MM16-15	Trunk fragment	-	-	Not oak
16	MM16-16	Trunk fragment	-	-	Not oak
17	MM16-17	Branch fragment	*Quercus*?	-	
18	MM16-18	Stump	*Quercus*	-	
19	MM16-19	Trunk fragment?	-	-	
20	MM16-20	Trunk fragment?	-	Yes	
21	MM16-21	Branch	*Betula?*	Yes	
22	MM16-22	Branch / trunk	-	-	Moved by Rod
23	MM16-23	Stump	*Quercus*	Yes	
24	MM16-24	Stump	-	Yes	
25	MM16-25	Branch?	*Quercus*?	Yes	Semi-stratified
26	MM16-26	-	-	-	Non-oak from underwater
27	MM16-27	-	-	-	Non-oak from underwater
28	MM16-28	Stump	*Quercus*	Yes	
29	MM16-29	Branch?	*Quercus*	-	
30	MM16-30	Stump	*Quercus*?	-	
31	MM16-31	Stump	*Quercus*	-	

Table 2. Oak sample details

Sample	**Cross-section dimensions**	**Number of rings (unmeasured rings)**	**Sapwood /bark**	**Av. ring width (mm)**	**Date range**
MM16_01	130 x 120	100	Absent	1.15	1-100
MM16_02	140 x 130	35(+100h)	Absent	1.51	1-35
MM16_04	130 x 115	35	Absent	3.70	1-35
MM16_23	240 x 220	40	Absent	5.00	1-40
MM16_25	160 x 90	131(+50h)	Absent	0.87	1-131
MM16_28	370 x 290	230(+30h)	Absent	0.74	1-230

Table 3. T-value matrix between three measured radii from MM16-01 (t values >3.5 are considered to represent a possible match).

Filenames	-	-	MM_01_A	MM_01_B	MM_01_C
-	start	dates	12	13	1
-	dates	end	98	100	77
MM_01_A	12	98	*	5.74	7.04
MM_01_B	13	100	*	*	8.54
MM_01_C	1	77	*	*	*

Figure 1. Map of Islay showing location of Loch nan Gabhar (red circle).

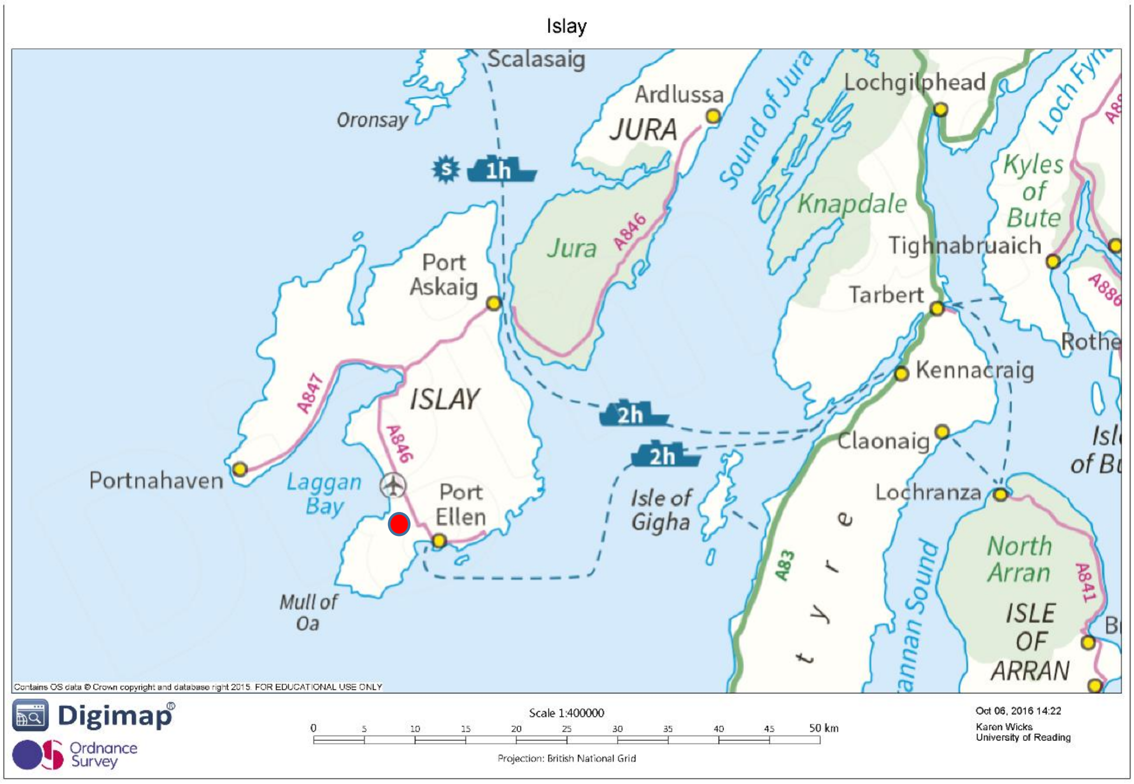

Figure 2. Topographic map showing the position of Loch nan Gabhar at 1:10,000 scale.

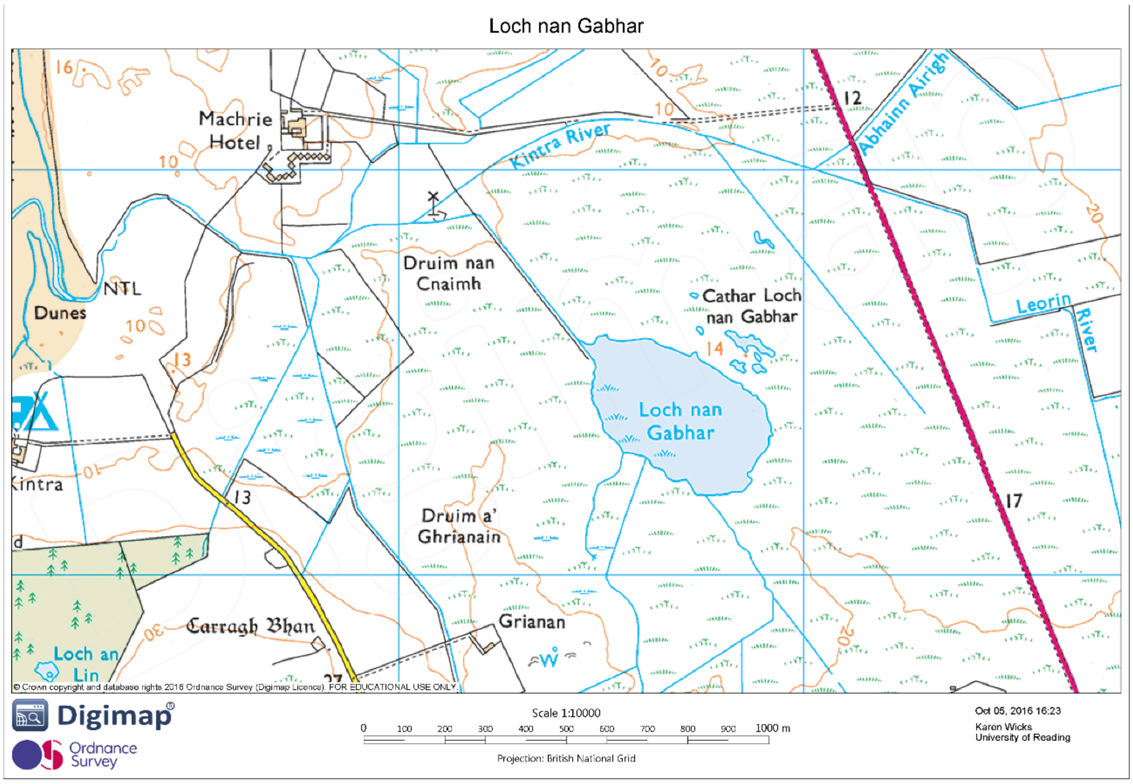

Figure 3. Photo looking northwest across Loch nan Gabhar, Islay.

Figure 4. Topographic survey map showing the distribution of tree stumps exposed at the shoreline of Loch nan Gabhar, along with the principle habitats surrounding the loch.

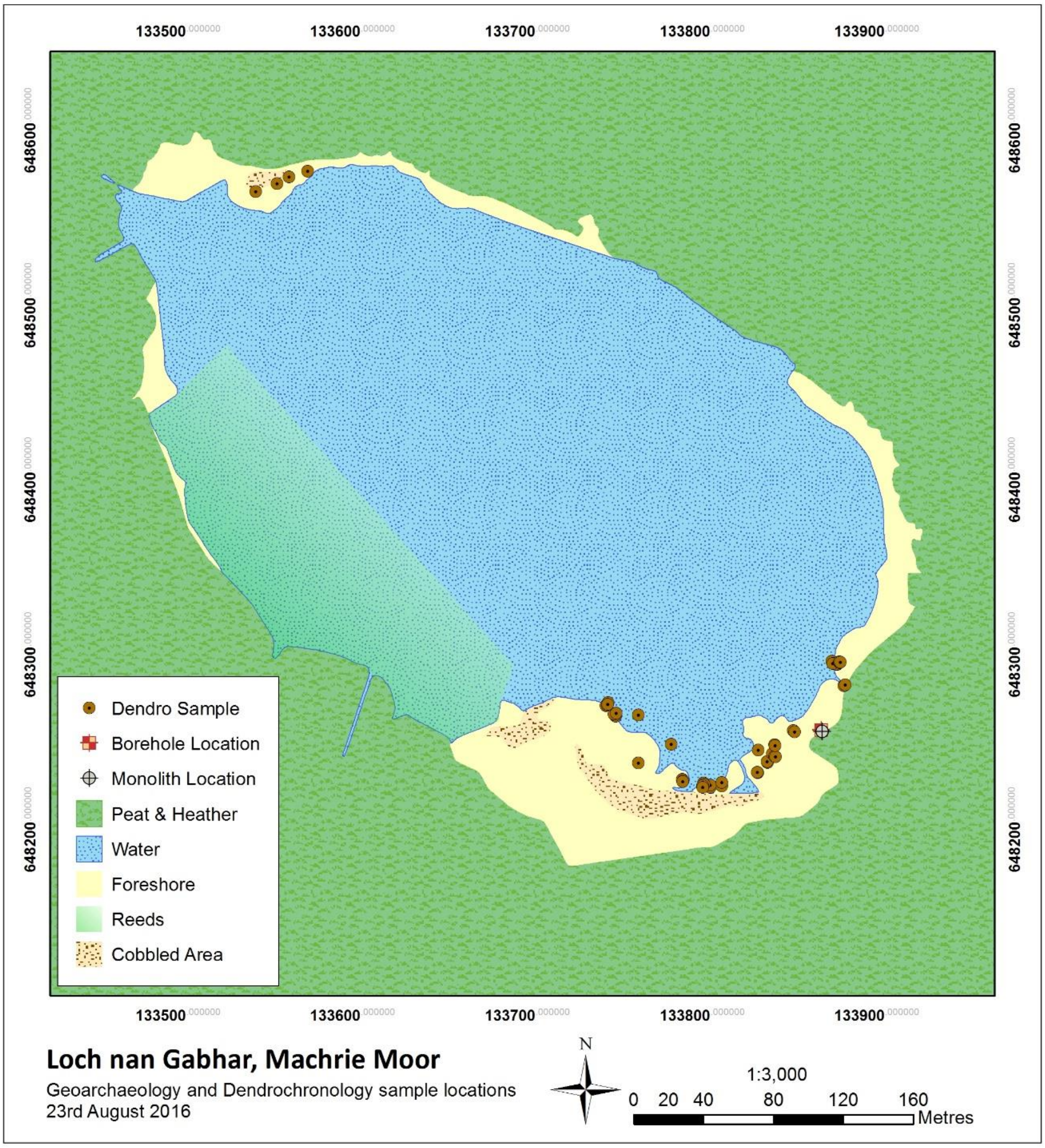

Figure 5. Photo showing Dr Rob Fry undertaking the topographic survey at Loch nan Gabhar.

Figure 6. Topographic survey map showing the distribution of tree stumps and branches exposed at the southern shoreline of Loch nan Gabhar.

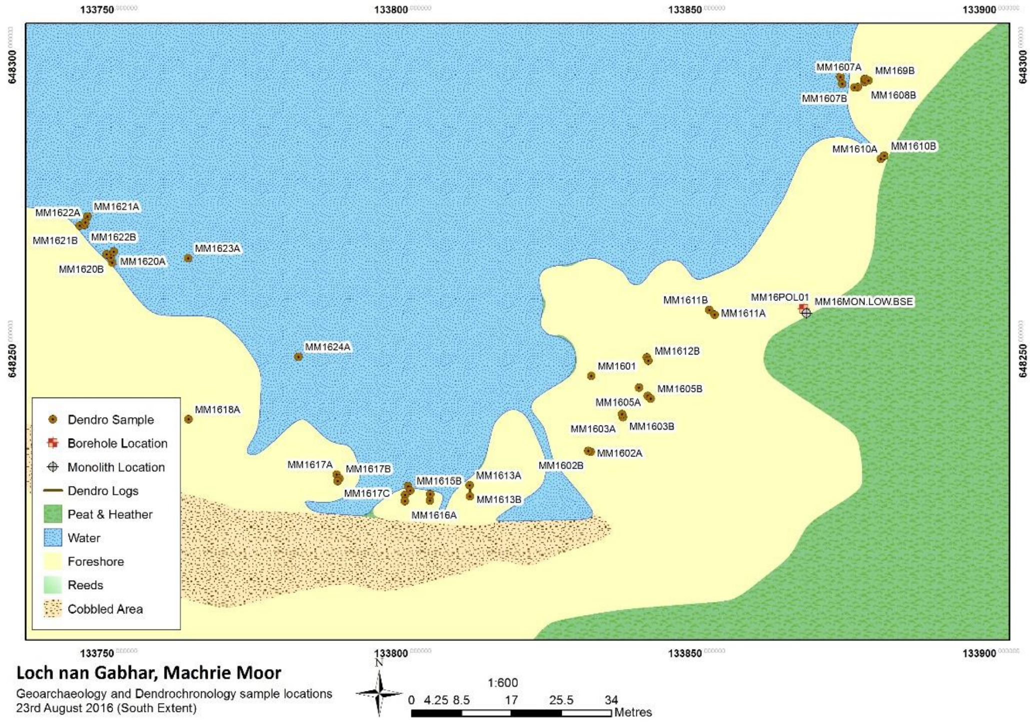

Figure 7. Topographic survey map showing the distribution of tree stumps and branches exposed at the northern shoreline of Loch nan Gabhar.

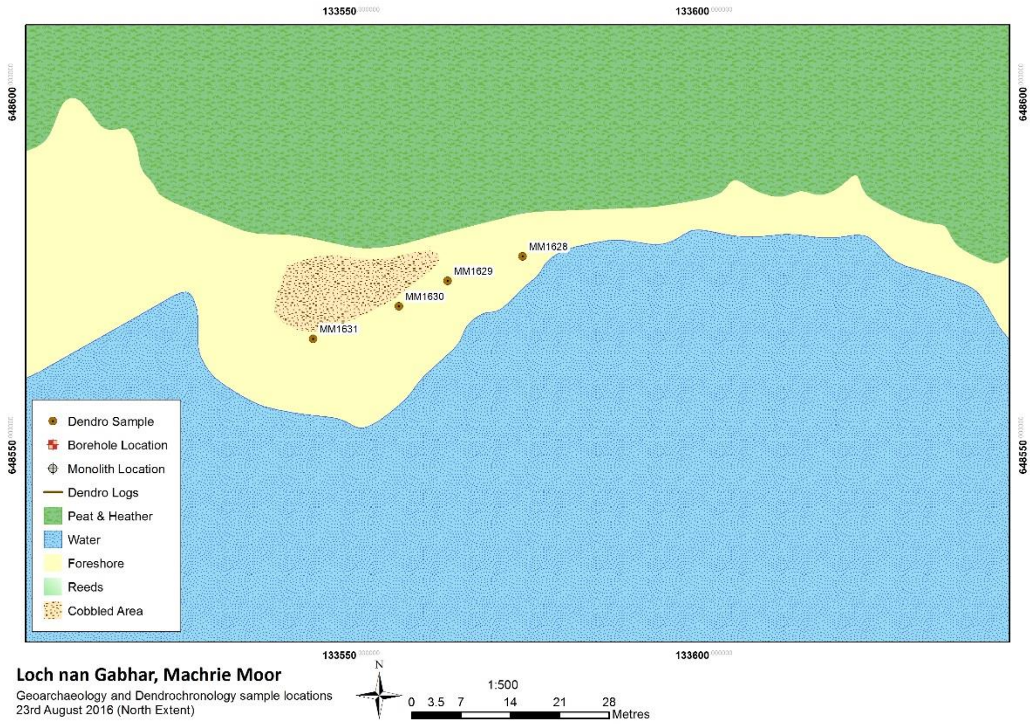

Figure 8. Photo showing MM16-01 Stump (*Quercus*)

Figure 9. Photo showing MM16-02 Trunk fragment (*Quercus*)

Figure 10. Photo showing MM16-03 Branch fragment (*Quercus*)

Figure 11. Photo showing MM16-04 Stump (*Quercus*)

Figure 12. Photo showing MM16-05 Branch fragment (*Quercus*?)

Figure 13. Photo showing MM16-06 Branch fragment (*Quercus*)

Figure 14. Photo showing MM16-07 Branch fragment (*Quercus*)

Figure 15. Photo showing MM16-08 Branch fragment

Figure 16. Photo showing MM16-09 Branch fragment

Figure 17. Photo showing MM16-10 Branch fragment

Figure 18. Photo showing MM16-11 Branch fragment

Figure 19. Photo showing MM16-12 Branch fragment

Figure 20. Photo showing MM16-13 Branch / trunk fragment

Figure 21. Photo showing MM16-14 Branch / trunk fragment

Figure 22. Photo showing MM16-15 Trunk fragment

Figure 23. Photo showing MM16-16 Trunk fragment

Figure 24. Photo showing MM16-17 Branch fragment (*Quercus*?)

Figure 25. Photo showing MM16-18 Stump (*Quercus*)

Figure 26. Photo showing MM16-19 Trunk fragment?

Figure 27. Photo showing MM16-20 Trunk fragment?

Figure 28. Photo showing MM16-21 Branch

Figure 29. Photo showing MM16-22 Branch / trunk

Figure 30. Photo showing MM16-23 Stump

Figure 31. Photo showing MM16-24 Stump

Figure 32. Photo showing MM16-25 Branch? (*Quercus* branch fragment)

Figure 33. Photo showing MM16-28 Stump (*Quercus*)

Figure 34. Photo showing MM16-29 (*Quercus*)

Figure 35. Photo showing MM16-30 Stump (*Quercus*)

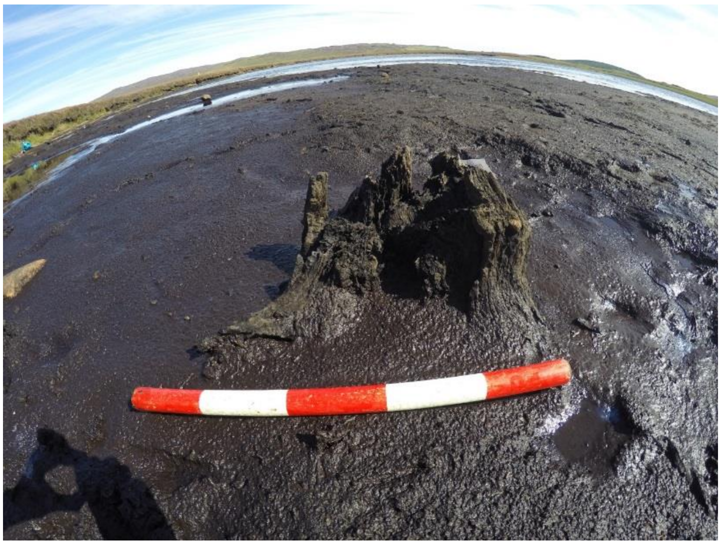

Figure 36. Photo showing MM16-31 Stump (*Quercus*)

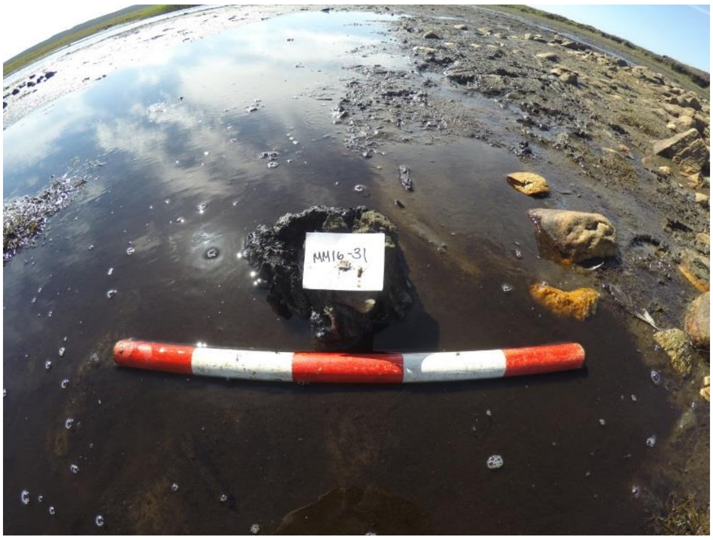

Figure 37. Photograph of sample MM16-01. Pins represent decadal blocks. The growth boundaries of rings after the final pin (around 15 rings) are too narrow to be distinguished.

Figure 38. Photograph of sample MM16-02. Pins represent decadal blocks. The growth boundaries of rings after the final pin (around 100 rings) are mostly too narrow to be distinguished.

Figure 39. Photograph of sample MM16-04. Pins represent decadal blocks. The wide distorted growth rings likely reflect the fact that only the root buttress remained of this tree, with the distortion reflecting that.

Figure 40. Photograph of sample MM16-23. Pins represent decadal blocks. The wide distorted growth rings likely reflect the fact that only the root buttress remained of this tree, with the distortion reflecting that.

Figure 41. Photograph of sample MM16-25. Pins represent decadal blocks. The growth boundaries of rings after the final pin are too narrow to be distinguished.

Figure 42. Photograph of sample MM16-28. Pins represent decadal blocks. The growth boundaries of rings after the final pin are too narrow to be distinguished. A large scar is evident to the right of the pith.

Figure 43. Visual matching between three measured radii from MM16-28. While the first 50 years from each radii show reasonable agreement the rest of the sequence contains many areas where the growth rings boundaries cannot be discerned and it is not possible to correlate the measured radii with confidence.

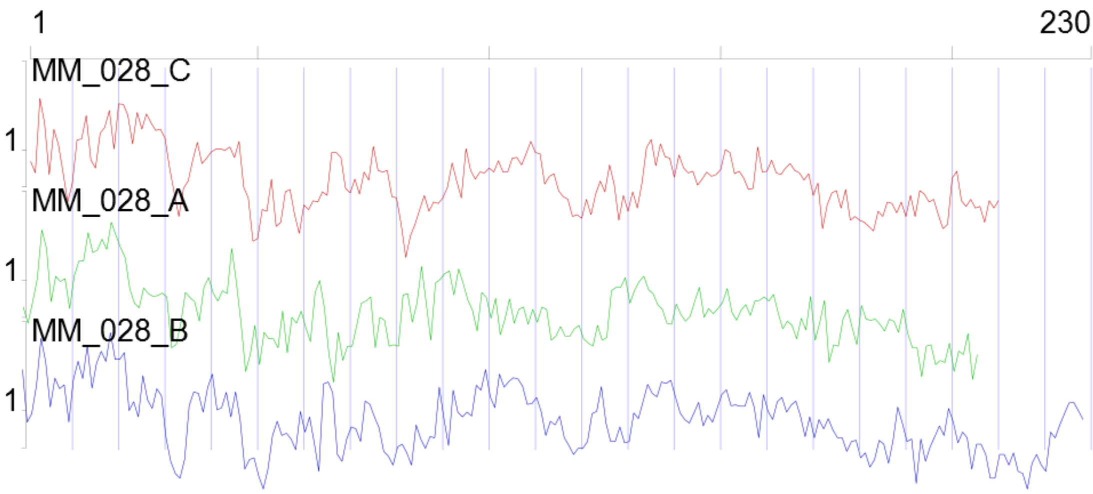

Figure 44. Visual matching of three measured radii from MM16-01

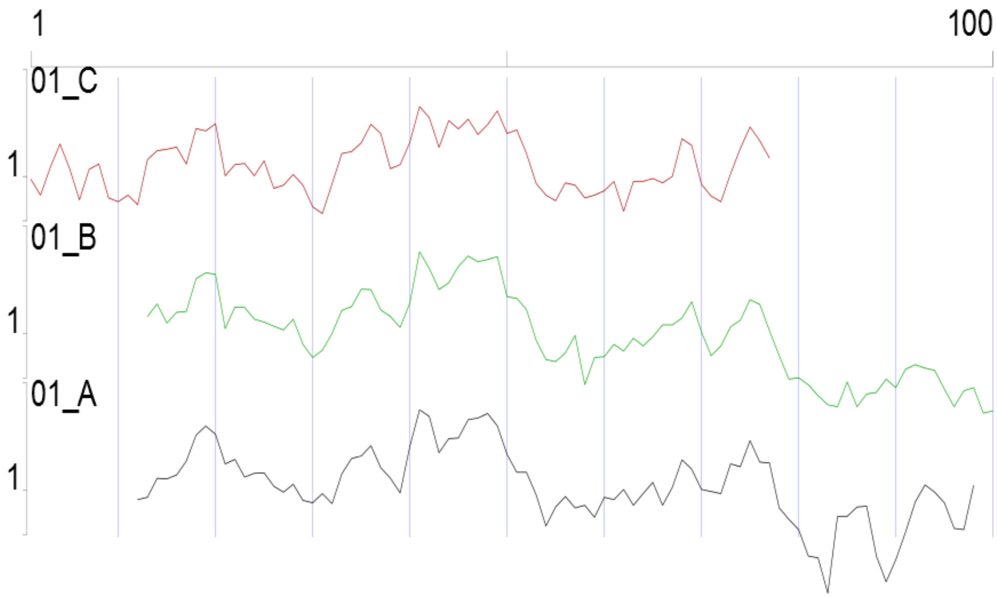

Figure 45. Peat sampling using a Russian corer for pollen analysis

Figure 46. Peat core collected from peat deposits beneath the fossil woodland.

Figure 47. Wrapping the peat core, with the peat bank providing the backdrop.

Figure 48. Section in peat bank exposed at the foreshore at the southern end of the loch.

Figure 49. Peat sampling of the peat bank section exposed at the southern end of the loch using monolith tins for pollen analysis.