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ORIGINAL ARTICLE

Prehistoric *Pinus* woodland dynamics in an upland landscape in northern Scotland: the roles of climate change and human impact

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Abstract Pollen, microscopic charcoal, palaeohydrological and dendrochronological analyses are applied to a radiocarbon and tephrochronologically dated mid Holocene (ca. 8500–3000 cal B.P.) peat sequence with abundant fossil *Pinus* (pine) wood. The *Pinus* populations on peat fluctuated considerably over the period in question. Colonisation by *Pinus* from ca. 7900–7600 cal B.P. appears to have had no specific environmental trigger; it was probably determined by the rate of migration from particular populations. The second phase, at ca. 5000–4400 cal B.P., was facilitated by anthropogenic interference that reduced competition from other trees. The pollen record shows two *Pinus* declines. The first at ca. 6200–5500 cal B.P. was caused by a series of rapid and frequent climatic shifts. The second, the so-called pine decline, was very gradual (ca. 4200–3300 cal B.P.) at Loch Farlary and may not have been related to climate change as is often supposed. Low intensity but sustained grazing pressures were more important. Throughout the mid Holocene, the frequency and intensity of burning in these open *Pinus–Calluna* woods were probably highly sensitive to hydrological (climatic) change. Axe marks on several trees are related to the mid to late Bronze Age, i.e., long after the trees had died.

Keywords *Pinus* · Pollen analysis · Climate change · Human activity · Scotland

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Introduction

In situ wood remains of *Pinus sylvestris* L. (Scots pine), bearing tool marks of prehistoric axes, were recovered from a blanket peat near Loch Farlary in Sutherland, northern Scotland (Fig. 1), during peat cutting. This paper describes the work undertaken to understand the environmental context of this unique archaeological find in Scotland. This has involved reconstructing vegetation and land-use histories, and investigating pedological changes and climatic factors that drive vegetation change. Archaeological interpretations of the axe marks are presented in Tipping et al. (2007).

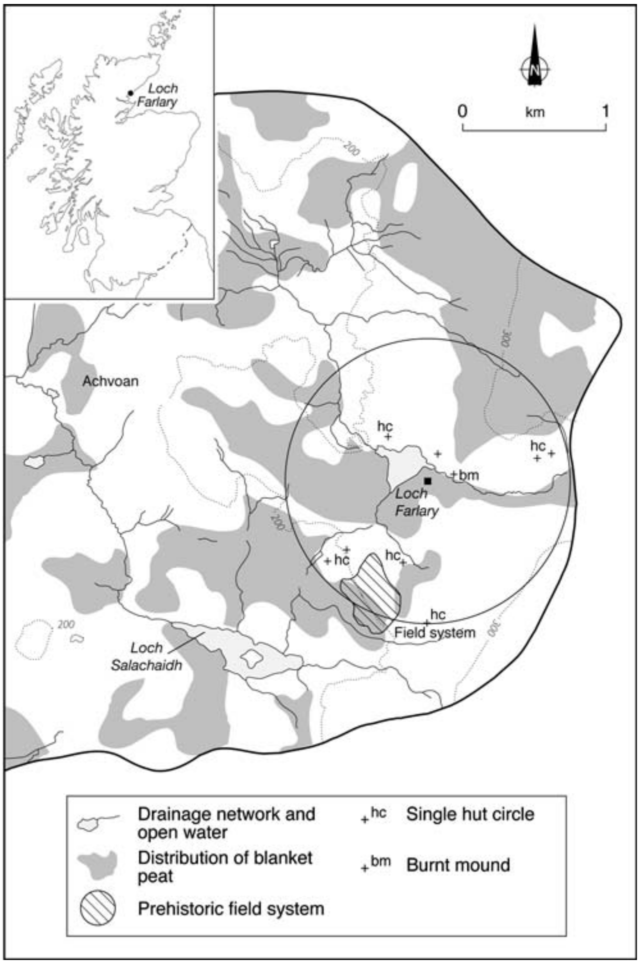

Fig. 1 Map of upper part of the Garbh Allt catchment, west of Golspie, Sutherland. The location of Loch Farlary, the distribution of blanket peat (based on mapping by the British Geological Survey at a scale of 1:63360), archaeological monuments and contours (in m) are shown. A *circle* of 1 km radius is used to suggest the probable maximum pollen catchment area. The location within Scotland is indicated on the *inset* map

Pinus woodland has an exceptionally complex history in the climatically sensitive region of northern Scotland. The dynamics of these woodlands, involving seemingly abrupt expansions and contractions of range, are often regarded as a response to climatic oscillations because of the apparent synchroneity of changes over large distances (Birks 1975; Bennett 1984, 1995; Dubois and Ferguson 1985; Bridge et al. 1990; Gear and Huntley 1991; Lowe 1993; Huntley et al. 1997). Such interpretations, however, have rarely drawn on independent palaeoclimatic analyses and so are often circular. Recent data sets (Anderson 1996, 1998; Davies 1999, 2003a; Tipping et al. 2006) have suggested that the link with climate change in the final *Pinus* decline at ca. 4000 cal B.P. is less clear. Anthropogenic activity in the form of woodland clearance has been regarded as implausible because of the widespread and synchronous nature of the *Pinus* collapse (Tipping 1994), but has not been entirely rejected (Birks 1975; Charman 1994; Bennett 1995). The discovery, then, of *Pinus* trees bearing well preserved axe marks of probable prehistoric age in blanket peat by Loch Farlary in northern Scotland provided the possibility of carrying out detailed investigations of the roles of climate and human activity in bringing about the decline in *Pinus*.

Loch Farlary is 5 km north-west of Golspie, close to the east Sutherland coast. Though near the coastline, it lies at a relatively high elevation (205 m OD) in the uplands above Dunrobin Glen, at the head of a catchment that drains west and then south to Rogart in Strath Fleet (Fig. 1). The bedrock is granitic, impermeable and gives rise to acid soils and peat. Blanket and basin peats typify large parts of the uplands above 150 m OD. The peat-covered area near Loch Farlary (referred to as the study area), where cut-marked *Pinus* wood recovered during peat cutting was investigated in this project, is indicated in Fig. 2. Also indicated are actively cut peat banks 1–4. These banks occur on low gradient slopes slightly higher than a shallow valley containing very small streams that drain to Loch Farlary. The banks provide peat faces of less than 1–1.25 m in thickness and with few wood remains. Most of the investigations reported on here relate to Bank 4.

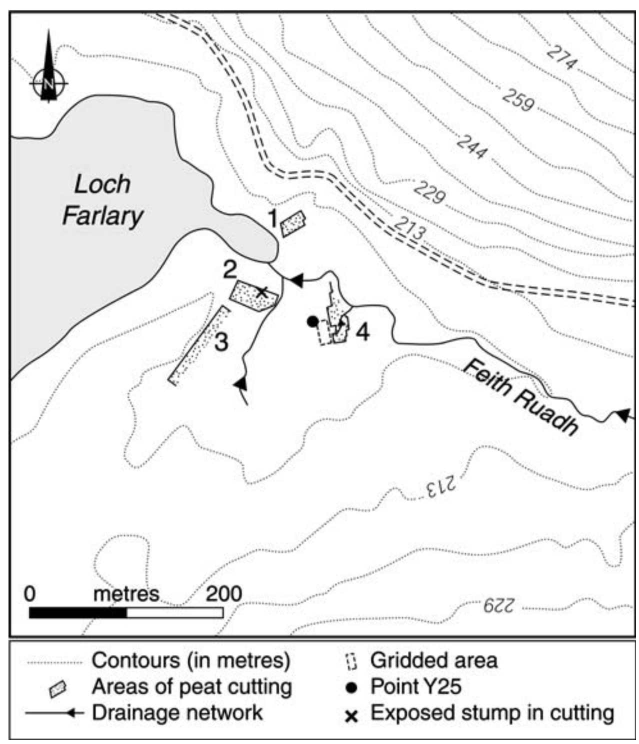

Fig. 2 The east shore of Loch Farlary showing the surveyed plan of the major peat banks (*1–4*) where cut-marked timbers were searched for, the gridded area west of Bank 4 that was intensively surveyed and the position of point Y25

Methods and data presentation

Topography, sediment stratigraphy and sampling

All features were surveyed using a Topcon Total Station. A grid, 25 × 12 m (A–Y and 14–25) was laid out over an area of 350 m^2. In each grid square, at 1 m intervals, the elevation of the surface with respect to OD (Ordnance Datum) was determined and the peat probed with a 2.5 cm internal diameter Eijelkamp peat corer to determine depth to bedrock and detect wood within the peat. Peat surface and bedrock contours were interpolated by computer modelling at 10 cm intervals (Fig. 3). The shapes and lateral extents of wood remains were defined by repeated probing.

The stratigraphy was recorded in the field at several locations and in detail along a transect from point A14 to beyond point Y25 (Fig. 4). Sediments from point Y25 (referred to as core/profile Y25) were also described in the laboratory (Table 1) from overlapping, closed-chamber Russian-type cores of 6 cm internal diameter and 1 m chamber length; these cores were used for all palaeoecological analyses. Samples of basal blanket peat for ^{14}C dating were also obtained at points A13 and L19 (Fig. 4) using an Abbey piston corer which effectively samples deposits lying directly on bedrock.

All pieces of wood detected within 80 cm of the peat surface in the grid area, i.e., those most threatened by disturbance, were excavated by hand. The part of the tree that was excavated was identified (trunk, root, branch), its shape sketched and whether, and where and from which direction it had been cut, was determined. Lifting was done by hand except for the exceptionally large Stump 2, which was lifted using ropes attached to the bucket of a mechanical excavator. All cut-marked pieces were retained, transported to the Conservation Laboratories of the National Museums of Scotland, washed free of peat and preserved after freeze drying in polyethylene glycol (PEG). Complete cross-sections of six vertical, in situ and entire (core to bark) *Pinus* stumps (Stumps 1, 3, 4, 6, 7 and 8; Fig. 5) were cut using a chain saw.

Radiocarbon and tephra dating

Seven peat samples from core Y25 were submitted for ^{14}C dating. Samples Beta-83358–Beta-83361 were 5 cm thick. The age was determined on the bulk samples using the

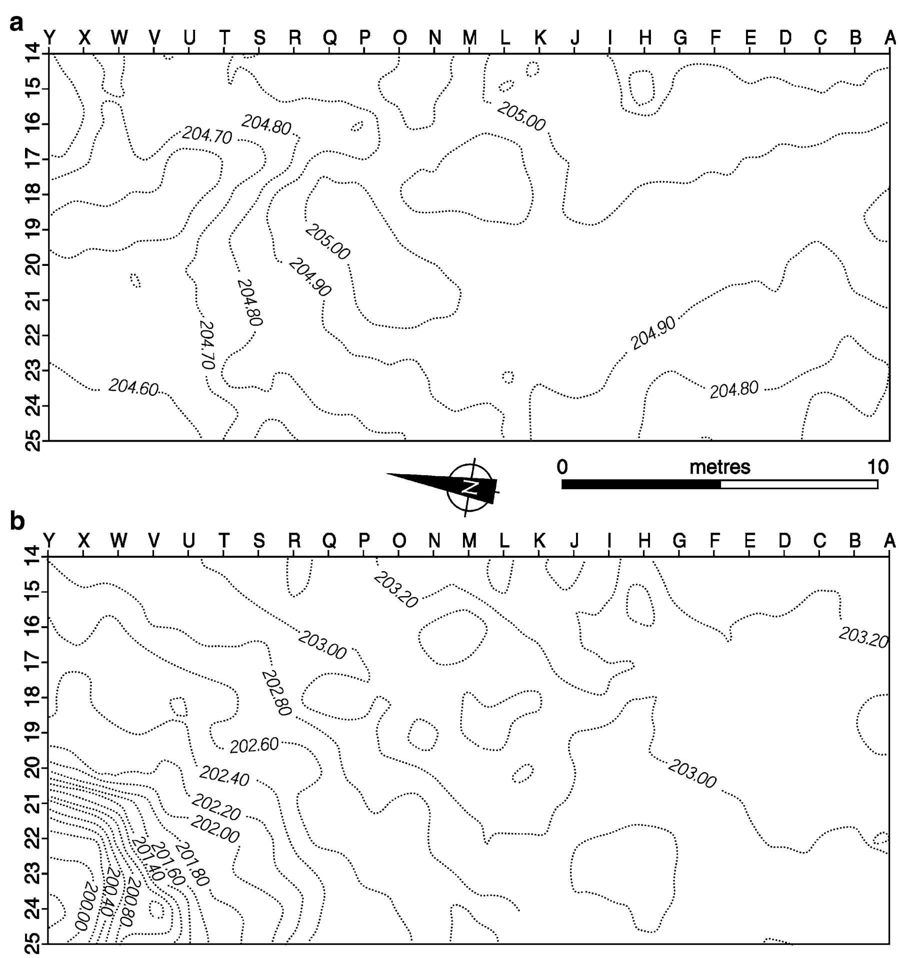

Fig. 3 **a** Interpolated ground surface contours surveyed to Ordnance Datum (OD) and **b** interpolated contours at the base of the peat within the grid (points A–Y; 14–25 at 1 m spacing)

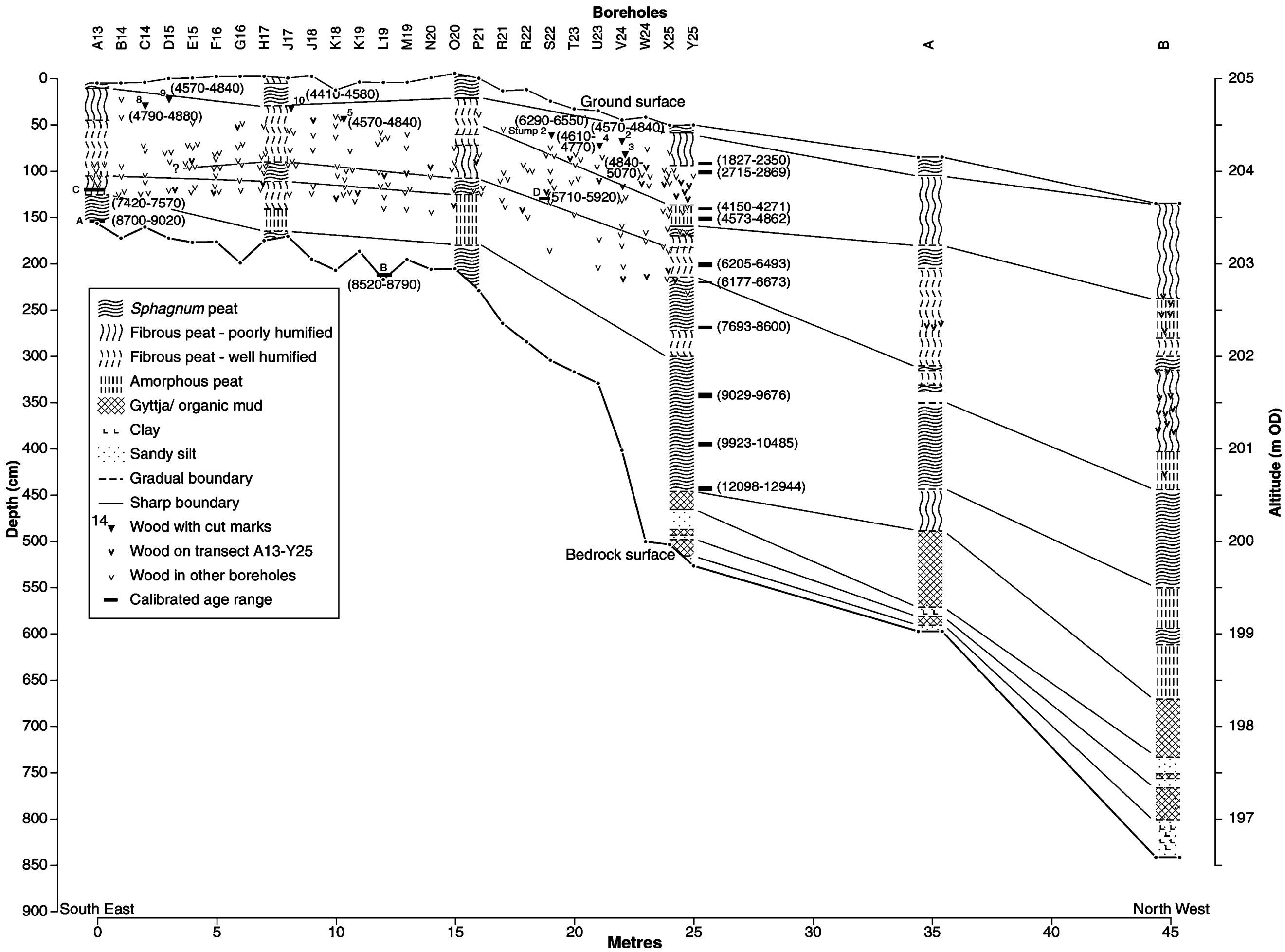

Fig. 4 Sediment stratigraphy recorded at six points along the slope between points A13 and B showing *a* depths of all timbers recorded in the grid, *b* depths of wood on the transect A13-A, *c* positions and sample numbers of ^{14}C-dated cut-marked wood, ^{14}C-dated blanket peat at points A13, L19 and the peat stratigraphy at Y25

conventional ^{14}C technique. Samples Beta-167560–Beta-167562 were also 5 cm thick. These samples were treated by alkali/acid/alkali washes and the humin fractions were assayed by conventional ^{14}C techniques. Samples from points A13 and L19 were 1 cm thick. These were also treated by acid/alkali/acid washes and the humin fractions assayed by AMS ^{14}C methods (AA-52518 to AA-52520). The INTCAL98 program (Stuiver et al. 1998) was used to calibrate the ^{14}C dates (Table 2).

Excavated roots subsampled for ^{14}C dating generally had bark. Shavings of the outermost few tree rings, obtained with a clean drill bit, were collected. The wood preservative, polyethylene glycol, was removed before AMS ^{14}C determinations were made on cellulose fractions.

The age-depth curve for profile Y25 was used to define depth ranges most likely to contain prehistoric tephras known in Scotland; in other words, a complete tephrostratigraphy was not aimed for. Contiguous peat slices, 1 cm thick, were taken from core Y25 over the intervals 35–50 cm, 80–100 cm and 155–170 cm. Peat slices were acid digested (Dugmore et al. 1992), residues examined with a petrological microscope and glass shards identified. Highest shard concentrations were noted at 42–44 cm, 81–82 cm, 90–92 cm and 169–170 cm. Shards from these depths were embedded in araldite resin, ground and polished to a thickness of around 75 μm and their geochemistry determined using a Cameca Camebax electron microprobe using quantitative WDS (wavelength dispersive) analysis. Results are given in Table 3.

Dendrochronology

The ages of six trees were established following methods in Ward et al. (1987) and Bridge et al. (1990), with ring width recorded to a precision of 0.01 mm from 2 to 4 radii per polished stump, using a Bannister incremental measurer linked to a computer. The CROS program (Baillie and Pilcher 1973) was used to test the significance of correla-

Table 1 Sediment stratigraphy at point Y25

Depth (cm)	Description
0–6	Dark brown, moderately humified, very fibrous peat with roots. Sharp lower boundary
6–16	Orange brown, poorly humified, fibrous *Sphagnum* peat with living roots. Sharp lower boundary
16–44	Dark brown, moderately humified, compact, fibrous peat, with fibrous sedge fragments and few living roots. Lower boundary gradual
44–86	Dark brown, increasingly humified, fibrous peat with fibrous sedge fragments. Lower boundary gradual
86–100	Brown, humified peat with herbaceous rootlets and occasional woody rootlets
100–105	Dark brown to black, well-humified herbaceous peat with some herbaceous rootlets. Upper boundary diffuse over 2 cm
105–114	Brown, humified herbaceous peat with herbaceous rootlets. Upper boundary diffuse over 2 cm
114–123	Dark brown to black, well humified herbaceous peat with some herbaceous rootlets. Upper boundary diffuse over 2 cm
123–133	Brown, humified herbaceous peat with herbaceous rootlets. Less recognisable macrofossil content than 105–114 cm
133–142	Dark brown to black, well-humified herbaceous peat with some woody detritus, probably roots at 133 cm. Upper boundary transitional over 1 cm
142–148	Light brown, humified bryophyte peat. Leaves of *Sphagnum* sp. present. Upper boundary transitional over 1 cm
148–164	Brown, humified bryophyte peat with herbaceous rootlets, and woody detritus concentrated between 148–150 cm. *Eriophorum* lens between 158–160 cm
164–176	Dark brown, well-humified mixed herbaceous and bryophyte peat. Woody rootlets at 171 cm. *Eriophorum* band at 168 cm
176–196	Brown humified bryophyte peat with some woody rootlets
196–301	Dark brown, well-humified herbaceous peat with some woody and herbaceous detritus. *Eriophorum* lens at 246–248 cm
301–316	Dark brown, well-humified mixed bryophyte and herbaceous peat
316–342	Dark brown, fibrous, well-humified bryophyte peat with some herbaceous rootlets
342–394	Dark brown, well-humified telmatic peat. Some recognisable fragments of herbaceous detritus. *Potamogeton*(?) fruit at 354 and 362 cm
394–410	Mid-grey clay with herbaceous detritus
410–422	Grey-brown (laminated?) clayey gyttja. More clay than 422–436 cm
422–436	Olive green and grey, homogeneous fine detrital gyttja with some clay. Occasional well-humified herbaceous stems
436–441	Grey silty clay over bedrock

tions between radii and between trees. Table 4 provides data on the length of record for each stump, mean ring width and variability (sensitivity).

Humification and pollen analytical investigations

Humification studies were carried out on contiguous 2 cm thick samples of peat taken from between 39 and 251 cm in core Y25. Peat between 149–156 cm and 233–244 cm was not available as it had been used for other analyses. Sample preparation and analysis followed the method of Blackford and Chambers (1993) using a calibrated Jenway 6061 colorimeter at a wavelength of 540 nm. Three replicates were taken per sample; within-sample variation was <0.5%. The mean of the replicates was taken as the percentage transmission value for each sample. The data are shown in Fig. 6 and have not been detrended (Blackford and Chambers 1995; Anderson 1996, 1998) because enhanced humification with depth does not seem to occur.

Samples of peat, 1 cm thick, from core Y25 were prepared for pollen analysis following standard techniques (Moore et al. 1991). Palynomorph identification was based on the key in Moore et al. (1991) and the pollen reference collection at Stirling University. Pollen and plant nomenclature follows Bennett (1994) and Stace (1997), respectively, with the exception of *Sorbus aucuparia* (cf. Boyd and Dickson 1987), and *Corylus/Myrica* (cf. Moore et al. 1991) which potentially includes pollen of *Corylus* and *Myrica*. *Vaccinium* type follows Bennett (1994). Grains were identified to *Erica* where colpus margins were sufficiently clear to permit distinction (cf. Oldfield 1959). The taxon Ericales includes all ericoid tetrads that could not be identified to a higher taxonomic unit. A total of 300 land pollen grains (TLP) were counted in each sample. *Pinus* stomatal guard cells (Parshall 1999; Froyd 2005) were identified following Trautmann (1953) and Hansen (1995). Microscopic charcoal fragments, i.e., black, opaque and angular fragments (Patterson et al. 1987), were recorded in four size classes: 10–25 µm, 26–50 µm and 51–75 µm, while fragments larger than 75 µm were individually recorded.

Percentage pollen, microfossil and charcoal data and charcoal data are presented in Fig. 7. Pollen percentage values are calculated relative to TLP, i.e., obligate aquatics and spores are excluded. Taxa outside the pollen sum are calculated on the basis of TLP + $\sum$taxon/group. Charcoal

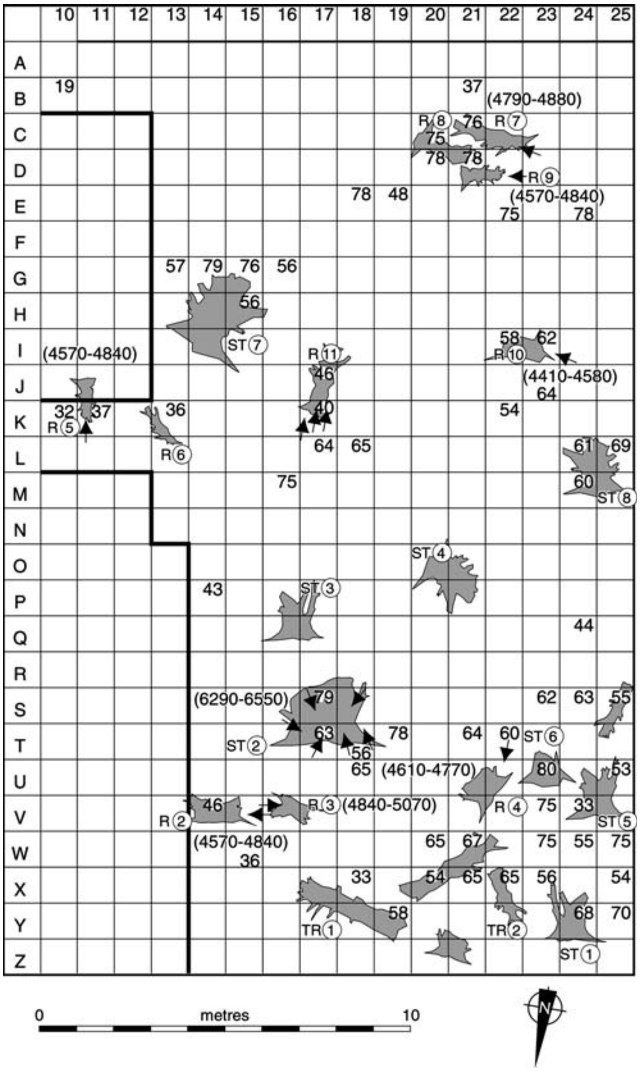

Fig. 5 Plan of the grid (grid squares A10–Z25) showing the locations and depths of all wood pieces hit during depth-probing <80 cm below the present peat surface (*numbers within grid squares*) and the approximate sizes and shapes of excavated wood pieces. The positions of roots and stumps with cut marks are indicated by *arrows*, and the calibrated age ranges of ^{14}C-dated timbers are given. *R* roots, *ST* stumps, *TR* trunks

and stomata are expressed as percentages of TLP. Diagrams were constructed using the programs TILIA and TILIA•GRAPH (Grimm 1991). Local pollen assemblage zones and subzones (LPAZ) were defined with the aid of CONISS (Grimm 1987).

Results

Topography and sediment stratigraphy

East and south of the grid, bedrock rises to the surface as a low mound (Fig. 2). Within the grid, the ground surface slopes gently northwest so that there is a fall of 40 cm between A14 and Y25 (Fig. 3) and then by a further 200 cm approximately over the next 80 m to Loch Farlary which lies at 202.5 m OD (Fig. 2). Bedrock surface contours show a uniform gentle slope that parallel the surface contours in the eastern part of the grid, but in the west there is a steep drop to a deep basin, a former arm of Loch Farlary.

Lacustrine sediments occur at the base of the three locations Y25, B and A within the deep basin (Fig. 4). The stratigraphy at Y25 is described in Table 1. Organic contents of these lake muds vary, with mineral-rich clays replacing organic muds (gyttja) above 410 cm and these in turn are overlain by gyttja above 396 cm. Above this, peat, the features of which are described below, prevails. On the higher mineral ground south of P21, basal peats are *Sphagnum* rich, but these give way to fibrous peats with Cyperaceae leaves and abundant wood remains. The uppermost ca. 30 cm of peat is *Sphagnum* rich and contains almost no wood. At point Y25, wood remains occur in two layers, at ca. 170 cm and 60–95 cm depth.

The distribution of wood remains found at all points in the grid has been superimposed in Fig. 4 on the generalised sediment stratigraphy between points A13 and Y25. This projects a 3D (three-dimensional) distribution pattern onto a 2D section. It shows that wood remains became common only after a substantial layer of peat had already formed. Wood was consistently recorded between 25 and 125 cm (Fig. 4). Wood remains recorded during excavation consisted of *Pinus sylvestris*, but slender stems of birch (*Betula*) were also rather common.

Chronology construction at Y25

The basal ^{14}C assay has a Late-glacial age but the peat lies above what is probably clay of Younger Dryas age. This may result from the presence of reworked carbon. Above this, the assays Beta-83359, 83360 and 83361 are on peat and are internally conformable. They suggest a steady peat accumulation rate of ca. 15 years cm^{-1} during the early Holocene. The tephra at 169–170 cm is distinctive because of its high K_2O and low CaO concentrations (>4.4 and <0.9%, respectively; Table 3). Comparison with published data (http://www.geo.ed.ac.uk/tephra) shows that it is most similar to the Hoy tephra, dated at only one site in Scotland to 5560 ± 90 B.P. (6177–6555 B.P.). Peat at point Y25 above ^{14}C assay Beta-83361 at 220 cm (ca. 8340 cal B.P.) and below the Hoy tephra formed at a markedly slower rate than earlier in the Holocene (ca. 40 years cm^{-1}). The calibrated age range of assay Beta-167562 from peat 17 cm above this tephra layer lies within the age range of the Hoy tephra. We infer from this that peat accumulation was high in this part of the profile The two tephra layers at 82–83 cm

Table 2 Details of the ^{14}C assays and calibrations obtained on sediments (a) Y25 and (b) at A13 and L19, and (c) on wood samples within the grid

Location	Depth (cm)	^{14}C Lab. code	^{14}C Age (B.P.)	$\delta\ ^{13}C$	Cal age[a] (cal B.P.)
(a) Calibrated ^{14}C dates from the profile at Point Y25					
Y25	50.0–55.0	Beta-167560	2660 ± 60	–26.2	2869–2715
Y25	100.0–105.0	Beta-167561	4220 ± 50	–27.1	4862–4573
Y25	150.0–155.0	Beta-167562	5570 ± 70	–24.7	6493–6205
Y25	217.0–222.0	Beta-83361	7500 ± 170	ND	8600–7963
Y25	290.0–295.0	Beta-83360	8410 ± 140	ND	9676–9029
Y25	342.0–347.0	Beta-83359	9090 ± 90	ND	10485–9923
Y25	389.0–394.0	Beta-83358	10570 ± 100	ND	12944–12098
(b) Calibrated ^{14}C dates from basal and mid-depth peats at points A13 and L19					
A13	151.0–150.0	AA-52518	7995 ± 45	–28.1	9020–8700 (93.2%)*
L19	211.0–210.0	AA-52519	7860 ± 45	–27.7	8790–8520 (82.3%)*
A13	120.0–119.0	AA-52520	6605 ± 40	–28.7	7570–7420 (95.4%)*
(c) Calibrated ^{14}C dates from wood excavated within the grid and sampled by SNH					
V14-15 (R2)		AA-53143	4185 ± 40	–23.6	4840–4570 (95.4%)*
V16 (R3)		AA-53144	4395 ± 50	–24.4	5280–5170 (11.9%)*
					5130–5100 (1.7%)*
					5070–4840 (81.8%)*
U/V21–22 (R4)		AA-53145	4195 ± 40	–25.5	4840–4780 (20.6%)*
					4770–4610 (70.5%)*
					4600–4570 (4.3%)*
S/T16-18 (S2)		AA-53146	5630 ± 55	–24.4	6550–6290 (95.4%)*
K11 (R5)		AA-53147	4175 ± 40	–25.1	4840–4570 (95.4%)*
C20–21 (R8)		AA-53148	4260 ± 45	–25.2	4970–4930 (3.0%)*
					4880–4790 (56.3%)*
					4770–4620 (36.1%)*
D21–22 (R9)		AA-53149	4175 ± 40	–25.2	4840–4570 (95.4%)*
I22–23 (R10)		AA-53150	4020 ± 40	–25.1	4790–4760 (1.2%)*
					4620–4590 (1.5%)*
					4580–4410 (92.7%)*
East of Z10		GU-3964	4140 ± 50	–26.2	4830–4450 (95.4%)*

ND not determined

* Probability

[a] 2σ range

and 90–92 cm are geochemically similar to each other (Table 3), and both can be correlated to published analyses of the Hekla 4 tephra found in Scotland (http://www/geo.ed.ac.uk/tephra) which has been dated to 3833 ± 11 B.P. (4150–4271 cal B.P., Dugmore et al. 1995b) or 4240–4280 cal B.P. (Hall et al. 1994). The primary deposit appears to be at 91–92 cm. Tephra shards were also found in nearly all samples between 83 and 90 cm. It is most likely that these shards were reworked from the initial airfall recorded at 91–92 cm. The reworked shards were concentrated between 82 and 83 cm. The tephra at 42–44 cm can be geochemically correlated with the Glen Garry tephra which has a calibrated age of 1827–2350 cal B.P. based on three ^{14}C dates (Dugmore et al. 1995a). These tephrochronological horizons are in good agreement with the available ^{14}C dates (Table 2a). The evidence points to continuous peat growth throughout later prehistory but with a gradually increasing peat accumulation time (from ca. 30–40 years cm^{-1} at about 2000 cal B.P).

Dendrochronology

The six trees that were investigated were long lived (Table 4), especially in comparison with other published sequences (Gear 1989; Bridge et al. 1990; Daniell 1997). Stumps 3, 4 and 7, though long lived, do not cross correlate with any other stump. This may indicate that *Pinus* trees

Table 3 Results of electron probe microanalysis of tephra shards from sediments at point Y25

Depth	SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	Total
43.5	71.99	0.44	12.52	3.31	0.01	0.36	2.16	3.91	1.98	96.69
43.5	71.99	0.44	12.52	3.31	0.01	0.36	2.16	3.91	1.98	96.69
43.5	71.52	0.52	12.46	3.71	0.05	0.38	2.35	4.10	2.08	97.16
43.5	71.11	0.49	12.65	3.60	0.04	0.36	2.43	3.93	2.01	96.62
43.5	71.06	0.50	12.48	3.66	0.05	0.37	2.29	3.83	1.95	96.17
43.5	70.65	0.48	12.19	3.55	0.07	0.35	2.18	4.02	2.01	95.51
43.5	70.61	0.48	12.31	3.55	0.07	0.37	2.29	3.86	2.00	95.53
43.5	70.03	0.57	12.66	4.01	0.10	0.41	2.44	4.16	1.86	96.23
43.5	69.20	0.63	12.87	4.09	0.09	0.51	2.72	3.91	1.88	95.89
43.5	68.79	0.62	12.60	4.29	0.05	0.54	2.80	4.36	1.75	95.80
43.5	67.69	0.90	12.96	4.56	0.10	0.91	3.18	4.27	1.70	96.25
43.5	59.90	1.18	13.44	7.47	0.08	2.80	6.53	3.32	1.11	95.82
82.5	72.31	0.10	12.95	1.86	0.08	0.01	1.27	4.99	2.73	96.31
82.5	72.23	0.09	12.81	1.90	0.09	0.00	1.31	4.53	2.84	95.80
82.5	71.80	0.13	12.93	1.72	0.06	0.01	1.23	4.40	2.82	95.10
82.5	71.78	0.11	12.74	1.88	0.09	0.03	1.35	5.23	2.79	95.99
82.5	71.37	0.12	12.60	1.94	0.13	0.00	1.31	4.94	2.88	95.29
82.5	67.81	0.19	13.75	3.94	0.16	0.04	2.42	5.09	2.20	95.59
82.5	66.37	0.27	14.02	4.60	0.20	0.04	2.68	4.88	2.15	95.20
91.5	72.80	0.05	13.03	1.86	0.09	0.03	1.32	3.57	2.94	95.69
91.5	72.43	0.09	13.22	1.91	0.12	0.05	1.30	4.81	2.75	96.67
91.5	72.30	0.07	12.92	1.96	0.10	0.05	1.36	4.97	2.82	96.55
91.5	72.21	0.10	12.69	1.89	0.09	0.04	1.34	4.90	2.78	96.03
91.5	72.10	0.04	12.82	1.86	0.07	0.01	1.25	4.82	2.81	95.79
91.5	72.06	0.09	13.15	1.85	0.10	0.05	1.28	4.59	2.78	95.95
91.5	72.05	0.10	12.90	1.83	0.11	0.00	1.42	4.38	2.80	95.58
91.5	71.97	0.09	12.97	1.87	0.10	0.06	1.26	4.92	2.83	96.06
91.5	69.89	0.10	13.85	2.77	0.15	0.00	1.89	4.66	2.50	95.81
91.5	69.67	0.19	13.72	2.92	0.13	0.07	1.96	4.28	2.47	95.42
91.5	69.06	0.17	13.76	3.56	0.18	0.08	2.23	5.36	2.36	96.76
91.5	68.46	0.22	13.92	3.42	0.16	0.07	2.29	5.51	2.36	96.41
91.5	68.41	0.23	13.67	3.63	0.21	0.07	2.18	5.18	2.38	95.95
169.5	69.93	0.19	14.37	2.30	0.06	0.22	0.83	5.52	4.64	98.07
169.5	69.88	0.15	14.20	2.23	0.06	0.15	0.76	5.91	4.44	97.78
169.5	69.83	0.17	13.99	2.12	0.03	0.10	0.61	5.43	4.67	96.95
169.5	69.77	0.15	14.02	2.00	0.07	0.16	0.67	5.74	4.60	97.19
169.5	69.57	0.17	14.16	1.88	0.01	0.12	0.63	5.11	4.66	96.30
169.5	69.51	0.19	13.99	2.02	0.04	0.13	0.67	4.99	4.62	96.16
169.5	69.26	0.17	13.89	2.22	0.03	0.16	0.73	5.50	4.47	96.43
169.5	69.16	0.19	14.32	2.14	0.08	0.22	0.80	4.28	4.46	95.64
169.5	68.90	0.18	13.97	2.18	0.08	0.18	0.82	4.87	4.73	95.91
169.5	68.74	0.17	13.99	2.07	0.05	0.19	0.65	5.25	4.48	95.58
169.5	68.60	0.18	13.93	2.03	0.02	0.09	0.64	5.38	4.51	95.38
169.5	68.00	0.18	13.91	2.03	0.07	0.19	0.75	5.74	4.45	95.31

Depths (cm) refer to the midpoint of 1 cm thick samples. Compounds are expressed in terms of percentages of the totals; total iron is expressed as FeO

Table 4 Lengths of records and ring-width statistics for the six pine stumps analysed

Stump	Length of record (years)	Mean width (mm)	Sensitivity (mm)
1	265	80	0.18
3	237	66.9	0.24
4	143	133.7	0.26
6	154	102.8	0.22
7	368	98.2	0.2
8	137	82.2	0.27

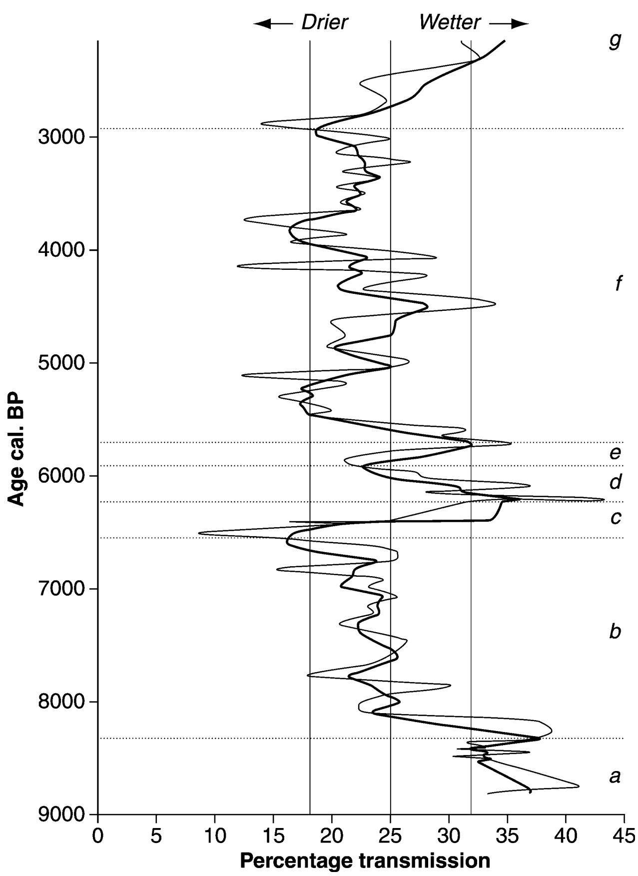

Fig. 6 Percentage transmission values (*thin line*) and the running mean of three values (*thick line*) plotted against age. The zonation is based on statistically significant changes, those exceeding 1σ of the mean obtained for all analyses

colonised peat surfaces intermittently for a long time. Stumps 1, 6 and 8 cross correlate with each other and are considered to have grown contemporaneously. Stump 6 began to grow 21 years earlier than Stump 1, which was only 3–4 m distant (Fig. 5). Stumps 1 and 8, 13 m apart, began to grow in the same year. Stump 1 outlived Stump 8 by 138 years. The chronology of 285 years, which is based on the cross-correlated stumps, is floating. Radiocarbon dates are not available for the stumps; the depths at which they were recorded, however, suggest that these trees are within the same age range as those for which ^{14}C dates are available, i.e., 4600–4800 cal B.P. (Table 2c).

Hydrology, fire, vegetation and land-use histories

The results relating to these aspects, including the pollen diagrams, are presented in Figs. 6 and 7. These are considered in the context of the "Discussion" which follows.

Discussion

Blanket peat inception and climate change

The data from the basal part of core Y25 (ca. 8500–8200 cal B.P.) suggest wet and acidic fen conditions. The vegetation consisted mainly of *Sphagnum*, Cyperaceae and *Salix* and supported open pools with *Menyanthes trifoliata* and *Typha angustifolia* (Fig. 7c). On granite bedrock surfaces that lay ca. 1.5 m higher, a *Sphagnum*-rich herbaceous blanket peat formed and spread rapidly between 9000 and 8500 cal B.P. (cf. ^{14}C dates at A13 and L19; Fig. 4; Table 2b) when conditions appear to have been exceptionally wet (Fig. 6). It is most likely that blanket peat establishment was driven by wet soil conditions. The date for the onset of this wet phase has not been established at Loch Farlary. Tipping (1996) suggested that a wet phase commenced in northern Scotland at ca. 10200–9800 cal B.P. The local vegetation—the record begins at ca. 8500 cal B.P.—included open *Betula* woodland with *Salix*, *Corylus*, *Sorbus* and *Juniperus*. This grew on mineral soils and probably also wet, albeit thin, blanket peat.

Local expression of large-scale climate change at 8200 cal B.P.

At ca. 8300–8200 cal B.P., peat accumulation in the deep basin slowed markedly to ca. 40 years cm^{-1}, i.e., about three times slower than before. Fen peat at point Y25 accumulated no faster after ca. 8200 cal B.P. than the blanket peat at A13. There was a pronounced shift at this time to a markedly drier peat surface (Fig. 6). Bog pools seem to have dried out and the contribution of *Sphagnum* declined (Fig. 7c). This pronounced shift to drier conditions in the record at Farlary appears to be contemporaneous with the major Holocene climatic excursion in the North Atlantic region (O'Brien et al. 1995; Alley et al. 1997; Bond et al. 1997; Stager and Mayewski 1997; Klitgaard-Kristensen et al. 1998; Nesje and Dahl 2001). Reduced precipitation and/or an increase in temperature may have been responsible for increased bog dryness at

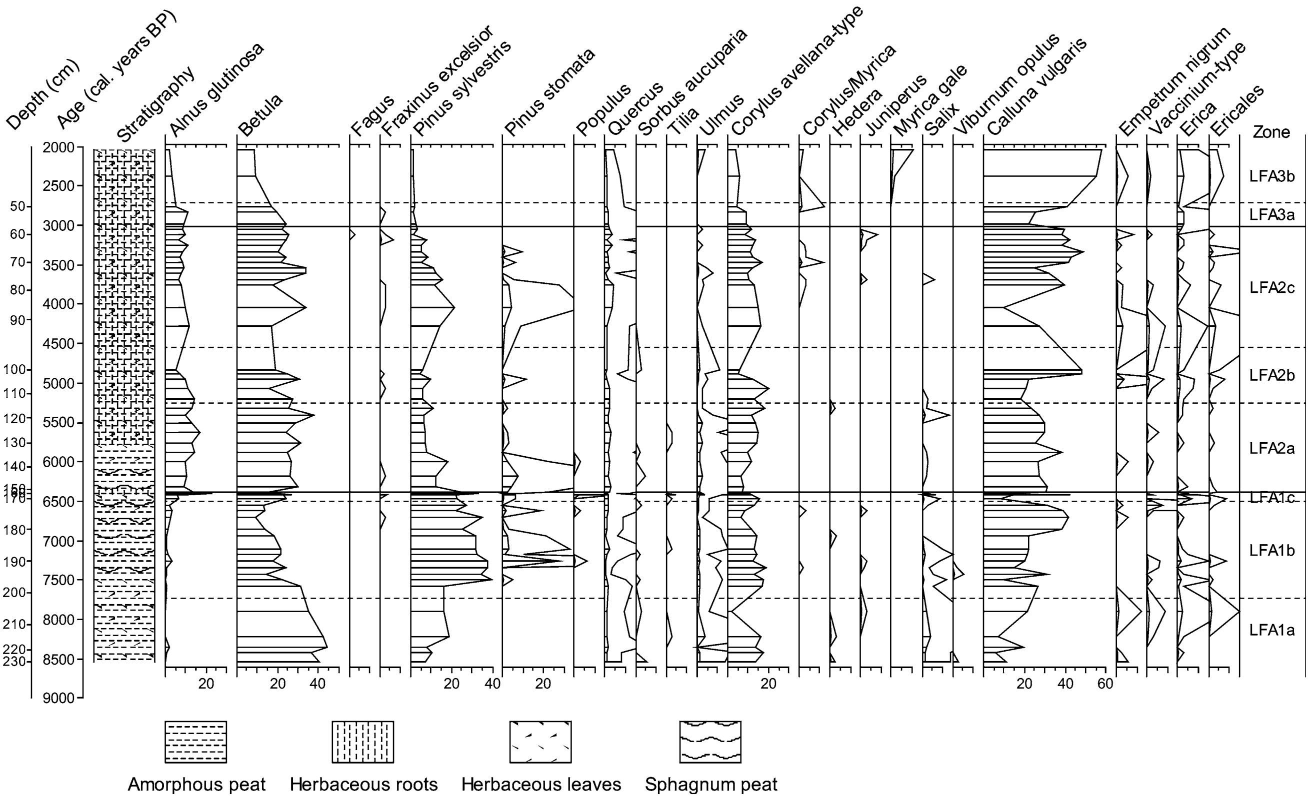

Fig. 7 Percentage based pollen and microfossil diagram for core Y25 plotted against age (cal B.P.; depths are also indicated). Local pollen assemblage zones and subzones were determined using CONISS

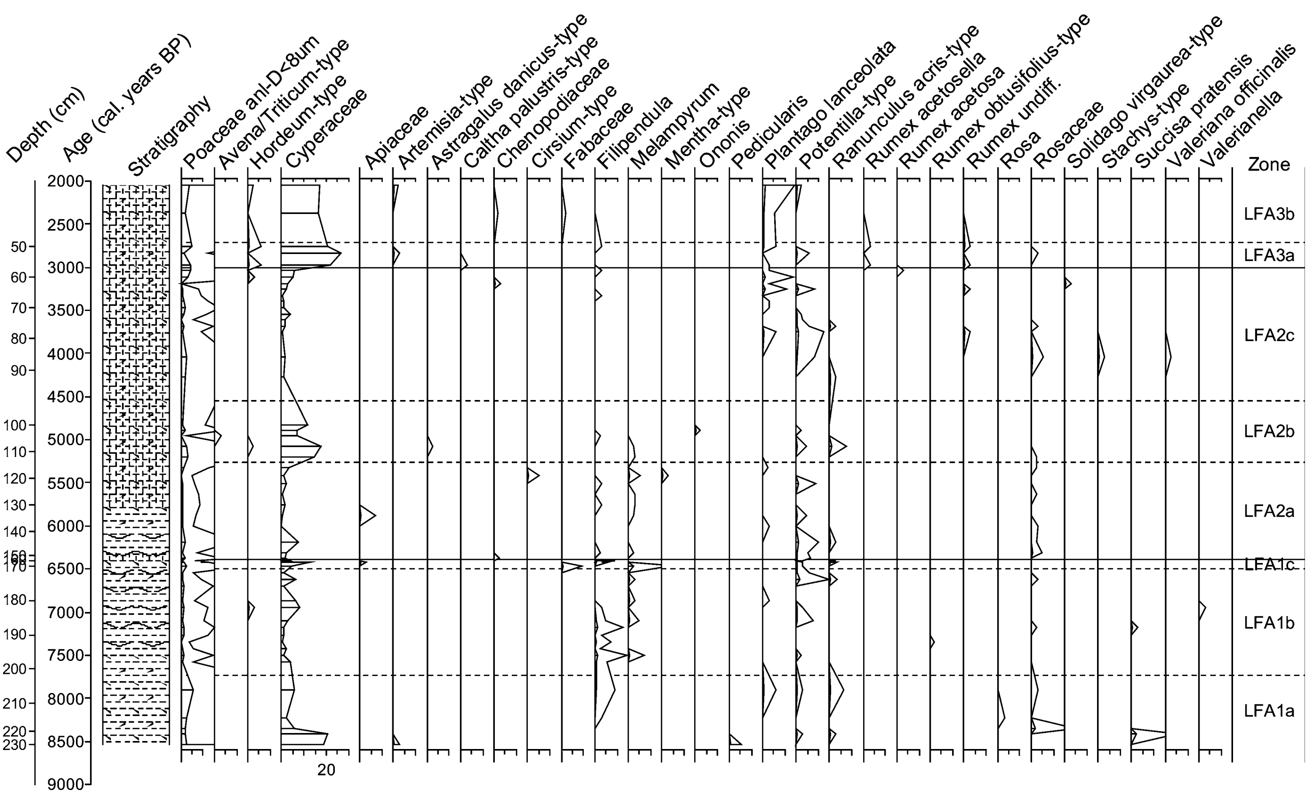

Fig. 7 continued

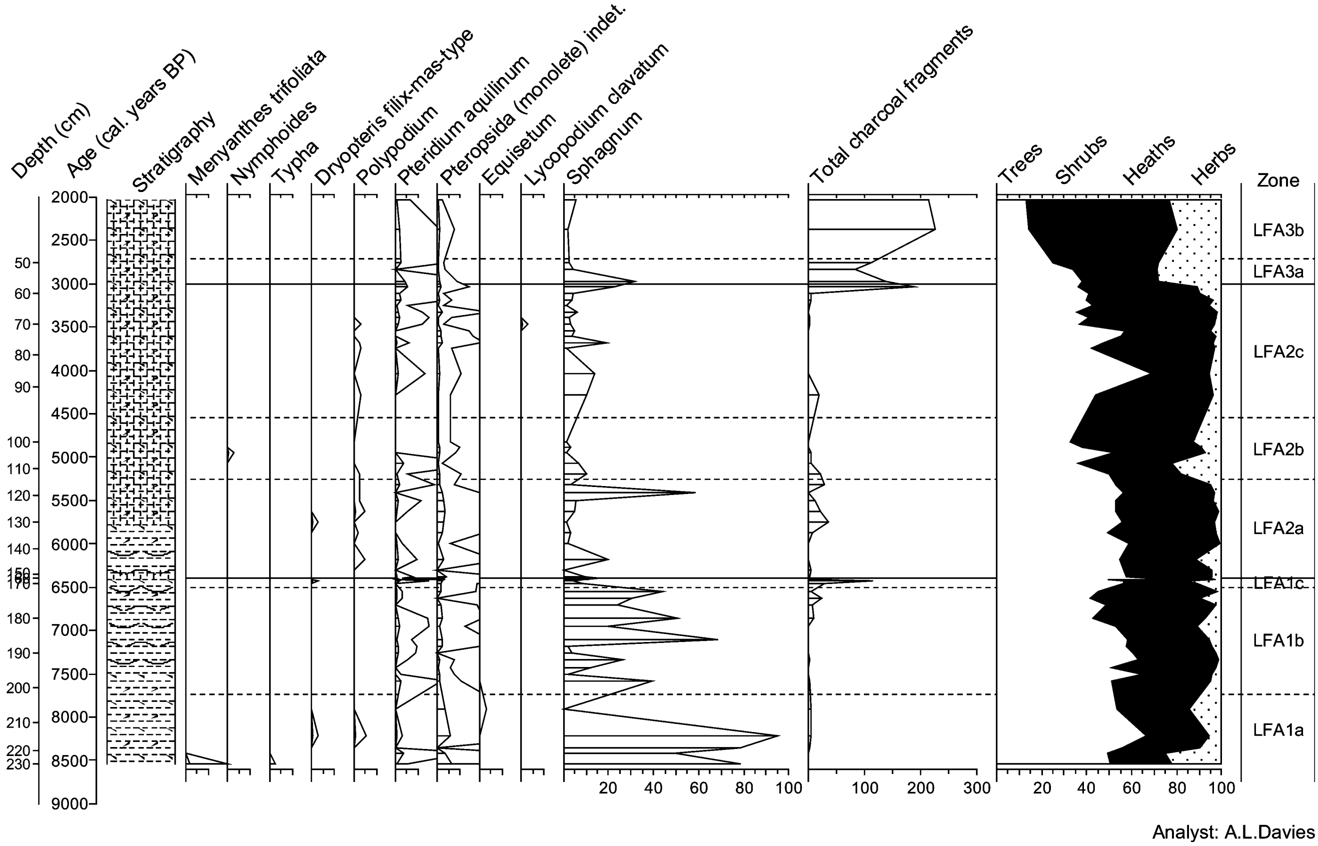

Fig. 7 continued

this time. The latter is unlikely given foraminiferal records from marine sediments northeast of Scotland indicate a 2°C reduction in temperatures (Klitgaard-Kristensen et al. 1998). Interestingly, the evidence suggests that the mire surface at Farlary continued to be dry for the next ca. 2,000 years (Fig. 6). The 8.2 ka climatic oscillation is usually regarded as brief but there is still considerable uncertainty as to the age and duration of this oscillation (cf. Rohling and Pälike 2005). At Farlary, although *Sphagnum*-dominated communities gave way to vegetation with more herbs and trees after ca. 7900 cal B.P. (Fig. 4), the character of the open *Betula* woodland remained more or less unchanged until ca. 7740 cal B.P. (Fig. 7). Changes in soil moisture were probably within the tolerance range of this woodland (Crawford 1997).

Pinus establishment

The oldest *Pinus* wood remains in the gridded area were recorded at a height above bedrock (Fig. 4) comparable to that which has been dated to ca. 7500 cal B.P. (^{14}C date AA-52520 at A13). Both stomatal and pollen records from Y25 (Fig. 7) support the view that *Pinus* expanded rapidly at this time (cf. Froyd 2005). The establishment of *Pinus* was late compared with regional expansion around 9500–8500 cal B.P. (Birks 1989; Bennett 1995), although it is comparable to the date for probable local growth 20 km to the west at Achany Glen (Smith 1996, 1998). Colonisation by *Pinus* of blanket peat at Farlary after 7750 cal B.P. was facilitated by dry conditions (Fig. 6), but peat had been dry for some 500–600 years prior to this. Colonisation was not coincident with, or triggered by, climate change, though colonisation may have been retarded by some component of the climatic excursion centred on 8200 cal B.P. Distance from seed source was probably most important in determining when *Pinus* reached these eastern hills from woods established earlier on the west coast (Bennett 1984, 1995; Birks 1989).

The apparent high density of wood remains in the blanket peat (Fig. 4) requires critical evaluation. No systematic ^{14}C dating of these earliest timbers was undertaken, and low peat growth rates in the blanket peat have conflated the resolution of the stratigraphic record. Stomatal records assuredly record the local presence of *Pinus* trees (Parshall 1999), but not necessarily their abundance because production of needles and stomata may have varied through time as a result of external stresses to growth (Willis et al. 1998). This is true for pollen production also

(Fossitt 1994; Ledig 1998; Lageard et al.1999) and there is no statistical correlation at Farlary between stomatal and pollen abundance. The impression is that *Pinus* trees probably replaced in large part birch and hazel scrub growing on peat and also on mineral ground. *Pinus* may have been excluded from better-drained soils by *Corylus* (Bennett 1984; Davies 1999, 2003b), but successfully competed on peaty and damper soils in relatively open plant communities with *Betula* and *Calluna*.

Mid Holocene vegetation dynamics

Calluna increased beneath and around the *Pinus* wood after ca. 7000 cal B.P. (Fig. 7). The bog surface at point Y25 became drier (Fig. 6). The rise in *Calluna* after 7000 cal B.P. and reductions in *Betula* and *Corylus avellana* type suggest a substantial reduction in woodland cover. Initially, *Pinus* was relatively unaffected. Conditions became suitable, perhaps through increased aridity, for *Vaccinium*, *Erica* and *Melampyrum* late in zone LFA1b, which probably formed a heath-like community comparable to that beneath present-day eastern Scottish *Pinus* woods (Steven and Carlisle 1959), and this perhaps reflects the establishment of a more continental climate. Fire may also have influenced vegetation dynamics, possibly stimulating *Melampyrum* growth (Godwin 1975) between 6860 and 6400 cal B.P. (Fig. 7). The peat surface may have been dry enough to burn (cf. a peak in charcoal and coincident peak in *Calluna* at 6420 cal B.P.). Fires seem to have had substantial impact on vegetation in the vicinity of Y25. This probably included an adverse affect on *Pinus* growth despite the drier soils (cf. lower *Pinus* pollen and stomatal values after ca. 6800 cal B.P.). The increased representation of *Ulmus* and *Quercus*, *Populus* and *Fraxinus* may be due, at least partly, to better representation of the regional pollen component.

Abrupt climate changes and the first *Pinus* decline ca. 6350–5500 cal B.P.

For a short period after ca. 6500 cal B.P., peat accumulation at point Y25 was high as a result of a shift to much wetter peat surfaces (Fig. 6). At ca. 6540–6200 cal B.P., the highest magnitude wet shift is recorded; this probably corresponds to that identified in north and west Scotland by several investigators (Bridge et al. 1990; Anderson 1998; Anderson et al. 1998; Tisdall 2000; Tipping and Tisdall 2004) and which appears to be regional in character and hence due to a climatic change.

With the shift towards wetter conditions, burning near the basin ceased (ca. 6400 cal B.P.; Fig. 7). It is concluded that dry climate, rather than deliberate firing by later Mesolithic communities, was responsible for the frequent fires prior to this (cf. Tipping 1994, 1996; Tipping and Milburn 2000).

At 6400 cal B.P., the *Alnus* curve rises (>10% TLP) which suggests local expansion of alder (Fig. 7). Favoured by wetter soils and climate, *Alnus* successfully competed with *Pinus* on increasingly wet peat at this time (Bennett and Birks 1990); at Farlary, however, which is quite elevated (200 m OD), it was not an important tree. The *Pinus* curve at Y25 declined after ca. 6370 cal B.P. However, the continuing high values for *Pinus* stomata between 6400 and 6000 cal B.P. suggest that there was still a substantial population of *Pinus* near the sampling site. These different patterns in pollen and stomata prior to 6000 cal B.P. may indicate local growth of trees close to Y25 while the *Pinus* population, or at least *Pinus* pollen production, declined at a regional level. One tree, with a very large bole, survived on the bog until ca. 6200 cal B.P. (Stump 2; Fig. 4; Table 2c; further details in Tipping et al. 2007).

After ca. 6350 cal B.P. peat growth rates slowed to ca. 30 years cm^{-1}, contemporary with an abrupt short-lived drying out of the peat surface at Y25 (ca. 6200–5940 cal B.P.; Fig. 6). A short phase of wetter peat surfaces abruptly follows (ca. 5940–5720 cal B.P.). The dating is too crude to enable changes in peat growth rate to be detected. A wetter phase at about this time has also been recorded in lake and peat sediments at Glen Affric, west of Inverness (Tisdall 2000, 2003a, b; Tipping and Tisdall 2004).

This complex sequence of short-lived events, probably driven by regional climate shifts, appears to have been profoundly destabilising to the local *Pinus* population. *Pinus* pollen percentages began to decline after ca. 6400 cal B.P. After ca. 6000 cal B.P., *Pinus* stomata were far less abundantly produced, transported or preserved; by ca. 5880 cal B.P. stomata are rather rare (Fig. 7). Between 6000 and 5880 cal B.P. the deciduous character of the local woodland became more emphasised with *Betula* and *Alnus* common on wetter soils and peats, and *Betula*, *Ulmus*, *Quercus*, *Corylus*, *Populus* and *Sorbus* the main taxa on mineral soils. The pollen data suggest that *Pinus* had become locally very rare by ca. 5500 cal B.P. There are no ^{14}C dates for wood between ca. 6200 and 5100 cal B.P. (Table 2c; Fig. 4). The tree populations were undoubtedly affected by the series of rapid hydrological changes (cf. Leuschner et al. 2007). Germination and seedling survival of *Pinus* were probably affected by the abrupt and rapid changes in soil wetness that occurred at frequencies much shorter than the life cycle of the trees. Within this sequence of abrupt changes, impacts on the vegetation by the Hoy tephra cannot be distinguished.

Fire impacted again on vegetation at ca. 5900 cal B.P. during a dry phase of short duration (Fig. 7). Burning effectively ceased when conditions became wetter. These correlations strongly suggest that fire frequency or intensity were determined by climate, the dryness of soils and plant communities and the ease with which they burned. Fire may either have been coincidental with declining *Pinus* woodland, causal in its decline or, less likely, was itself determined by the presence of pine woodland. Whitehouse (2000) has argued for the last mentioned at a site in eastern England, but this interpretation is not in agreement with ecological observations and palaeoecological data that suggest that *Pinus* is tolerant of a wide range of fire regimes (Bradshaw and Browne 1987; Agee 1998; Lageard et al. 2000).

The negative relationship between *Pinus* and fire in the earlier part of the Holocene record from Farlary may be due to a complex interaction between burning, organic matter content, soil mycorrhizal activity, all factors which probably influenced the stability of *Pinus* woodlands. Whatever the precise relationships, the data clearly show that high charcoal values are associated with climatically induced peat surface dryness. Gear and Huntley (1991) suggest that this is also the case during the later Holocene in comparable situations in the northernmost part of Scotland.

Vegetation change ca. 5500–5000 cal B.P.

The *Ulmus* decline at Farlary broadly coincides in age with the 'classic' regional decline (Parker et al. 2001). The decline in *Ulmus* pollen representation probably reflects a decline in the *Ulmus* population at both local and regional levels. *Corylus* may have benefited from the decline in *Ulmus*. There are no indications of external stresses to explain the *Ulmus* decline at Farlary. Changes are not recorded in humification (Fig. 6); it is assumed that peat surfaces continued to be dry and fire seems not to have been a disturbing factor (Fig. 7). There is no evidence for human woodland disturbance or farming activity.

Later Neolithic farming and re-establishment of *Pinus* on the bog surface

Over some 150–200 years after ca. 5100 cal B.P., a decline in some tree populations, though by no means all, is inferred from the pollen data (Fig. 7). In particular, *Corylus* and *Alnus* declined and, slightly later, *Betula*. Heath species expanded. The decline in woodland was probably anthropogenic in origin, though fire apparently was not used (Fig. 7). Woodland clearance probably facilitated the comparatively rapid expansion of heath. Sustained but low grazing pressure may also have had a role, probably also suppressing grazing sensitive herbs such as *Melampyrum* (Rich et al. 1998). Grassland development was probably restricted because of the abundance of heath on the poor soils. Single pollen grains of *Avena*/*Triticum* (oats/wheat) and *Hordeum* type (possibly barley) may represent sporadic local cultivation of cereals. Woodland regeneration begins at ca. 4900 cal B.P. but it should be noted that density of sampling is low in this part of the profile. The available evidence suggests reduction or removal of grazing pressures and there is no evidence for cereal cultivation.

Pinus recolonised the bog surface at ca. 5000 cal B.P., either immediately before or during partial clearance of deciduous woodland, or within the phase of woodland regeneration. *Pinus* trees had been locally scarce for ca. 1,000 years. Strong evidence for the re-establishment of *Pinus* trees on the bog comes from the ^{14}C dated timbers (Table 2c). With the exception of Stump 2, the relevant dates all lie between 5100 and 4350 cal B.P. The timbers may not have been all contemporaneous (Long and Ripeteu 1974) but Roots 2, 4, 5, 8 and 9 grew at the same time. The cross-correlated tree-ring records from three of the six trees (above) support the idea that the peat was colonised by a sizeable population of pine trees. These trees were very long lived (Table 4), and appear from their ages and growth characteristics not to have been stressed. *Pinus* pollen values increase after ca. 4830 cal B.P. (zone LFA2c; Fig. 7a) and thus support the macrofossil evidence for pine growing on peat at this time.

Pinus stomata, however, are well represented only after ca. 4300 cal B.P. That pine grew near the coring location is not in doubt since core Y25 was taken only 10 m distant from *Pinus* timbers that have been ^{14}C dated to 5100–4400 cal B.P. The poor stomatal representation at this time remains unexplained. Conditions influencing *Pinus* needle retention or stomatal guard cell development may have been different from the earlier period (ca. 7900–7600 cal B.P.) when *Pinus* is well represented by all lines of evidence.

The age relations of the cut-marked trees and the cut-marks

Eight of the eleven cut-marked timbers recovered during excavation (Table 2c) died between ca. 5100 and 4400 cal B.P. Most trees died between ca. 4950 and 4600 cal B.P. Root 10 died before ca. 4400 cal B.P., i.e., before metal working was introduced to Great Britain (Parker Pearson 1999). Yet, the wood was cut in all instances by metal axes (Tipping et al. 2007). It follows that the timbers were worked after the trees had died, and probably long after. Stump 2 and Roots 2, 3, 4 and 5 were cut with metal axes leaving flat facets that suggest an Iron Age date. Roots 8, 9 and 10 were cut with metal axes leaving dished facets. Such facets are tentatively assigned on typological grounds to mid or later Bronze Age axe types. Cutting probably took place at different times in the context of peat cutting (see below).

The final *Pinus* decline at Farlary

Pinus wood was recorded during excavation at Y25 to a depth that dates to ca. 3200 cal B.P. It is clear from pollen analyses that *Pinus* trees continued to grow at Farlary considerably after 4000 cal B.P. (Fig. 7), when further to the north and west across northern Scotland, *Pinus* no longer grew on bogs (Gear and Huntley 1991; Daniell 1997; Huntley et al. 1997).

Pinus values began to decline at Y25 after ca. 4030 cal B.P. (Fig. 7), which is comparable to the so called pine decline at other sites in northern Scotland (Tipping 1994; Bennett 1995; Huntley et al. 1997). It is probable that the deposition of H4 tephra at Farlary preceded by several hundred years the beginning of the second pine decline. The suggestion by Blackford et al. (1992) that tephra deposition may have caused the pine decline is not supported by the present data; other authors (Birks 1994; Hall et al. 1994; Huntley et al. 1997) also failed to find a link between tephra deposition and the decline in *Pinus*. Whereas the decline of *Pinus* is normally considered to be of short duration—over a century or so (Gear and Huntley 1991; Huntley et al. 1997)—at Farlary the decline in *Pinus* pollen representation is gradual, and continues until ca. 3500 cal B.P. Such a gradual decay is not unique (Birks 1975; Kerslake 1982; Bridge et al. 1990; Charman 1994; Anderson 1995; Davies 1999), and has been interpreted as indicating the persistence of isolated *Pinus* populations after much of the pine population in northern Scotland had died. This is probably also the case at Farlary. The situation is not completely clear-cut, however, given that there may be reworking of tephra (see above) and hence also pollen and stomata. *Pinus* stomata are not recorded after 3300–3200 cal B.P., which is considerably after the possibly reworked tephra record. It is concluded that *Pinus* had become locally extinct by 3200 cal B.P.

The cause of this second and final *Pinus* decline at Farlary is unclear. Commonly attributed to a sharp climatic excursion during which the watertable in bogs rose rapidly to create conditions unfavourable to *Pinus* (Dubois and Ferguson 1985; Bridge et al. 1990; Gear and Huntley 1991; Lowe 1993; Tipping 1994; Huntley et al. 1997; Willis et al. 1998), recent peat humification data suggest only small and not necessarily substantial hydrological fluctuations (Anderson 1995; Anderson et al. 1998; Tisdall 2000, 2003b). Some studies have indicated a major lake level rise at ca. 3600 cal B.P. (Smith 1996, 1998; Anderson et al. 1998) but other investigations have failed to provide supporting evidence (Tisdall 2000, 2003a). It appears that major precipitation change in the region occurred only after *Pinus* began to decline. At Farlary an increase in mire surface wetness was not detected as *Pinus* declined (Fig. 6). Indeed, some of the lowest humification values, and thus possibly the driest conditions, occurred between 4100–3800 cal B.P. After this the peat did not get significantly wetter.

If the pine decline was diachronous, as suggested by several analyses (Birks 1975; Kerslake 1982; Bridge et al. 1990; Charman 1994; Anderson 1995), human activity might be more readily invoked (Birks 1975; Charman 1994; Tipping 1994). At Farlary, however, despite the occurrence of axe marks, there is no convincing evidence that the *Pinus* woodland was cleared by felling at ca. 4000 cal B.P. After ca. 3500 cal B.P. there were increased grazing pressures at Farlary, with higher representation of *Plantago lanceolata* and *Pteridium* from zone LFA2c onwards (Fig. 7). Human impact increased after ca. 3260 cal B.P., and after ca. 3040 cal B.P. there was also increased burning (Fig. 7c) which may have been used to improve the grazing quality of *Calluna* heath. By 3000 cal B.P., all trees had probably been removed from the vicinity of Loch Farlary. The prehistoric archaeological elements of this upland area, from hut circles and small field systems to burnt mounds (Fig. 1), relate to this mid to late Bronze Age horizon of comparatively intensive farming activity (e.g., McCullagh and Tipping 1998; Cowley 1998). It is most reasonable to see this farming population as responsible for the dish-faceted axe marks on the roots of some long dead trees; this activity occurred in the context of removing pine timbers during peat cutting, as frequently happens today (Tipping et al. 2007). These farmers lived in an environment where trees were scarce. It is not surprising then that timbers preserved in peat were used to supplement an otherwise scarce resource (Carter 1998; also Tipping et al. 2007).

Conclusions

The work has established the peat-stratigraphic and temporal distributions of ^{14}C dated *Pinus* wood in a peat-covered shallow basin beside Loch Farlary, northern Scotland. Pine timbers were preserved at high density within a 1 m-thick layer in blanket peat and as two thinner layers in the faster accumulating lake-edge peat. Excavation of timbers within 80 cm of the bog surface, i.e., those most immediately threatened by continued peat cutting, revealed 11 *Pinus* roots cut by later prehistoric metal axes. Six trunks were dendrochronologically investigated. Multi-disciplinary investigations, including pollen, macrofossil and tephra analyses and also humification estimations, were carried out on a core from near the edge of the basin. This enabled vegetation and land-use history, and also changes in bog surface wetness, to be reconstructed in considerable detail for the period ca. 8500–3000 cal B.P.

Fen peat began to replace lake sediments and infill the former arm of the lake in the early Holocene. Between 9000 and 8500 cal B.P., blanket peat grew on more elevated ground (acid bedrock). This was favoured by wet soils and a markedly wet climate. An open deciduous woodland of birch, willow, hazel, rowan and juniper grew on peats and mineral soils. This survived a major climate shift to pronounced aridity at ca. 8200 cal B.P. The dry peat surfaces were colonised by *Pinus* at 7600–7500 cal B.P. It is suggested that the rate of *Pinus* seed dispersal across Scotland determined colonisation in eastern Scotland, rather than climate change. More marked aridity between 7000 and 6500 cal B.P. fragmented the deciduous woodland, altered fire frequency/intensity and facilitated the expansion of heath. Sharp, extreme and highly variable climatic shifts then led to alternating phases of dry and wet mire surfaces and changes in fire frequency/intensity that led to destabilisation and fragmentation of the *Pinus* woodland after 6400 cal B.P. Over the subsequent 400 years, *Pinus* declined, becoming a rare tree at Farlary, and alder expanded in the deciduous woodland.

Late Neolithic farmers, who pursued pastoral and arable farming, briefly disturbed the deciduous woodland for about to 150–200 years beginning at ca. 5100 cal B.P. During this phase, or perhaps during subsequent woodland regeneration, *Pinus* trees were re-established on dry peat surfaces in substantial numbers. *Pinus* re-colonisation may have been facilitated indirectly by human activity. All but one of the trees that were cut by later people grew between 5200 and 4350 cal B.P.; the exception was a massive 3 m bole and root system that formed part of the population that colonised the peat before 6000 cal B.P. *Pinus* trees widely colonised the peat from ca. 5200 cal B.P. Despite the nutrient poor substrate, six trunks grew to mean ages exceeding 200 years. Stomata are poorly represented which it interpreted in terms of high stress levels for the pine tree population.

After 4000 cal B.P. *Pinus* gradually declined around Loch Farlary and finally became extinct at ca. 3250 cal B.P. probably because of low density grazing pressures from domestic stock rather than increased mire surface wetness. The axe marks on the *Pinus* timbers (dated to 5200–4350 cal B.P.) were made by metal axes that are datable, at the earliest, to after ca. 4200 cal B.P. At the time of cutting (middle to late Bronze Age), the timbers were probably already buried by peat.

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