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A dendrochronological study of subfossil pinus sylvestrrs l. stumps from peat deposits at Badanloch in the far north of Scotland

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A DENDROCHRONOLOGICAL STUDY OF SUBFOSSIL
PINUS SYLVESTRIS L. STUMPS
FROM PEAT DEPOSITS AT BADANLOCH
IN THE FAR NORTH OF SCOTLAND

by

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

The following figures are in a pocket inside the back cover:

LIST OF PLATES

SUMMARY

A dendrochronological study is presented of 54 subfossil *Pinus sylvestris* L. stumps collected from Badanloch in the far north of Scotland by Gear (1989). The methods of sampling, finishing and ring width measurement are indicated, and the methods of data processing used are described and discussed. Results for the successful crossmatching of 31 samples are presented together with growth statistics and an analysis of the population dynamics of the subfossil wood, together with an investigation into the causes of its expansion and decline. The chronology for the site created by the crossdating is linked to two radiocarbon dates (4405 and 4370 ±50 BP) provided by Gear (1989). A comparison of the results of the whole project is made with those from another dendrochronological study (Gear 1989) made at Lochstrathy, some 15km to the north. The significance of the similarities found is discussed in the context of work by other authors and it is concluded that evidence of a rapid climatic change in the region, allowing formation of *P. sylvestris* forest in the far north for a period of about 500 years, is confirmed.

1 INTRODUCTION

The presence of sub-fossil Scots Pine (*Pinus sylvestris*) stumps in Scottish peat bogs was first described scientifically by Lewis (1907), his findings being later interpreted as supporting the Blytt and Sernander scheme of climatic periods (Samuelsson 1910). Subsequent workers found evidence (both macro-fossils and pollen) for the presence of Scots Pine beyond its present day northern limits (shown in Fig. 1), but supposed it never to have reached the far north-east of Scotland during the Holocene. Birks (1975), through her own work and a review of others, concluded that there was a marked decline in the presence of *Pinus sylvestris* in the north and west of Scotland and Ireland at about 4000 BP, attributing this to an increase in wetness of the blanket bog surface on which the trees were growing. This particularly affects the regeneration of the pine (McVean, 1963a, b) as will be discussed later. Birks noted the synchroneity of this decline at the edge of the trees' range, but felt further evidence was required before any palaeoclimatic significance could be attributed to it.

Bennett (1984), using published work, constructed maps (at 9000, 7500 and 4000 BP) for the distribution of *Pinus sylvestris* since the last glacial (Figs. 2-4). He also differentiated between evidence from pollen diagrams and from radiocarbon dated macro-fossils, arguing that a pollen frequency greater than 20% of total tree and shrub
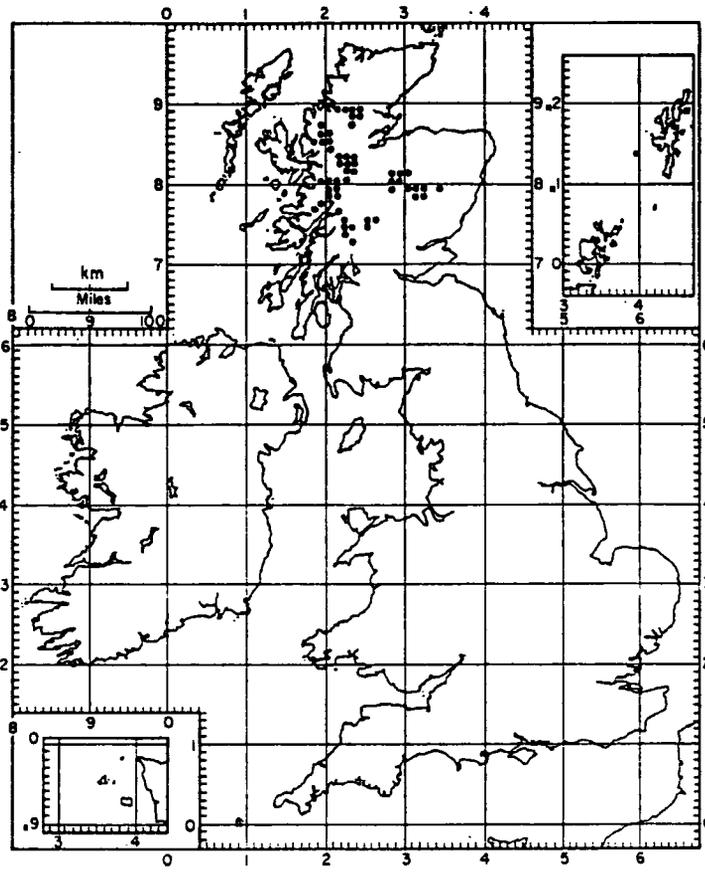
The distribution of *Pinus sylvestris* L. woodlands of undoubted natural and native origin in the British Isles (after Steven & Carlisle 1959).
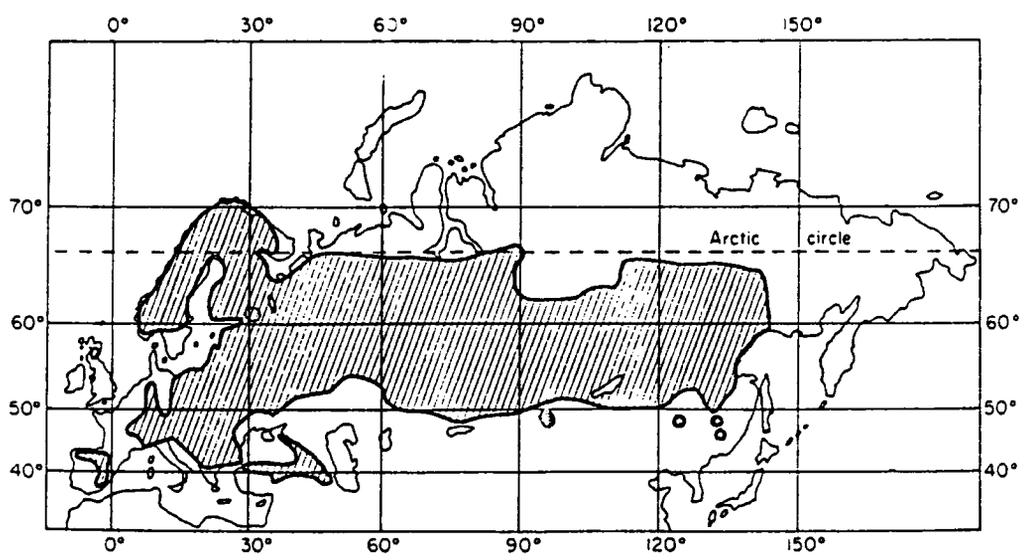
The world distribution of indigenous *Pinus sylvestris* L. woodlands (after Steven & Carlisle 1959).

Figure 1   Modern British and world distribution of P. sylvestris (reproduced from Carlisle and Brown 1968)
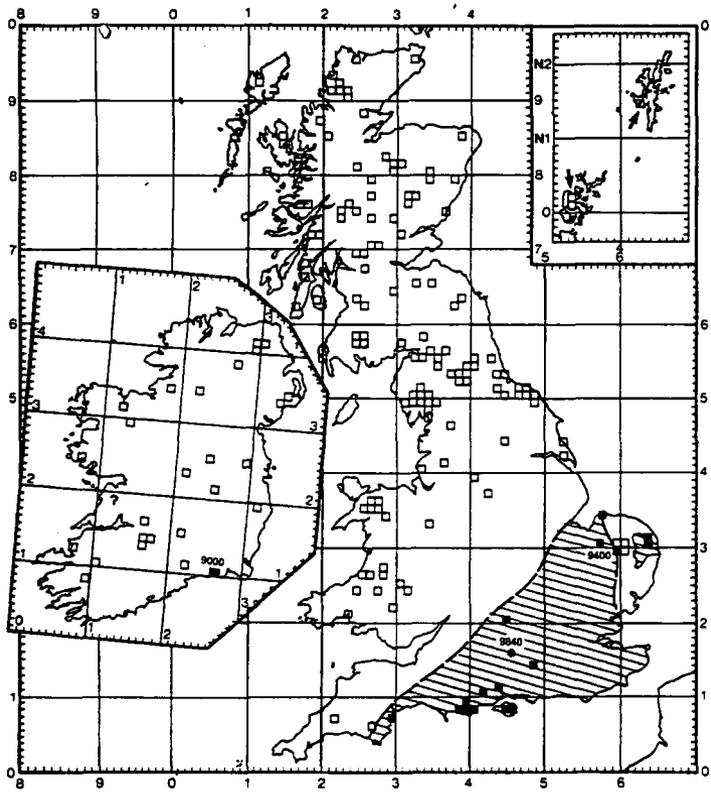
Distribution of *P. sylvestris* in the British Isles at about 9000 BP (shaded area). Symbols: ●, ^{14}C date for macrofossil; ■, pollen evidence for presence (with ^{14}C date of first appearance, where available); □, pollen evidence for absence.

Figure 2
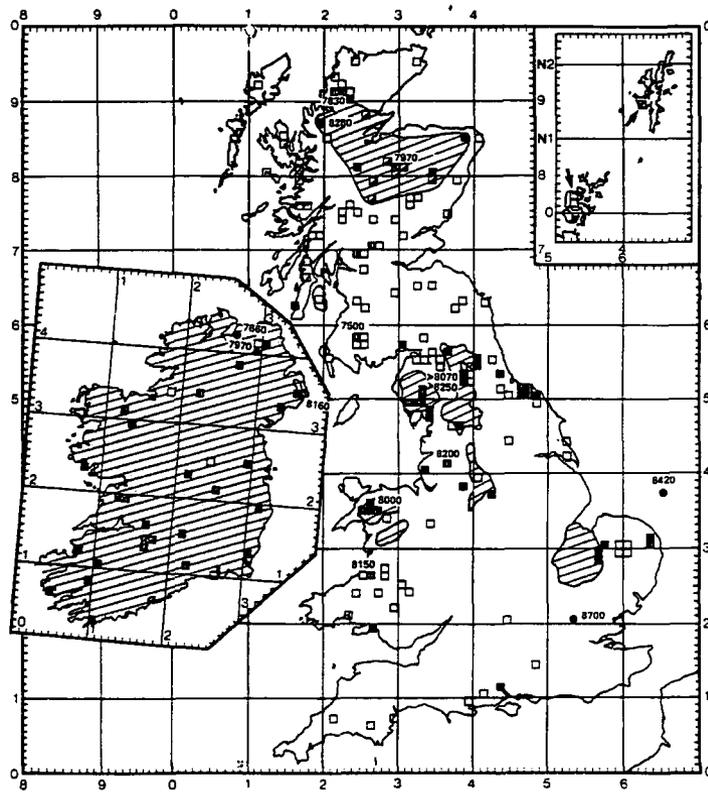
Distribution of *P. sylvestris* in the British Isles at about 7500 BP (shaded area). Symbols as Fig. 2, except ◪, pollen evidence for presence, probably from this period.

Figure 3
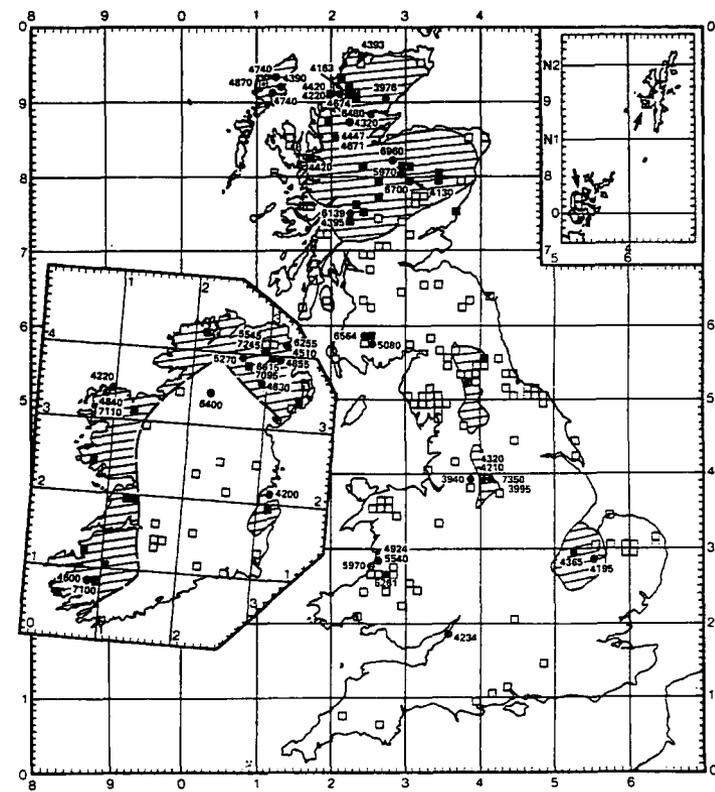
Distribution of *P. sylvestris* in the British Isles at about 4000 BP (shaded area). Symbols as Figure 2

Figure 4

(reproduced from Bennett 1984)

pollen was required to indicate a significant presence of Scots Pine in a locality, whilst macro-fossils rarely occurred in sufficient density in a stratified sequence to give any indication of changes in abundance. On this basis he suggested that the presence of sub-fossil stumps in the far north of Scotland coupled with the apparent absence of any significant pollen record indicated either a sparse distribution (in space and time) in favourable sites through chance long-distance dispersal, or low pollen production from trees at the edge of their range. He also concluded that it was impossible to determine whether the decline in Scots Pine around 4000 BP caused the spread of blanket bog or vice versa, though recognising that the overall range of the species was controlled climatically.

Gear and Huntley (1991) mapped occurrences of sub-fossil pine stumps in the far north of Scotland, obtaining radiocarbon dates and making a detailed palynological study of the region. Through this they intended to test whether Scots pine had indeed occurred sparsely over the region through thousands of years, or whether pine forest had extended northwards for a period brief enough to have been overlooked in previous conventional pollen studies. They found evidence of widespread pine presence throughout the area with the exception of the extreme north east tip of the mainland (Fig. 5). The radiocarbon dates obtained gave an age range of about 590 years (4405 - 3815 BP) for the stumps across the region, each site tending to span a period of approximately 350 - 400 years. For one site, Lochstrathy (Nat. Grid ref. NC 796491) this was confirmed dendrochronologically, and a fine resolution pollen study was made. This revealed a very narrow phase of high pollen values (>30% of the terrestial pollen sum) confirming the presence of pine forest for the short time span in question. Stratigraphic analysis of charcoal from the samples, together with changes in the presence of other pollen taxa suggested that considerable changes had taken place in the wetness of the blanket bog. These changes, coupled with the regional scale (about 70-80 km) and synchroneity of the range of expansion and contraction of the pine forest were seen to be evidence of climatic influence. Gear and Huntley estimated the rate of forest boundary movement from their data and found it to be around 375 - 800 m yr^{-1}, which was consistent with estimates for larger scale post-glacial migrations and probably represents the maximum rate attainable (Huntley 1991). This agreed well with similar events elsewhere in northern Europe suggesting the effects of a broad-scale change in atmospheric circulation, probably a northwards shift of the jet-stream.

Gear (1989) also collected samples from stumps at other locations in the region in order to supplement the detailed dendrochronological studies of the original survey. Included
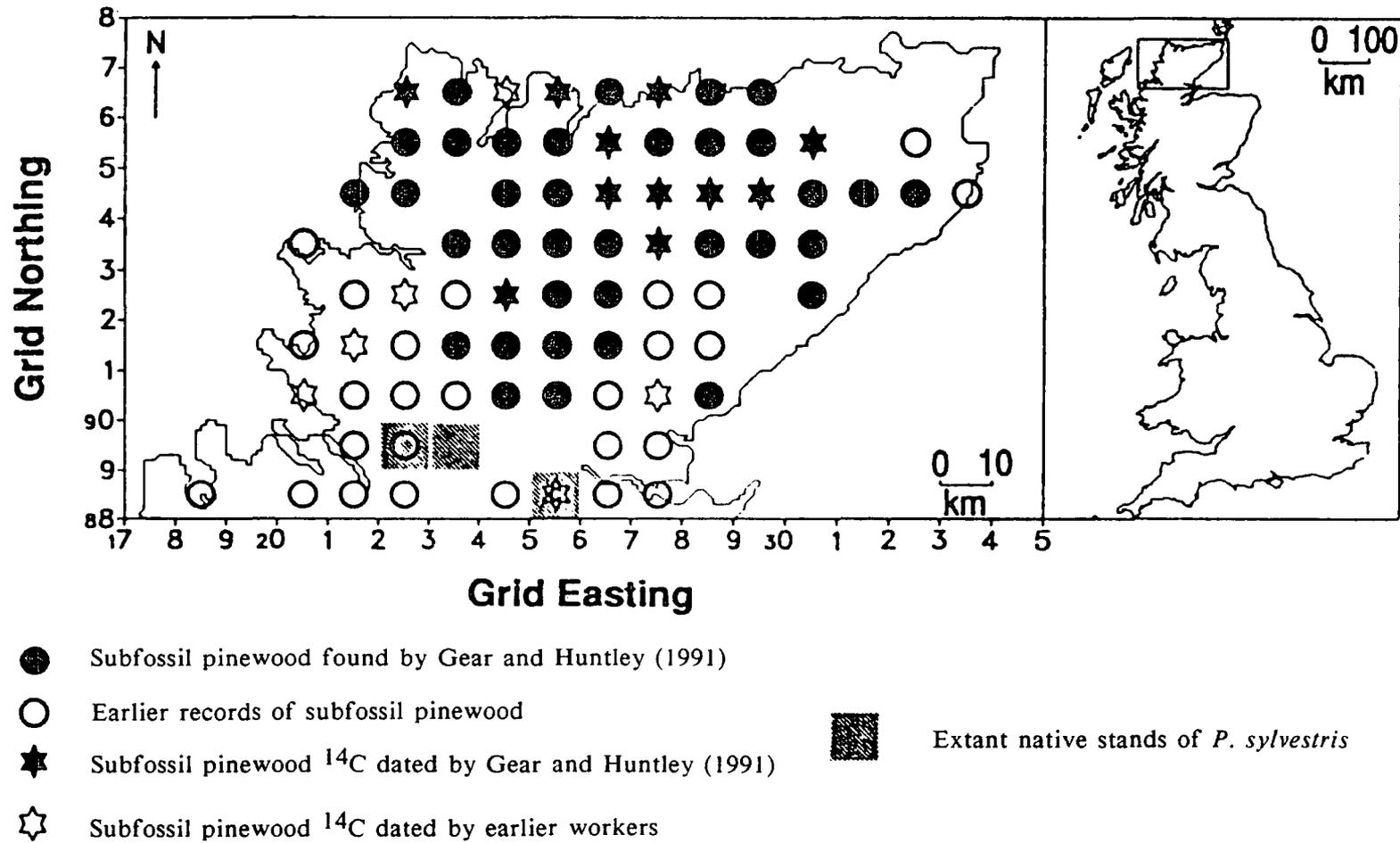
Figure 5   Northern Scotland showing sites of subfossil stumps located in earlier studies.

(reproduced from Gear and Huntley 1991)

in these was the site at Badanloch (NC 786330), 15 km due south of Lochstrathy, from which 100 samples were collected, and two radiocarbon dates were obtained. This site was chosen for the present study, the objectives of which are to investigate the following:

1) The total time span that trees occupied the site.
2) The average age and ring widths (growth statistics).
3) The rôle of fire in the woodland history at Badanloch.
4) The population dynamics of this sub-fossil woodland.
5) The cause of the extinction of trees at Badanloch.

These results are compared with those from Lochstrathy to determine which are indicative of regional trends and which due to entirely local factors.

There were two reasons for selecting Badanloch. Firstly, there are a large number of stumps preserved in their original positions, possibly enough to permit a study of the structure of part of the original wood. Secondly, the distance of Badanloch from Lochstrathy (15 km due south) represents a significant difference in terms of the suggested 70-80 kms (Gear and Huntley 1991) north-south movement of the forest boundary, and a difference in timing at the two sites would reinforce this view of pine migration.

2 THE SITE

The *Pinus sylvestris* stumps sampled were recovered from the southern edge of Loch Badanloch (Fig. 6) where they had been exposed by erosion of the blanket peat by wave action (Plate 1). The surface of Loch Badanloch lies at about 122 metres above sea level on a plateau between Strath Halladale to the east and Strathnaver to the west, both valleys running more or less north-south and opening onto the north coast. The outflow of the loch is controlled by a dam (constructed in the sixties) which regulates the water in the River Helmsdale. The present level of the loch is therefore higher than in the past, and this is supported by the fact that sub-fossil stumps may be seen stretching out from the shore line until submerged. The loch itself is surrounded by blanket peatland used for grazing, with forestry plantation to the north and west. The present vegetation on the peat is dominated by *Calluna* and *Eriophorum* spp. The whole area (underlain by acid metamorphic rocks - the Moine schists) is one of rolling relief, with the nearest higher ground being about 1.5 km to the west with an elevation
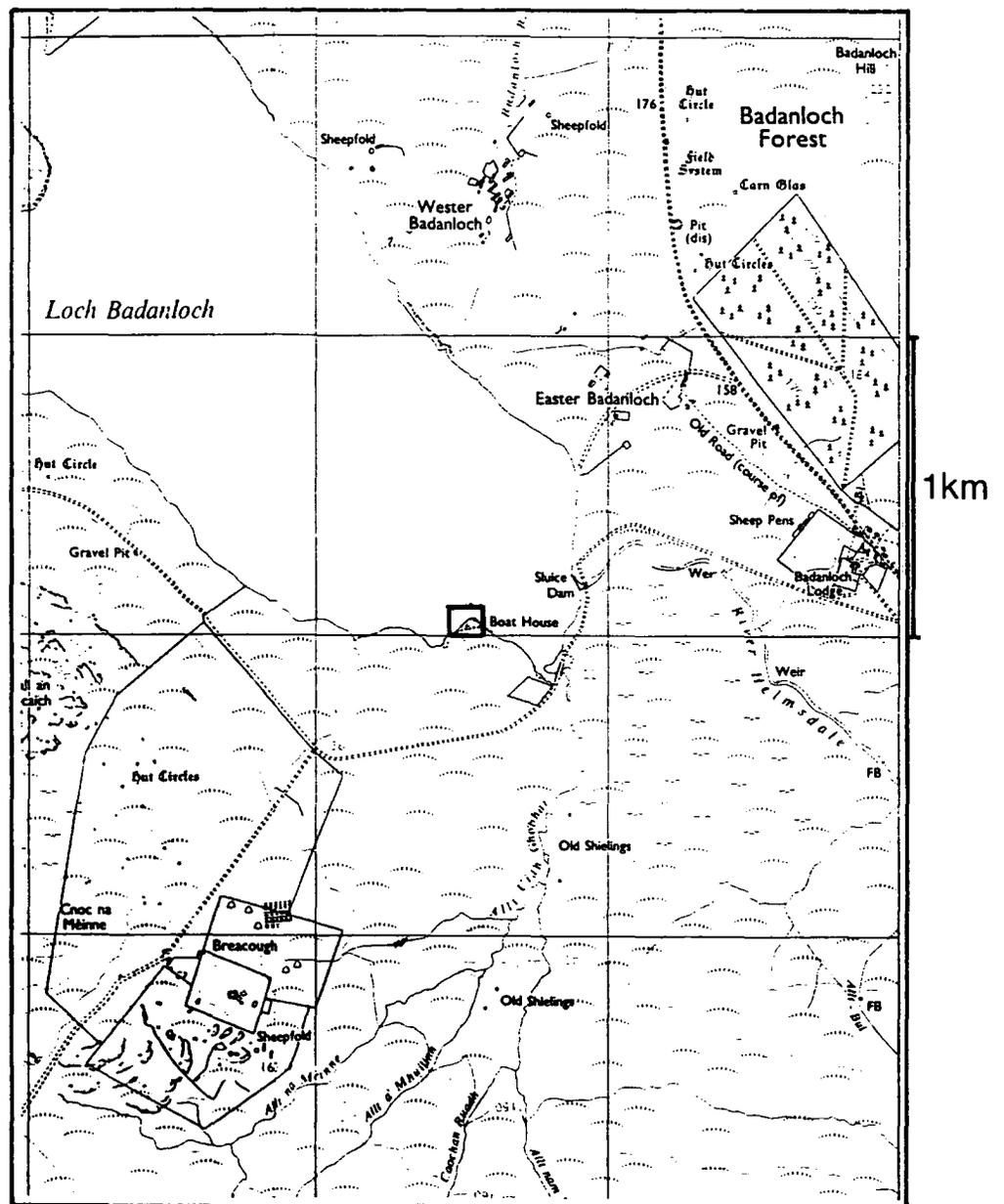
Figure 6 Location of Badanloch and study site

Plate 1   Badanloch - view ENE across the sampling site
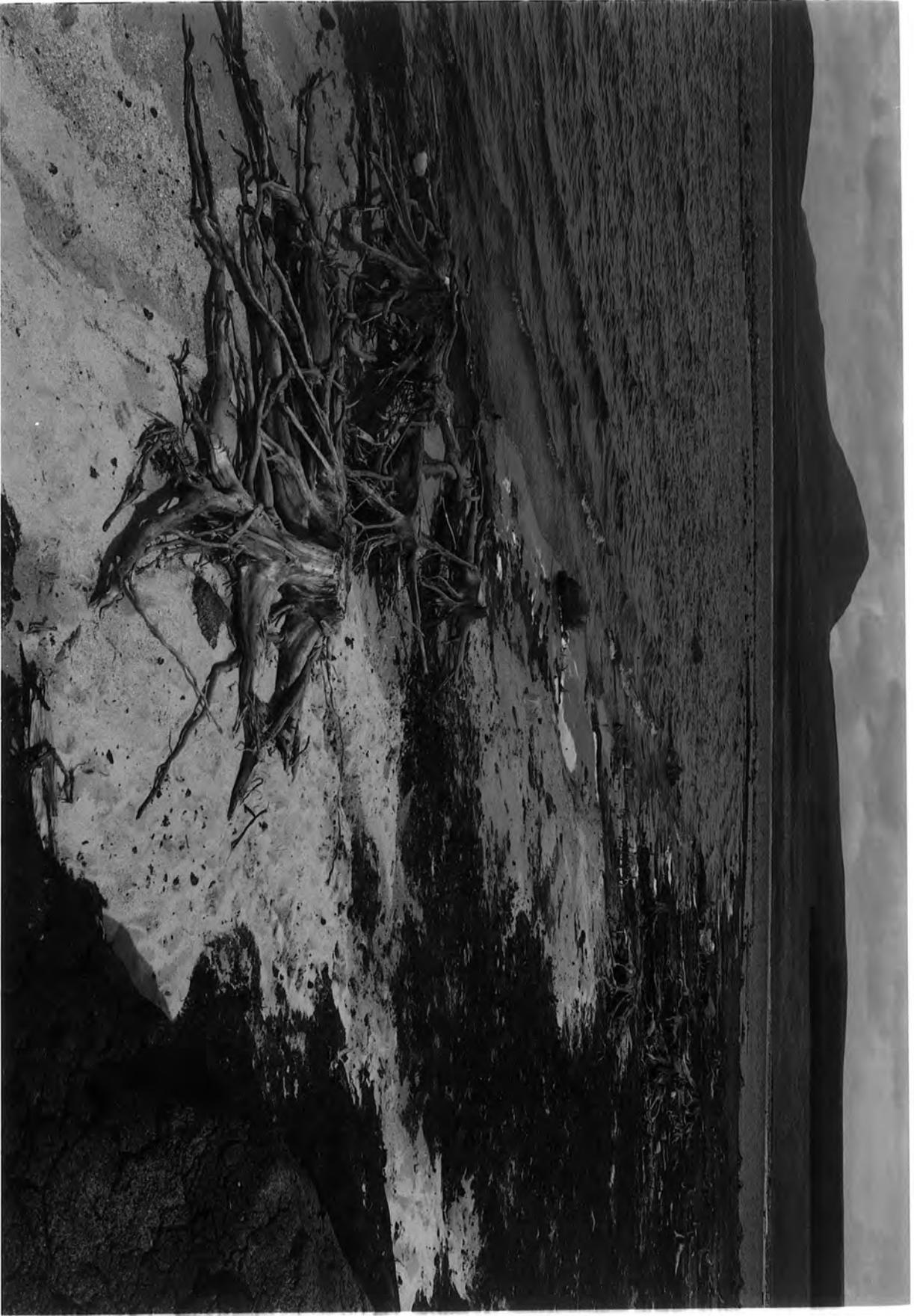
of about 230 m, and peaks of up to 300 m within 4 or 5 km. Badanloch is exposed to winds from the north and east, the coast being about 30 km to the north, but the site is sheltered to some extent from the west and south by mountains rising to over 700 m. at a distance of about 10 km.

When sampled by Dr. A. J. Gear in 1988 the peat covering the stumps had recently been eroded and the sub-fossil trees were occupying the same relative positions as in life, still embedded to some extent in the shore. When the site was revisited by Dr. Gear and the author in 1992 it was apparent that further erosion had taken place and some of the trees had become shifted in the intervening period (A. J. Gear, pers. comm.). However, the plan (Fig. 7 in pocket inside rear cover) shows the 1988 positions. The level of the water was considerably lower (by up to a metre) than in 1988 and a large number of stumps in the loch itself were revealed by this, emphasising that the group sampled was part of a larger general cover of trees and not an isolated clump (Plate 2).

3 METHODS

3.1 Sample collection

Transverse sections were collected from the original stumps by A. J. Gear in 1988 using a 16" bar Stihl 024-Woodboss chainsaw to saw off sections in most cases between 2 and 4 cm thick. This was done as high up as possible into the remains of the trunk in order to minimise the effect of distortions in the ring patterns due to root structures at the base of the tree. However, the decay and erosion of the stumps, together with the results of attacks (either in life or subsequently) by wood-boring beetles etc. (Plate 3 - possibly caused by *Criocephalus rusticus* L.) meant that some sections were less than ideal for dendrochronological analysis. The samples were labelled, wrapped in polythene to prevent drying and brought back to Durham where they were stored in a cold room at 4° C.

3.2 Drying and polishing

At the start of the present study (April 1992) the samples were removed in batches from the cold room and allowed to dry out slowly. This was done using two locations, one damper than the other, in order to control the drying rate to some extent and

4

Plate 2   Badanloch - view NW, unsampled stumps in water
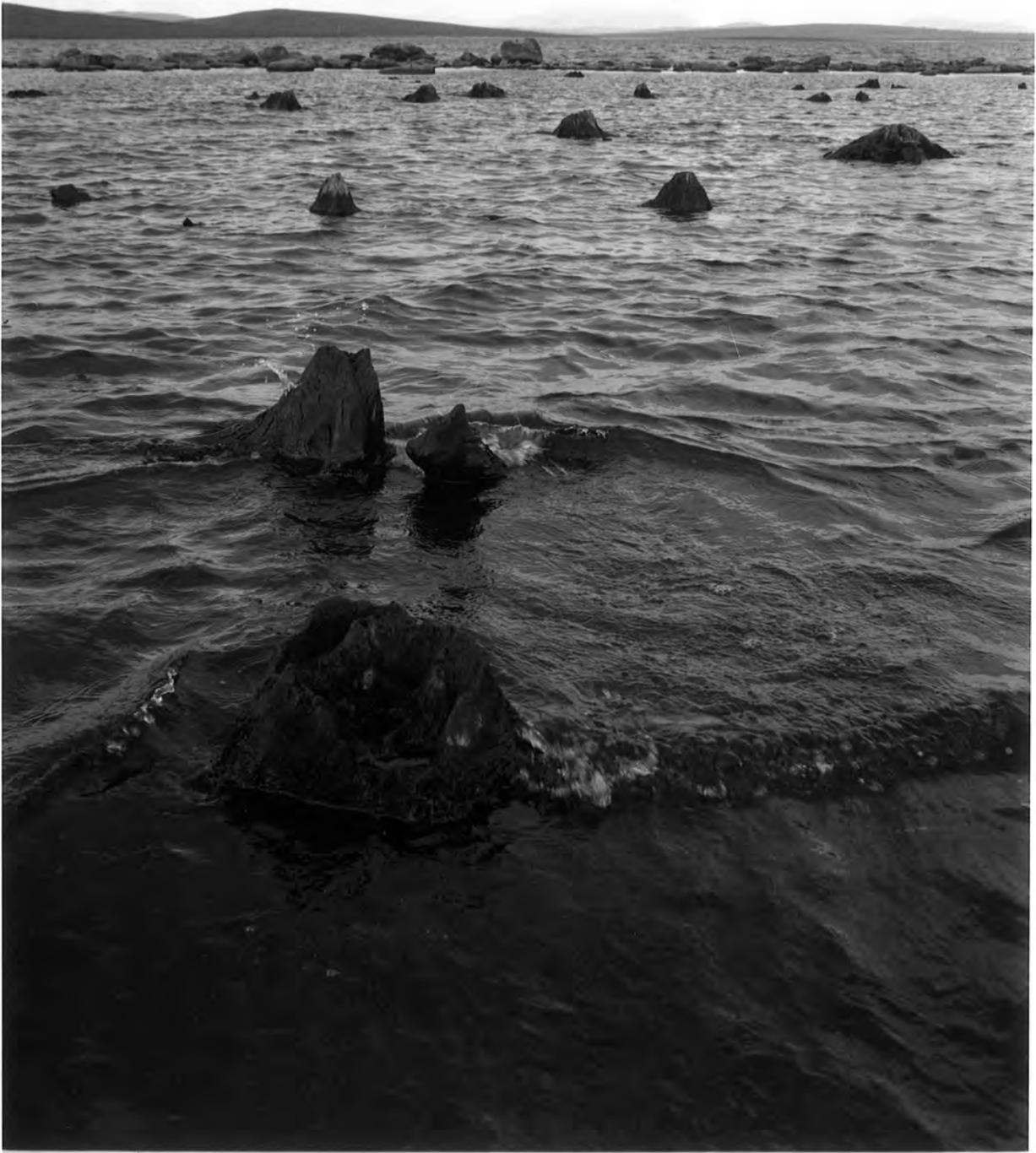
Plate 3   Sampled stump showing damage by wood boring beetles

minimise splitting. Experience has shown that the time scale of the study was rather too short to achieve this satisfactorily, because some splitting did take place.

When the samples were dry enough they were sanded and polished to reveal the ring structure for counting. At the beginning it was found important to avoid overheating through prolonged mechanical sanding as this would melt any resin left in the wood, obscuring the structure and clogging the sanding medium. As a result the finishing was carried out in several stages, which after some refinement were as follows:

1) A flat surface was produced on the section removing gouges etc. caused by the chainsaw. This was done by smoothing the sample using a 0.75 HP industrial belt sander with a 36 grit belt.

2) A Black and Decker hand drill, running at 2400 rpm, with a flexible rubber backing disk was used with a 40 grit sanding disk to smooth the surface till any scratches from the belt sander were removed.

3) As 2 with an 80 grit disk, removing the marks of the 40 grit disk.

4) As 3 with a 120 grit disk.

5) As 4 with a 180 grit disk

6) The final polish was given using a lambswool bonnet in place of the disks, yielding a surface on which the individual cells could be discerned.

Some heating of the surface of the section was inevitable, producing rapid local drying at the surface, with the result that the polish was gradually lost through moisture rising to the surface from the body of the sample. The work was therefore done in batches (about 10 samples) and the final polishing (180 grit and lambswool) repeated before ring measurement if necessary.

3.3 Ring measurement

The ring-widths in the samples were next measured and recorded. First, the sample was examined for distortion (due either to stress or growth of roots), and in one or two cases rejected if this was too extreme. Otherwise three radii were marked in pencil on the surface of the wood, following the lines of least distortion. At this stage prominent rings were followed round and marked on each radius to provide a cross check of ring numbers between them. This was to give an indication of missing or false rings during measurement. Also any cracks following the line of the rings were checked for charcoal as evidence of fire damage. Little was found, and seemed all to be indicative of damage after the trees' death, as it occured in radial cracks.

The widths were measured using a stereo microscope and graticule eyepiece along each radius from the centre outwards. This was done initially using a Carl Zeiss stereo microscope with x25 eyepieces and x1.6 objective which yielded a magnification of x40 and graticule measurement in 0.03125 mm divisions, hence an accuracy of ± 0.016 mm. This was shortly replaced by a Russian OGME-P2 stereo microscope with x8 eyepieces and x7 objective giving a magnification of x56 and a graticule measurement of 0.014 mm/division, thus with an accuracy of ± 0.007 mm. The sample was moved past the microscope head on a screw driven mechanical platform, the sample and/or graticule eyepiece being rotated to ensure measurement at right angles to the rings. The measurements were recorded to the nearest graticule division as a number of divisions and entered on floppy disks as ASCII files (filenames of the form BADnnn, where nnn is the sample number) for subsequent computer processing.

3.4 Data processing

The graticule measurements recorded were converted to measurements in units of 0.01 mm and plotted as curves radius by radius for initial inspection. Simple routines written for the purpose (programs CONVERT and RINGPLOT - see appendix) were used for this. A typical example is shown in Fig. 8a. A third routine (program RINGSTND - see appendix) was then used to produce standardised values from the 0.01 mm measurements for visual sample matching, these values being calculated using the following expression:

New variable = (Variable - Mean)/Standard Deviation

thus producing a set of values expressed in terms of standard deviations and with a mean of zero (Davis 1973). These were again plotted for comparison as in Fig. 8b.

On completion of the measurement, standardisation and plotting of the ring widths, the sample with the longest series was selected to form the basis of the crossmatching for the site. The matching was done in this way as many of the samples were fairly short-lived, and long overlaps (>40 years) are desirable for good correlation (Pilcher 1990). The sample chosen was no. 144 (BAD144) which yielded a span of 357 years. Extra radii (D and E) were measured and the original 3 (A,B,C) were carefully compared and checked for false and missing rings. The main series for dating was eventually based on the D radius, with corrections based on the E radius applied to it. These in turn had been adjusted through comparison with the other radii, particularly A, as radius B passed through areas of distortion and C was very close to D anyway. Fig. 9 (in pocket inside rear cover) shows the final combined series (BAD144CD) after

6

bad118   Totals: A - 37 B - 56 C - 58   Offsets: A - 0 B - 0 C - 0

BAD118.STD   Totals: A - 37 B - 56 C - 58   Offsets: A - 0 B - 0 C - 0
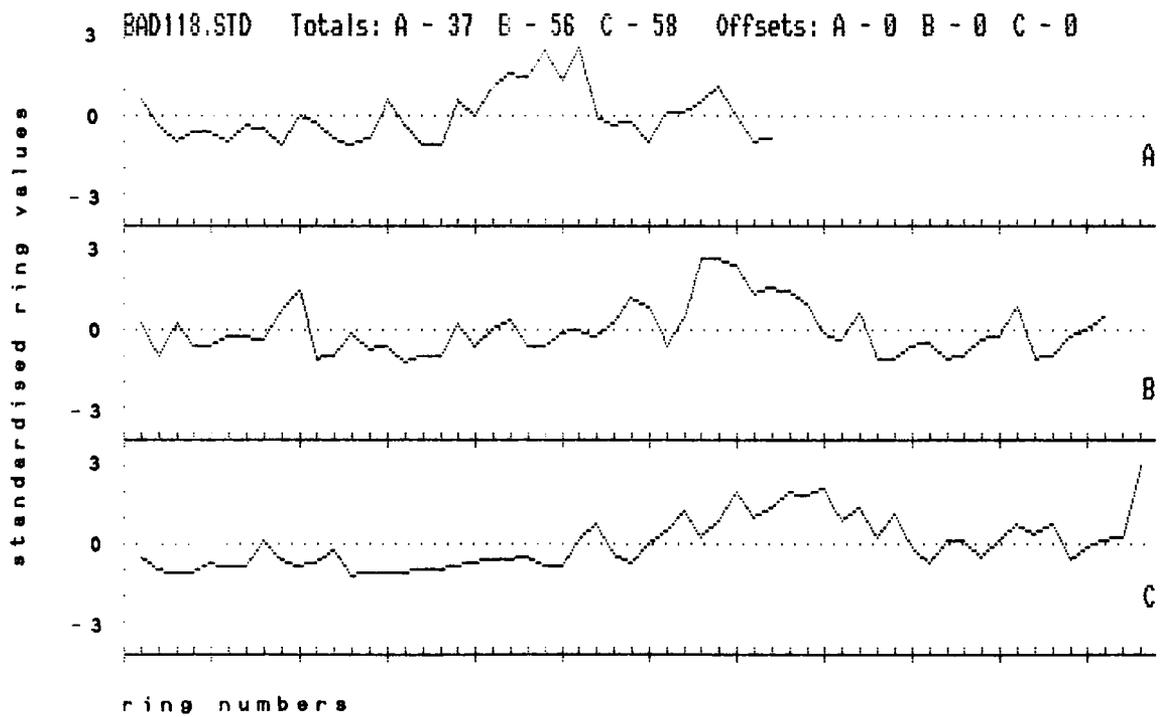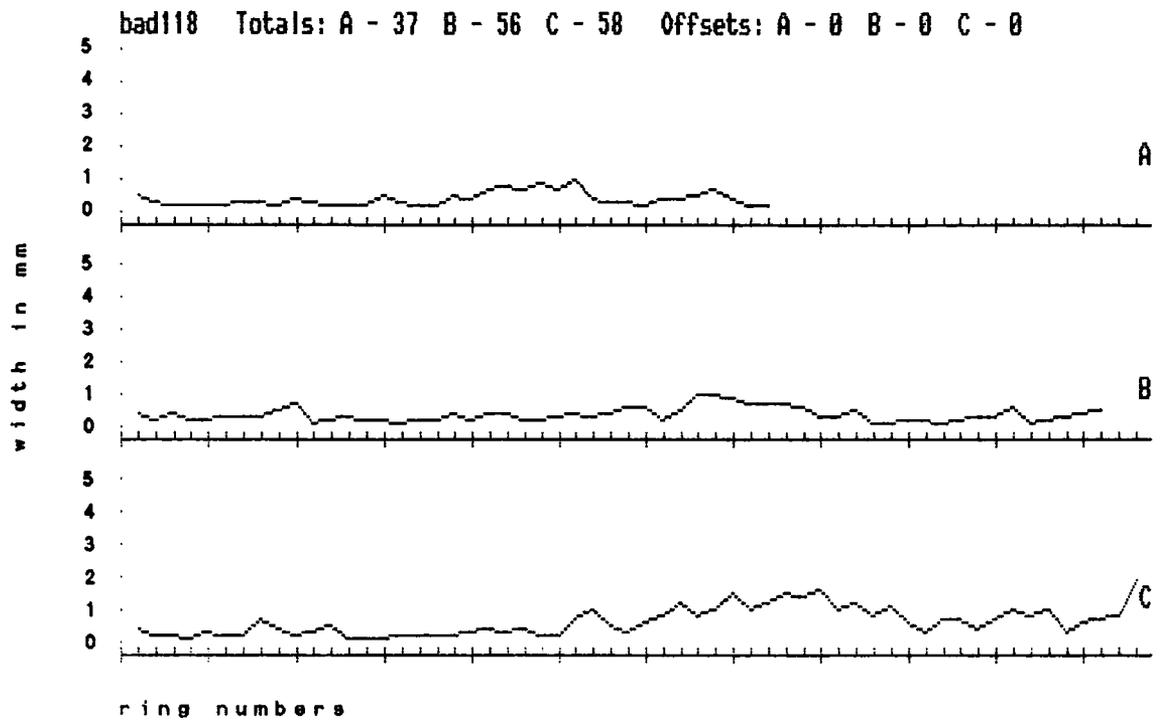
Figure 8 a and b   Examples of raw and standardised ring plots

standardisation, as used for the visual matching. Also marked on it are the regions where corrections have been applied from E. These corrections were calculated from the raw data by multiplying the ring width to be inserted by the mean of D values divided by the mean of E values, the means being taken across the range of overlap of the two radii. For example, ring 84 inserted in radius D from radius E was calculated as:

$$\text{New}_{84} = \text{E}_{84} \times (\text{Dmean}_{1-198}/\text{Emean}_{1-198}),$$

198 being the length of the E radius.

As no comparisons with an undistorted radius were possible beyond ring 198, the D radius was recounted from this point as an additional check. Ring no 1 was imported from the A radius, multiplied by the ratio of the A and D means as described above.

Having thus obtained a long sequence of ring width data which was confidently felt to be free of missing rings, effects of root distortion etc., the next stage was to match the other samples to this which was done on the following basis.

Cook (1990) describes a series of tree ring values as the sum of a number of subseries attributable to different factors affecting the tree's growth. He summarises this in the form of the following equation:

$$R_t = A_t + C_t + dD1_t + dD2_t + E_t$$

where:

R_t = the observed ring width series

A_t = the age-size-related ring width

C_t = the climatically related environmental signal

$D1_t$ = endogenous disturbance pulses

$D2_t$ = exogenous disturbance pulses (stand-wide)

E_t = unexplained year to year variability.

The d is an indicator of the presence or absence of $D1_t$ and $D2_t$ at any time in the series.

In the context of the present study the climate parameter, C_t, is of the most concern. Also it affects the ring sequences regionally and thus all those in the study area, whereas the other parameters (with the exception of $D2_t$) may well affect different trees individually. Indeed, in the absence of any clearly identifiable stand-wide event ($D2_t$) synchronising the different ring width sequences, the climate signal is the only basis for cross dating the samples.

This signal was extracted using the method first outlined by Baillie and Pilcher (1973). Their original method was first to remove long-term growth trends from the data by using a high pass filter in the form of a "5 year rolling mean". This was done by converting each ring width to a percentage of the mean of five ring widths of which it was the centre value. The data was then normalised by taking the natural logarithm of the percentage figure obtained.

To perform the cross dating they then "slid" the sets of ring data past each other calculating the product moment coefficient "r" for each position. As the data had been normalised they were able to calculate a value of Student's "t" for the probability of the observed "r" having arisen by chance using the formula

$$t = (r \times SQR(N-2))/SQR(1-r^2)$$

where N is the number of degrees of freedom given by the number of rings overlapping (SQR = square root). This process would indicate positions with a high probability of matching, but Baillie and Pilcher pointed out the importance of visual matching as a check on spurious correlations. Their method was later refined by Orton (1983), Munro (1984) and evaluated by Wigley et al. (1987). All these authors stressed the need to allow for multiplicity by calculating a modified probability to allow for the increased possibility of chance matches brought about by the autoregressive nature of tree-ring series.

In the present study, as in that by Gear (1989) at Lochstrathy, the Baillie and Pilcher method was used in two programs written by Dr.Brian Huntley, RINGWID5 and CROSDAT4. The former of these produced the Baillie and Pilcher 5 point filtered, normalised values, the latter performing the crossmatching. The output of CROSDAT4 gave the best match position with its individual probability p, and a multiple probability P derived from the expression:

$$P = 1-(1-p)^M$$

where M is the number of attempted matches (Wigley et al. 1987). CROSDAT4 also calculated the next best match with its multiple probability and the ratio of this probability to the multiple probality of the best match. This is referred to as the isolation factor (IF) by Wigley et al. (1987). As these authors recommended, matches were accepted as significant if P<0.1 AND IF>5. These matches were then verified by visual comparisons which were performed by superimposing each ring series to be checked on the main series (BAD144CD) using a light box. If they matched well visually then series showing values of P<0.05, IF<5 were accepted. In one case (BAD120) where the visual match was particularly good, though P = 0.05306, IF<5, the

match was included. The results of the crossmatching, together with multiple probabilities and IF are given in Table 1. From this it can be seen that in fact most matches met a more stringent criterion than that of Wigley et al. (1987), namely $P < 0.05$, $IF > 5$. In this context it is worth noting that dendrochronologists traditionally have accepted a less rigorous test of significance, using only the individual probability, p. All the p values for the successfully matched samples in this study lie in the range $p = < 0.00001$ to 0.00024. The same criteria were used to test crossmatches between radii of the same sample as a test for missing and false rings and as an indication of distortion. In particular the various radii of BAD144 were checked against the constructed main series, in all cases matching within the strictest set of criteria.

Summarising, at the end of processing the rings of 54 samples had been counted and measured (in most cases 3 radii for each section) and 30 samples had been successfully crossmatched to the main series constructed from BAD144. Of these 30, 24 were located on the plan (Fig. 7 in pocket inside rear cover) made by Gear (1989). Within the other 6, 2 radiocarbon dates, SRR-3566 of 4405±50 BP and SRR-3567 of 4370±50 BP for samples BAD011 and BAD012 respectively, were available, again from the work of Gear (1989). It was unfortunate that these were not from samples located on the plan, but they were collected from the immediate vicinity. Finally, an estimated density of 431 subfossil stumps ha^{-1} was calculated, based on the number of stumps marked on the original plan, and allowing for areas underwater or still covered in peat.

4 RESULTS

4.1 Plan of sample locations

The plan (Fig. 7 in pocket inside rear cover) was reduced from the original survey plan made by Gear (1989). It shows the positions of all the stumps in the area covered, both sampled and unsampled. The plan also distinguishes between those samples eventually counted and those rejected. The continuous line marks the approximate position of the eroded peat face (Plate 4), the shore lying to the north of it. The overall position is indicated by the grid reference NC 785330 (though as this is only accurate to 100 metres the relationship of the area of the plan to the shore of the loch is shown in Fig 6, page 3a earlier). The apparent absence of stumps in the north-west of the plan is because this area is covered by the waters of the loch, though it seems likely that the stumps continue to extend in this direction. The gap between 143,144 and 149 and the bulk of the stumps on the plan should be noted.

Table 1 - SAMPLE MATCHING TO BAD144 WITH PROBABILITIES

SAMPLE	RADIUS	MATCH(+5)*	MULTIPLE PROB.	IF	
127	2	1	0.00968 *<0.05*	12.42	*>5*
125	2	31	0.01712 *<0.05*	8.317	*>5*
139	1	43	0.00610 *<0.05*	34.80	*>5*
122	3	43	0.01185 *<0.05*	8.520	*>5*
128	3	55	0.01270 *<0.05*	46.77	*>5*
108	2	54	0.01711 *<0.05*	22.01	*>5*
138	1	55	0.00847 *<0.05*	19.00	*>5*
273	1	61	0.00323 *<0.05*	33.43	*>5*
158	1	62	0.01001 *<0.05*	13.74	*>5*
156	1	72	0.00072 *<0.05*	19.94	*>5*
116B	1	120	0.01500 *<0.05*	23.19	*>5*
113B	1	122	0.03942 *<0.05*	10.21	*>5*
132	1	125	0.03554 *<0.05*	9.267	*>5*
341 ·	1	138	0.00882 *<0.05*	60.96	*>5*
118	3	139	0.03540 *<0.05*	8.644	*>5*
012	6	178	0.00177 *<0.05*	19.44	*>5*
145	2	168	0.02711 *<0.05*	5.480	*>5*
135	1	232	0.02453 *<0.05*	8.774	*>5*
129	1	272	0.00144 *<0.05*	104.0	*>5*
272	2	274	0.01436 *<0.05*	43.97	*>5*
124	1	92	0.07714 *<0.1*	5.242	*>5*
107	2	144	0.05015 *<0.1*	10.19	*>5*
141	3	11	0.04760 *<0.05*	4.636	*<5*
159	1	35	0.04349 *<0.05*	3.257	*<5*
011	1	45	0.00884 *<0.05*	1.491	*<5*
133	1	85	0.01953 *<0.05*	1.023	*<5*
157	1	120	0.01805 *<0.05*	3.546	*<5*
009	1	147	0.01996 *<0.05*	4.649	*<5*
117	3	149	0.00542 *<0.05*	1.007	*<5*
120	2	145	0.05306 *<0.1*	1.506	*<5 VIS*

*i.e. in site years

Plate 4   View of site looking SW – edge of blanket peat in background
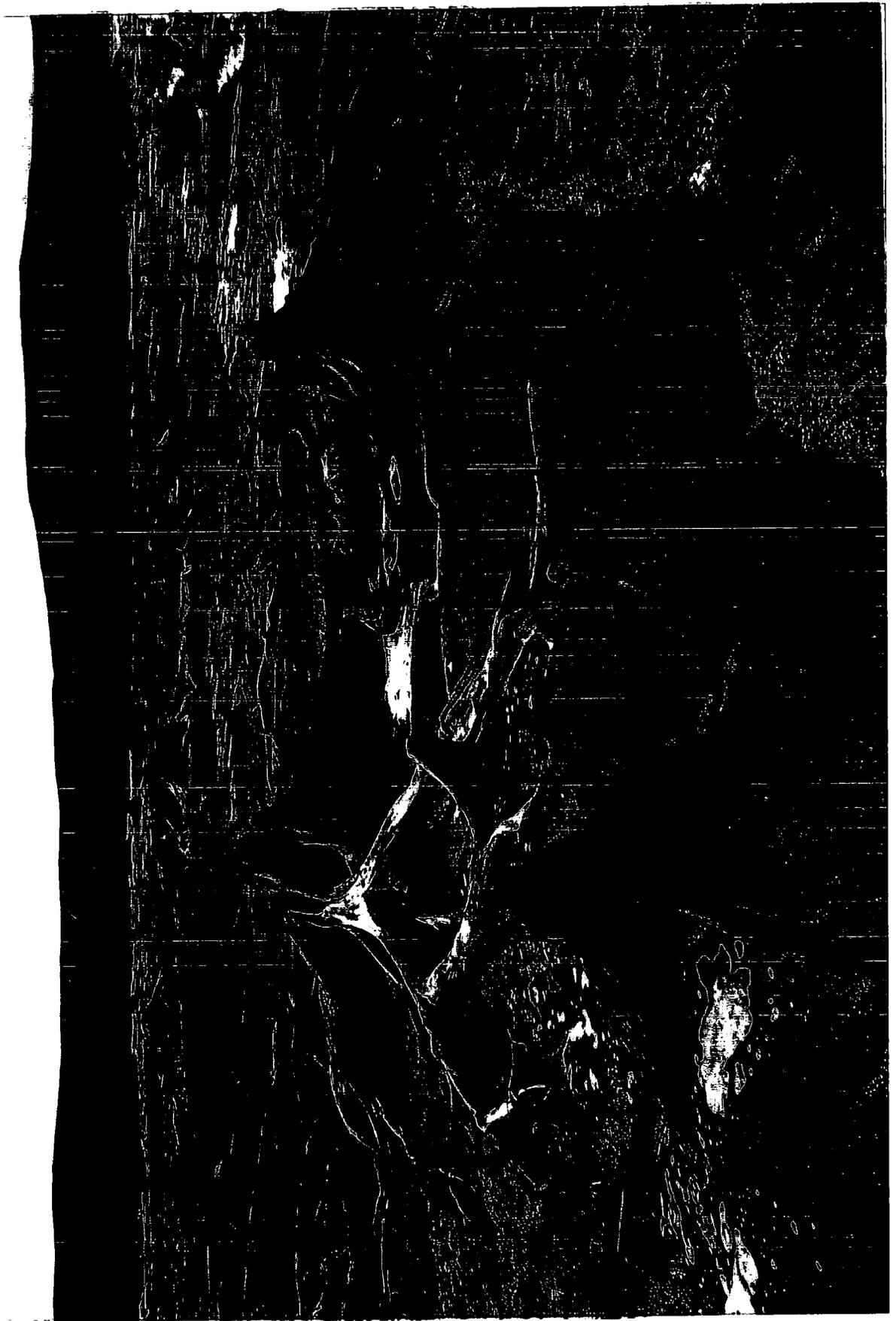
4.2 Lifespan distribution of population

A histogram (Fig. 10a) of the lifespans of the 54 samples measured was constructed. The figures for lifespan used should be regarded as minima as few of the samples had retained their bark, and there was evidence that outer rings were missing in some cases (cf Bridge et al. 1990). As can be seen the lifespan plot approximates to a normal distribution with the exception of one outlier, BAD144, with an age in the class 340-360. Without BAD144 the mean lifespan was calculated as 89.2 years, and the median 84 years. The histogram in Fig. 10b is from a site on Rannoch Moor where subfossil remains of *Pinus sylvestris* were studied by Bridge et al. (1990) and is reproduced from their paper. It is included for comparison as the overall pattern is very similar, with a normal distribution about a mean of 100-125 years, with one or two outliers of much greater age.

4.3 Crossdating of samples

Fig. 11 shows the results of the crossmatching of samples to the BAD144CD series. A time scale (0-400 years) has been attached to the diagram, starting at 5 years before the beginning of BAD144CD and finishing 38 years after it. This time scale, referred to as Site Years, is used in all the figures except 8a, 8b and 9 where the origins are the beginning of the series in question. As the key to Fig. 11 indicates, the different lines refer to different degrees of certainty of fit, the thicker portion of each line being the span of the radius matched, the thick plus thin being the total lifespan where this is calculated from the other radii measured. BAD120 has been included in the multiple p<0.05 classification for clarity. From this plot, the total time span of crossmatched samples at the Badanloch site is 392 years as compared with 344 years at Lochstrathy (Gear and Huntley 1991). The plot also suggests that recruitment occured in phases, these being at between 25-75, 110-175, and possibly at 275 site years, whereas mortality is generally more constant. Recruitment seems to cease after 275 years. The long life span of BAD144 is particularly striking.

4.4 Radiocarbon dates

Fig. 12 shows the positions of the two radiocarbon dated samples (BAD011 and BAD012) on the dendrochronological "Site Years" time scale. The radiocarbon dates plus 1 and 2 standard deviations either side are placed on the same scale at the centre of the section of rings from which they were taken. This was the outer 50 rings in the

BADANLOCH - tree lifespan

20 year age classes

CLASHGOUR A - tree lifespan

25 year age classes
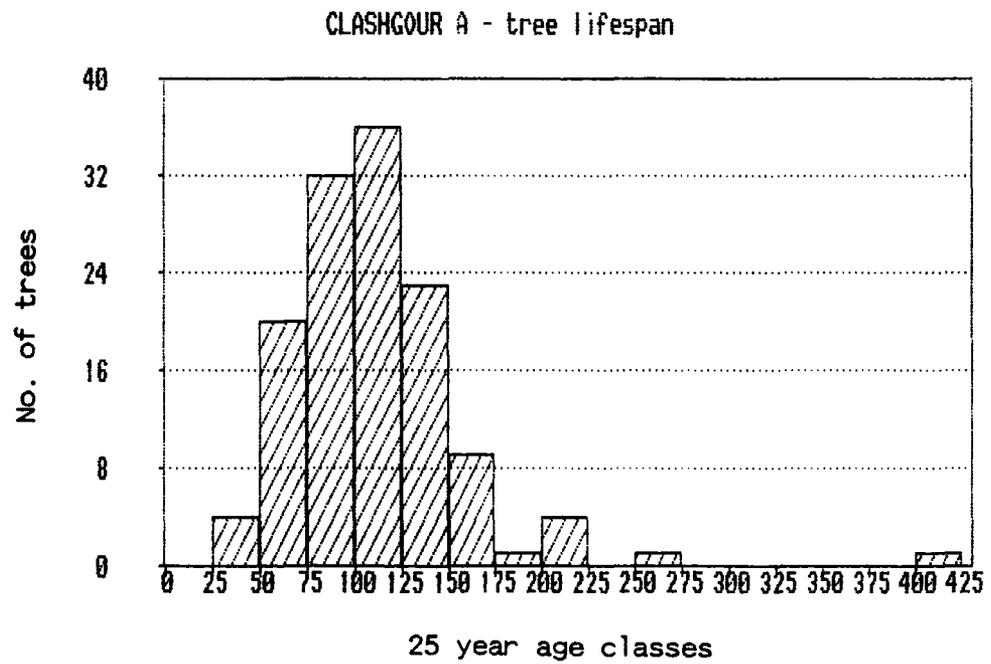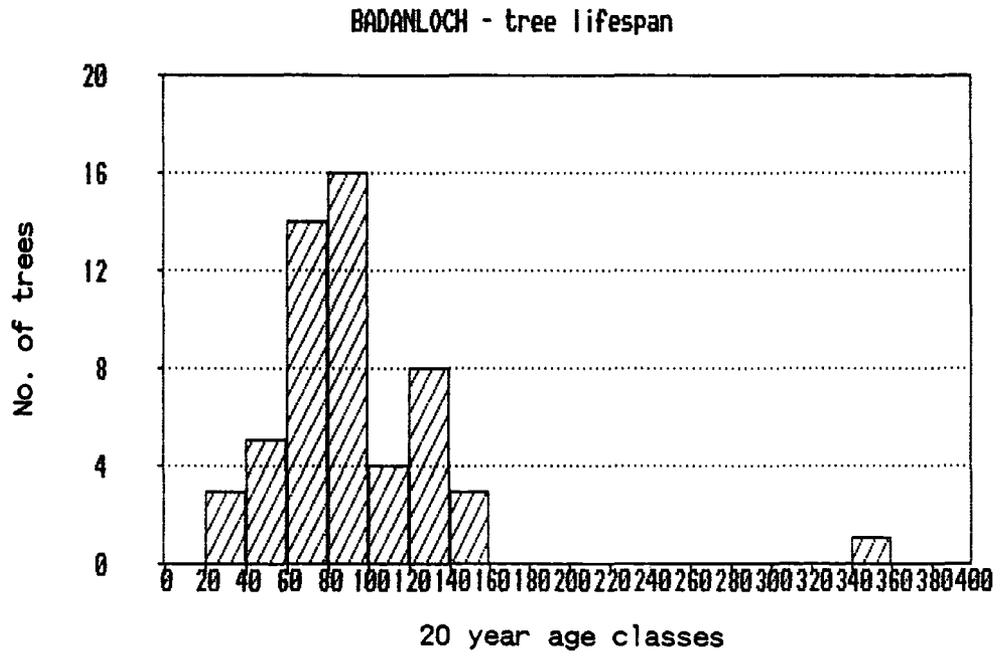
Figure 10 a and b   Lifespan distribution - Badanloch and Clashgour A

BADANLOCH - relative life spans of samples
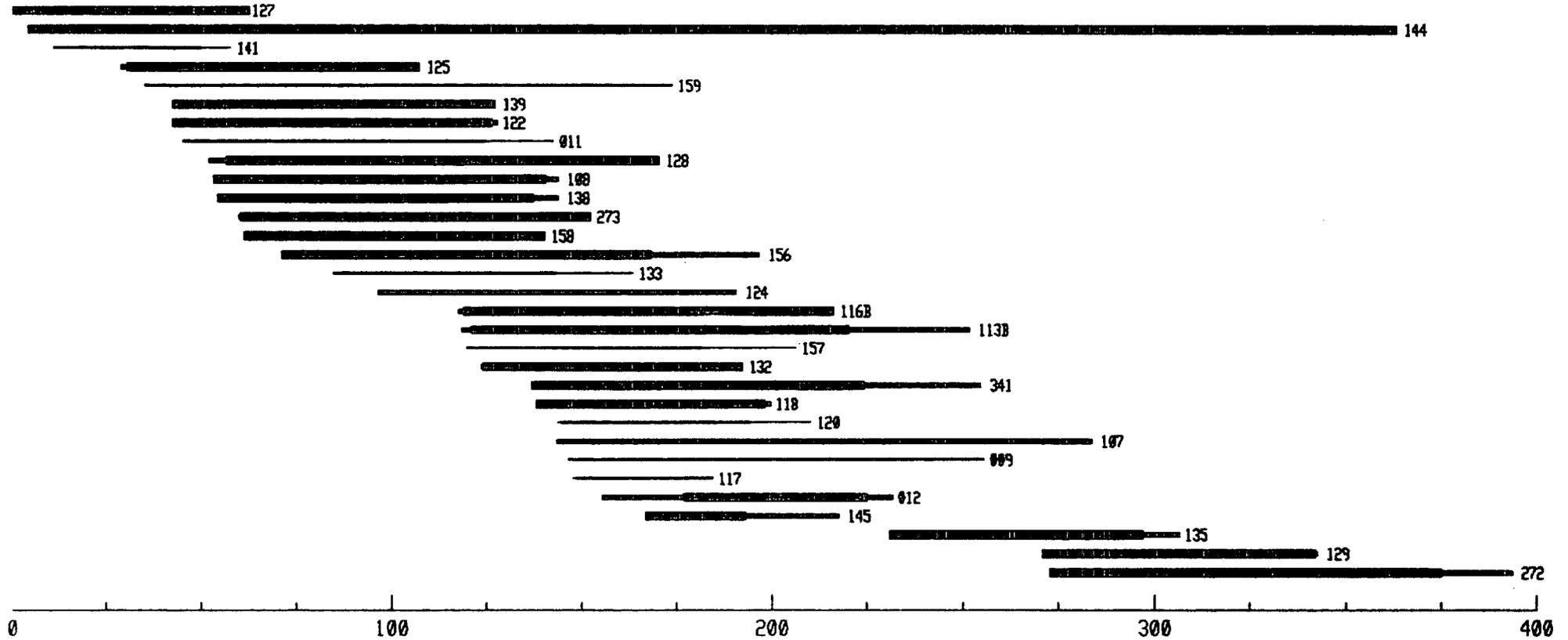
Site years (based on BAD144) ->

Legend:
- multiple P <0.05 IF>5
- multiple P <0.1 IF>5
- multiple P <0.05

Figure 11 Crossmatching of Badanloch samples

BADANLOCH - relation between RC & dendrochronological dates

Site years (based on BAD144)

0	100	200	300	400
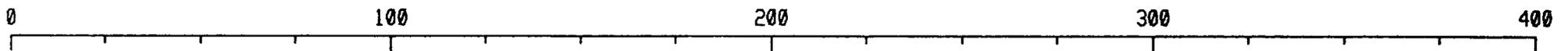
BAD144

BAD011

SRR-3566

BAD012

SRR-3567

4500	4400	4300	4200
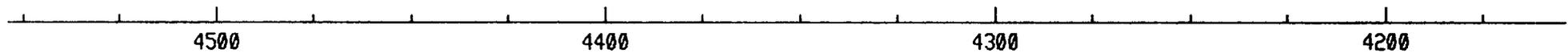
Uncalibrated ^{14}C years B.P. based on the mean of the 2 RC dates

Dendrochronological span of sample (solid line - section used for RC date)   SRR-3566 = 4405 ± 50 years BP

Radiocarbon date of sample with limits of 1 & 2 SD either side   SRR-3567 = 4370 ± 50 years BP

Figure 12 Radiocarbon dating at Badanloch

case of BAD011 and the outer 30 in the case of BAD012. As these points are 99 years apart on the dendrochronological scale and 35 years apart in ^{14}C years, it can be seen that the dates on the dendrochronological scale are within the one standard deviation limits of the radiocarbon dates. The scale of uncalibrated ^{14}C years at the bottom of the diagram has been fixed on the mean of the two positions suggested by the radiocarbon dates, giving a date of 4554 BP for the origin of the site years scale (4553 BP for the appearance of the first tree crossmatched on the site) and 4154 BP for the end (4161 BP for the death of the last crossmatched tree). This suggests a final decline at about the same time as at Lochstrathy (Gear 1989, Gear and Huntley 1991), but a first appearance about 50-60 years earlier, consistent with the lower limit of the migration rates suggested by Gear and Huntley (1991). However this difference is close to the error limits of the ^{14}C dates and therefore may not be significant.

4.5 Ring widths

The mean ring widths were calculated for each radius and an overall mean annual increment calculated for the site, giving a value of 0.77 mm $year^{-1}$ as compared with a range of 0.59-0.84 mm $year^{-1}$ for the Lochstrathy sites. The mean ring widths for the crossmatched radii were 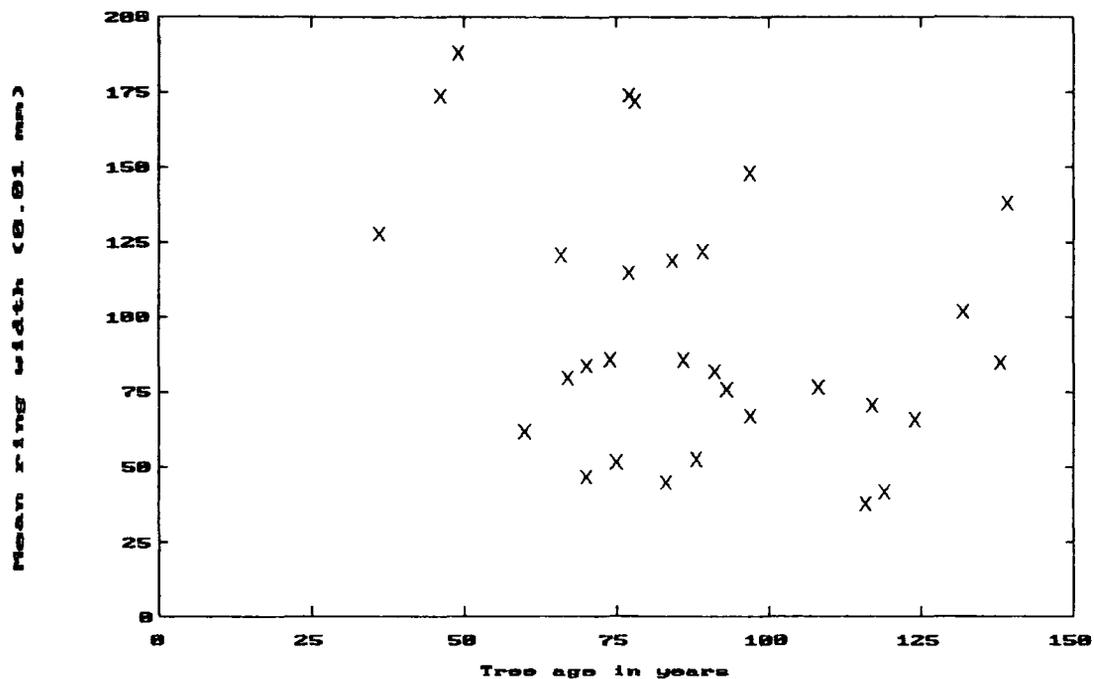plotted against the lifespan of their sample of origin and against their mid-lifespan date on the site time scale. The first of these scatterplots (Fig. 13a) shows a random pattern, there seeming to be no particular relationship between mean ring width and lifespan. Similarly, the second (Fig. 13b), shows no overall pattern, but there is a tendency for larger mean ring widths not to occur much after 175 years. This could be due to biological factors, but the low number of samples occuring after this date make this difficult to determine. As another approach to this a curve of the standardised ring widths of the main BAD144CD series was plotted, together with a rolling 10-year mean (using program CURVSMTH - see appendix) of the same values (Fig. 14). As discussed earlier in section 3.4, this latter curve gives a good indication of climatic influence and in fact shows a sharp decline from 175-200 years onwards, tallying with the apparent decrease in maximum ring width across the site. A further illustration is Fig. 15, which shows the largest mean ring width found for each 25 year period, each mean value being dated as the middle of the life of the tree from which it is taken. The two bars without hatching represent periods in which no mid-life point occurs, and are inserted as the means of the two adjacent values. The pattern corresponds well with that of the BAD144CD rolling 10-year mean, again suggesting an overall climatic influence, albeit modified in individual trees by local factors such as competition or slight variations in site quality.
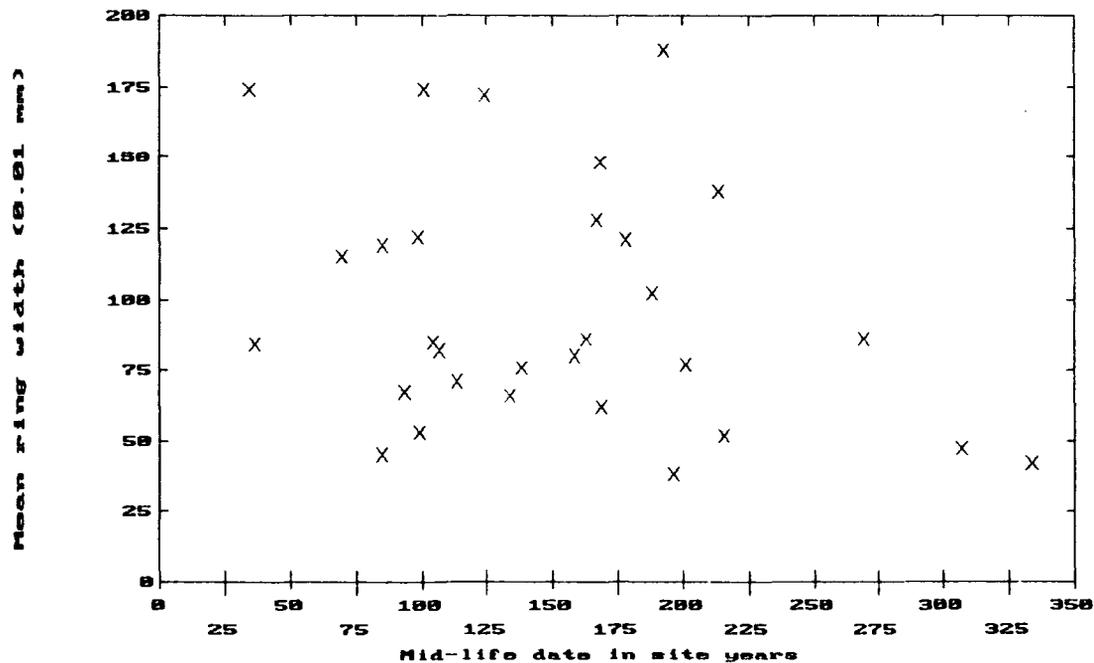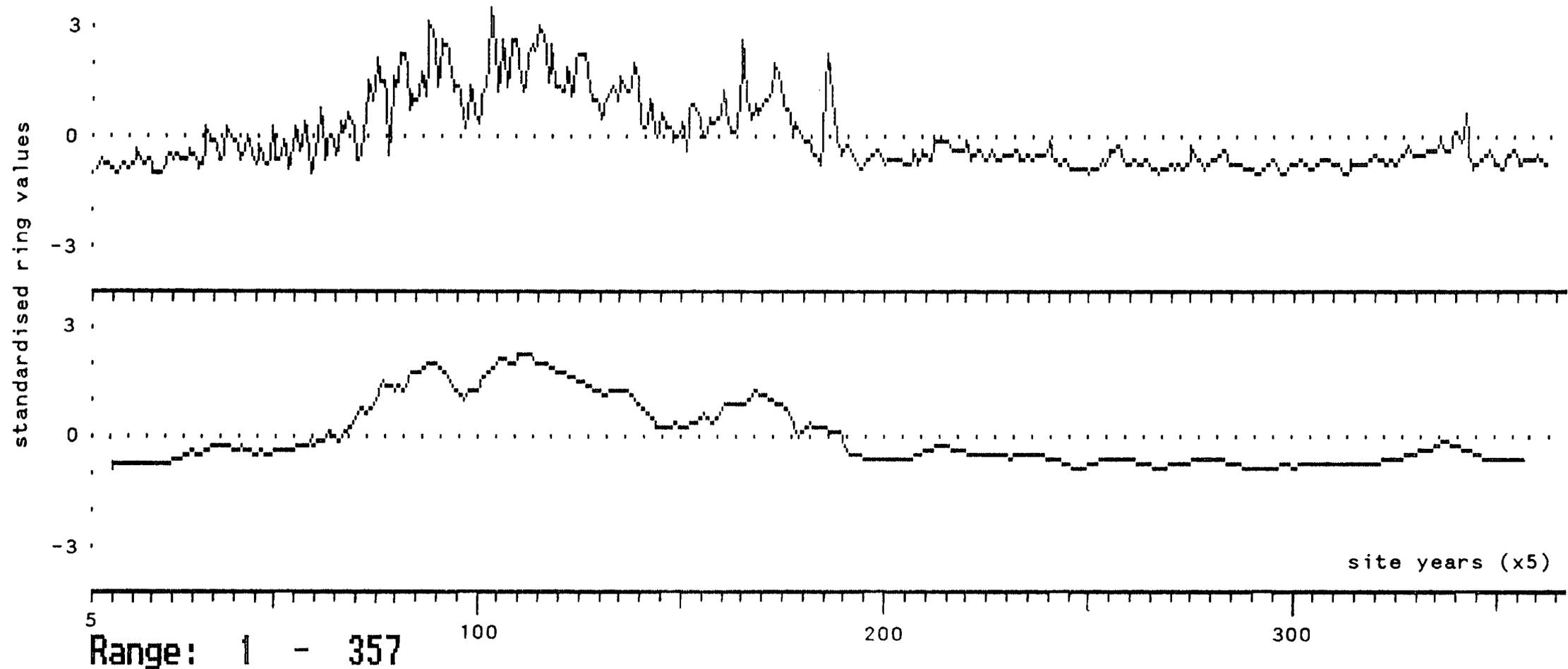
Figure 13 a and b   Ringwidth against tree age and mid-life date

BAD144CD.STD   16-09-1992   Radius - A   Rolling mean =   10

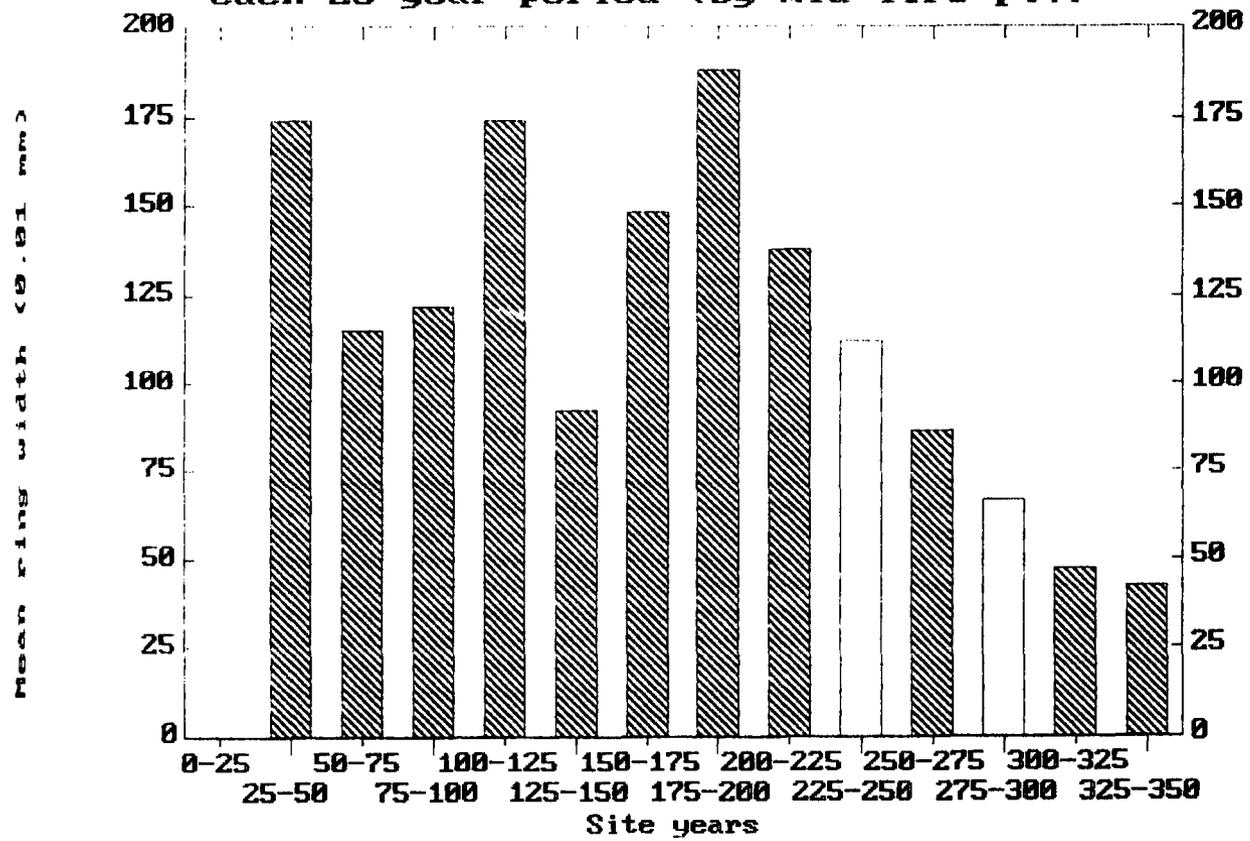Figure 14   BAD144CD - standardised data and 10 year rolling mean

Figure 15 Max. mean ring width in 25 year intervals

4.6 Population dynamics

Table 2 shows the ages of the individual samples in 25 year age classes derived from the data of Fig. 11. These provide the basis for the calculation of the mean age of the stand, no. of trees alive, trees born and trees dying in these intervals. Figs. 16a and b are plots of the mean age figures, the first one including BAD144, which because of its long lifespan has a dominating influence later in the site's history. The second (without BAD144) shows dips in the mean age of the population due either to increased recruitment or mortality of older trees, or to a combination of both, with an overlying trend towards greater age as recruitment tails off. Fig. 17 shows the lifespan of the samples (again excluding BAD144) plotted against their dates of birth, the random scatter suggesting other factors affecting the trees' death than any overall change in lifespan. These observations are summarised in Fig. 18 which shows birth and deaths in 25 year classes, with the number of trees alive on a year by year basis. Three increases in recruitment are clear, one culminating at around 75 site years (4479 BP), one at 150 site years (4404 BP)and a smaller one at about 275 years (4279 BP). Each of these tallies with an overall increase in the number of trees alive. However the numbers dying increase sharply at around year 150, at the peak of the second recruiting phase, possibly as the first generation start to die off at roughly the same age. Indeed the recruitment at this point may be a response to space created by the dying trees, though the number of dated samples is rather too small to be certain of this. The numbers dying subsequently appear to be roughly proportional to the numbers left alive, suggesting lack of recruitment as the main cause of declining population. This view is further reinforced by Fig. 19 which shows a cumulative plot of births and deaths in 25 year classes. Here the fall-off in recruitment is very marked from 175 site years (4379 BP) onward, ceasing from 275 years. The death rate is low till about 125 site years when the first generation reaches an age of about 100-125, after which it increases and remains roughly the same as the birth rate till the population starts to decline at about 200 site years (4354 BP).

Lastly, the data for the number of trees alive on a year by year basis permit an estimate of maximum tree density per hectare to be made as a modification of the density of subfossil stumps quoted in 3.4. This works out as a maximum of 236 ha^{-1} occuring in the period between 125 and 175 site years (4428-4378 BP) assuming the ratio of sampled and dated stumps to unsampled ones to be constant. This is low compared with the figures given by Goodier and Bunce (1977) of between 350-780 trees ha^{-1} for well stocked modern Scottish woods, but rather denser than their figure of <100 ha^{-1} for what they describe as open forest.

BADANLOCH - tree ages at 25 year intervals

0	25	50	75	100	125	150	175	200	225	250	275	300	325	350	375
	20	45	70	95	120	145	170	195	220	245	270	295	320	345	101
	24	49	46	71	90	115	103	82	106	106	131	68	53	76	
	14	39	40	65	80	98	78	81	87	103	43	28	51		
		21	32	57	73	78	57	80	81	18	3	26			
		15	32	57	71	65	56	62	78		1				
		7	30	55	70	53	55	56	69						
		7	23	48	65	32	51	56							
		5	21	46	63	31	37	53							
			20	45	53	30	36	44							
			15	40	40	26	31	32							
			13	38	28	12	31								
			3	28	7	11	28								
				15	6	6	27								
				3	5	6	19								
					1	3	7								
						2									

	0	25	50	75	100	125	150	175	200	225	250	275	300	325	350	375
MEAN including BAD144	0	19.3	23.5	29.2	47.7	51.8	44.9	52.7	74.6	107.7	119.3	89.6	105.5	143	213	101
MEAN excluding BAD144	0	19	20.4	25.5	44.1	46.9	38.2	44.4	61.2	85.2	77.3	44.5	42.3	52	76	101
No. of trees alive	0	3	8	12	14	15	16	15	10	6	4	5	4	3	2	1
Trees born	0	3	5	6	2	4	6	2	0	0	1	2	0	0	0	0
Trees dying	0	0	0	2	0	1	6	4	5	4	1	3	1	1	1	1

Table 2. BADANLOCH - tree ages at 25 year intervals

Mean Age of trees at 25 year intervals
including BAD144

Site years
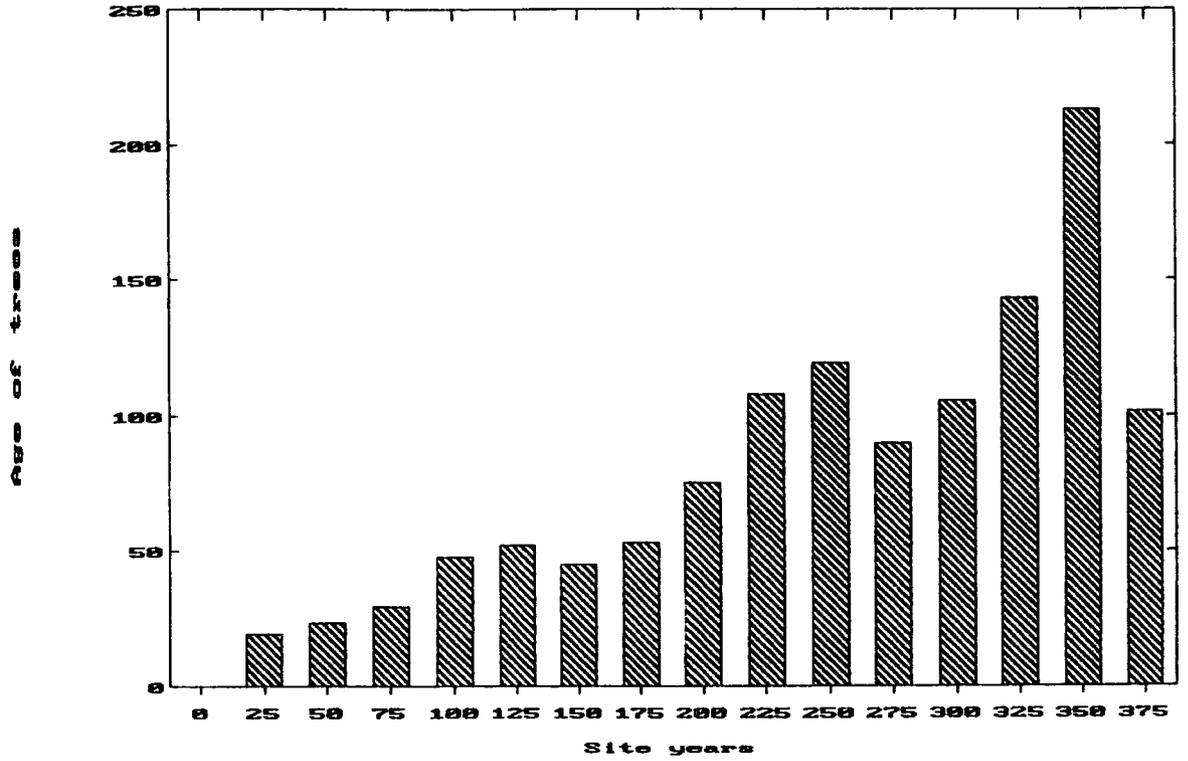
Mean Age of trees at 25 year intervals
excluding BAD144
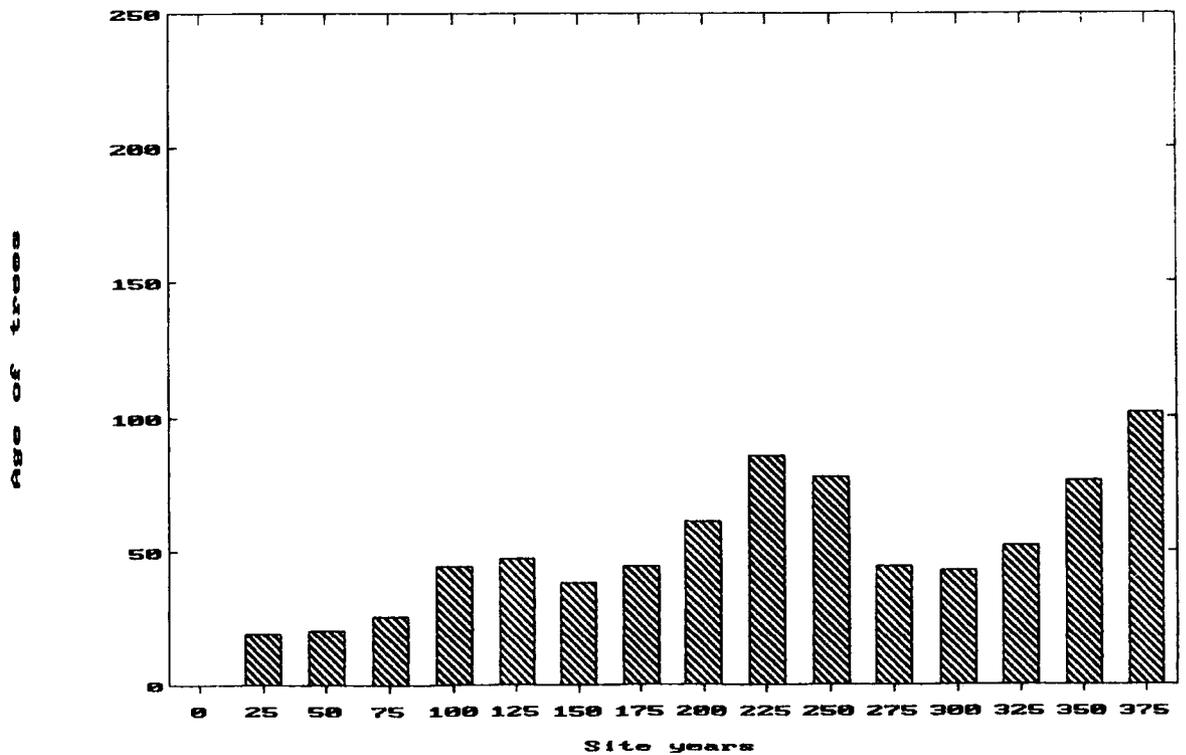

Site years

Figure 16 a and b Mean ages of trees with and without BAD144 at 25 year intervals

Lifespan against birth date

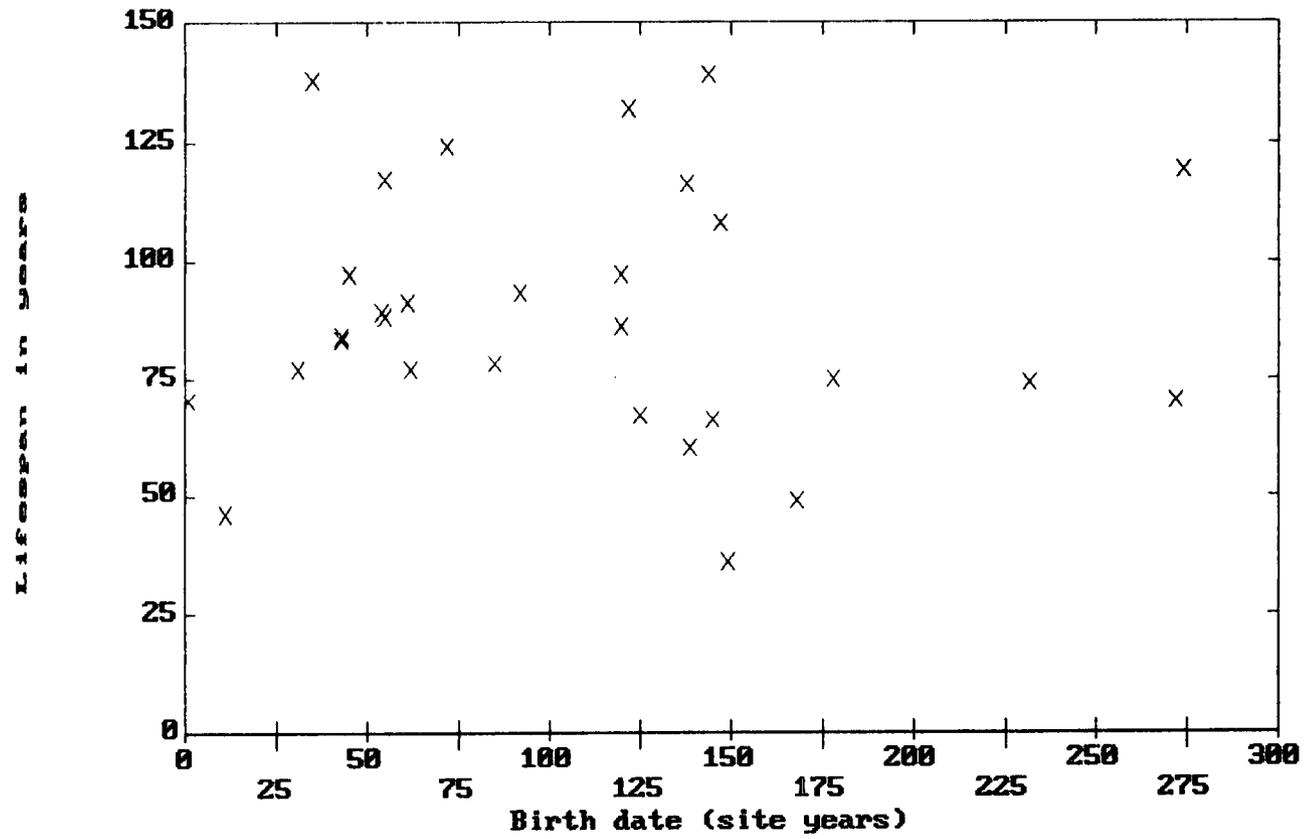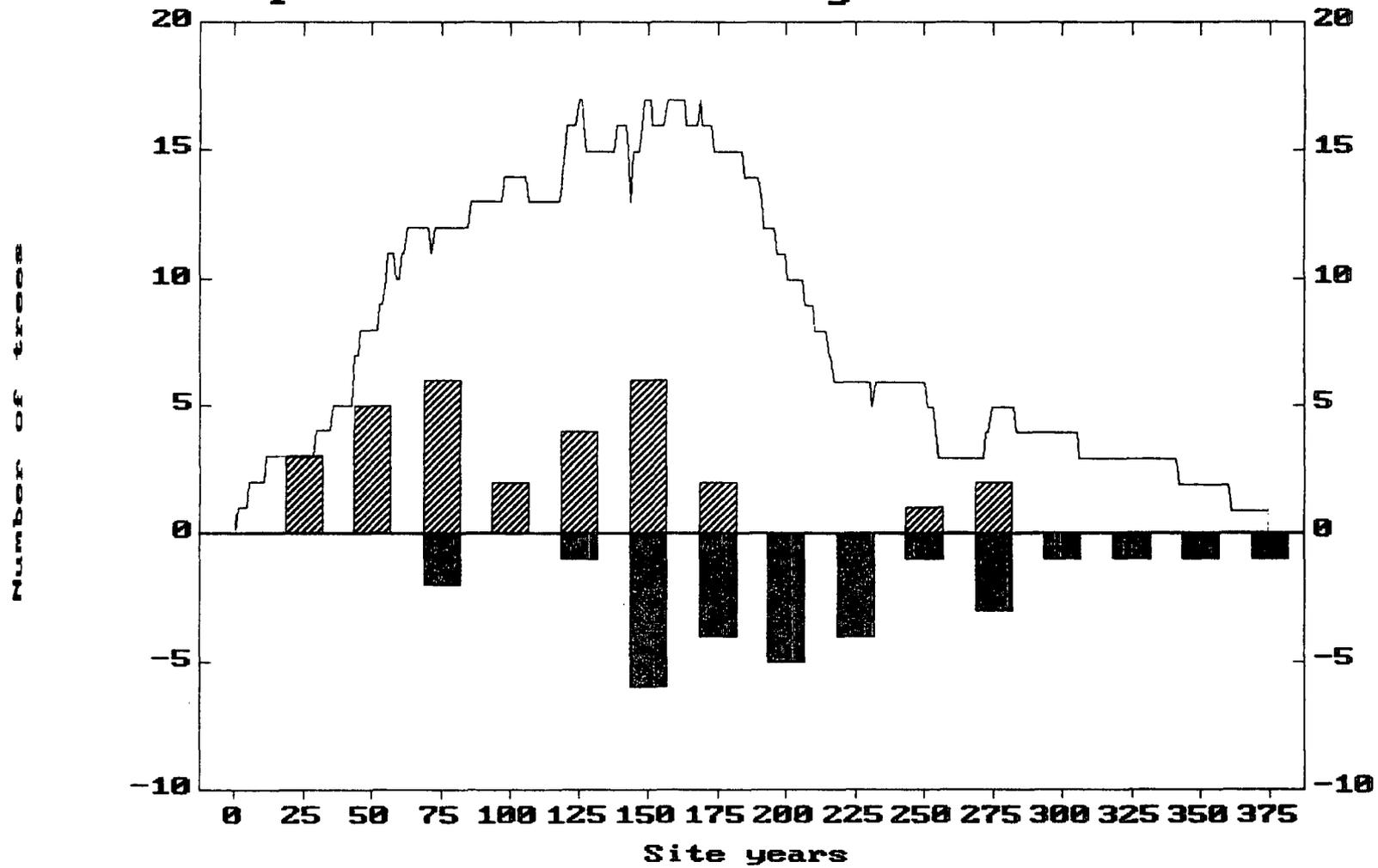Figure 17 Tree lifespan against germination date

Figure 18 Births and deaths in 25 year intervals and trees alive year by year

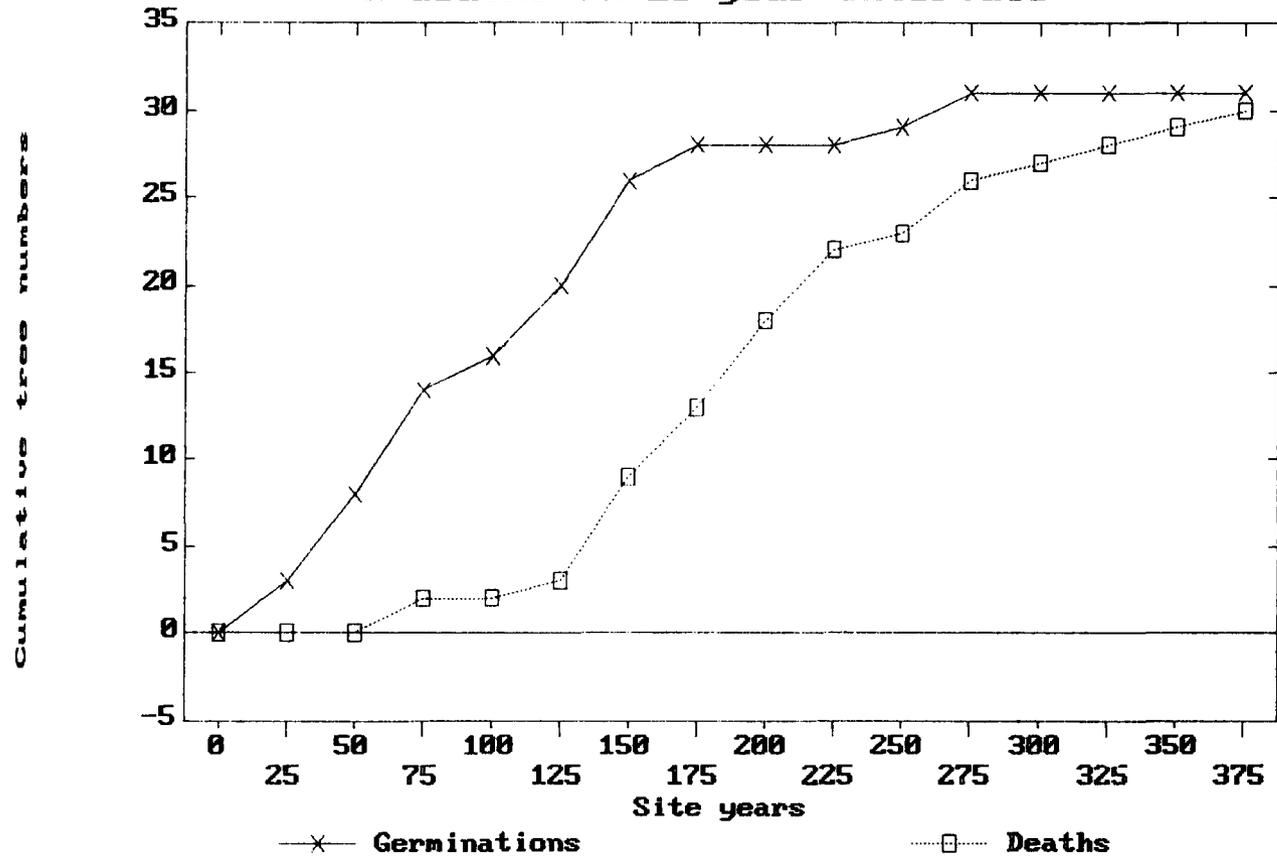**BADANLOCH — cumulative nos. of births & deaths in 25 year intervals**

Figure 19 Cumulative births and deaths in 25 year intervals
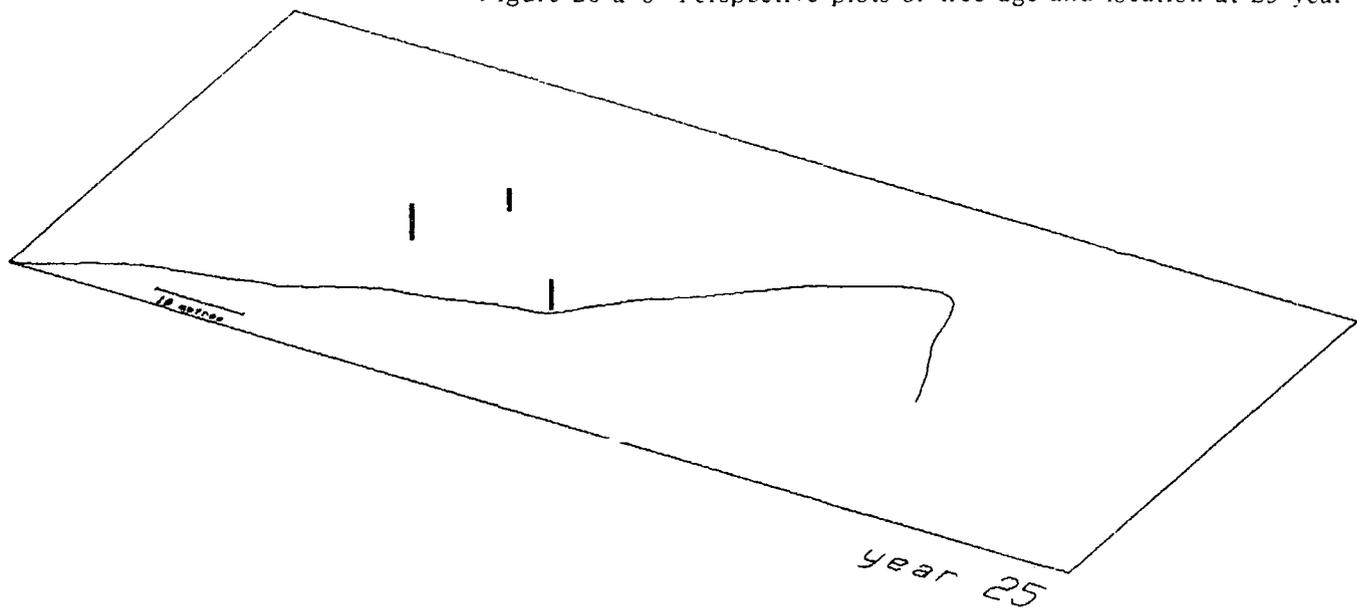
4.7 Pattern of growth and colonisation

Finally, a set of perspective 3-D plots (Figs. 20a-o) is presented to illustrate the sequence of growth for those trees which have been crossmatched and whose position is known. These plots were prepared for 25 year classes (in site years), and show the area covered by the plan (Fig. 7 in pocket on rear cover). As before, the continuous line represents the boundary of the eroded peat. The short side of the rectangle is the N-S axis, so the angle of view is approximately to the north-west. The trees are represented as vertical bars whose height is proportional to their age at the end of each 25 year class, thus the height of the bars bears no relation to the possible physical height of the original trees. During the first 25 year class in which they appear the trees are represented by thin bars, subsequently by thick ones. After a tree has died it is represented by two dots, one above the other, at the point at which it was growing. As there are a large number of stumps either unsampled or undated, for clarity the positions of these have been plotted separately on an overlay (Fig 20p in the pocket on the rear cover) which may be fitted over any of the 3-D plots.

The sequence revealed by these plots is one of initial colonisation by two or three trees (always bearing in mind the presence of other undated ones) which then appear to give rise to seedlings in their immediate vicinity. These then seem to replace their originators in about 75 years or so. The one exception to this, the tree in the foreground, BAD144, persists to an age of 357 years, an age approaching the 395 years of the oldest specimen recorded in Britain (Steven and Carlisle 1959). This dominance is is also indicated by a slight gap between it and the other trees, though when non-dated stumps are taken into account there are signs that it might have been part of a local group. Also the edge of the peat is very close, and other trees close to BAD144 may still be hidden in it. The clumpedness of the distribution seems to persist up to year 150 when the population seems to get more scattered. There then seems to be a period of more sparsely distributed, older trees with little recruitment till about 250 years when two trees appear in about 25 years. After that all recruitment ceases and by year 375 all the dated trees are dead. Clearly, this can only be a partial demonstration of population dynamics because of the presence of the other undated stumps, but some ecological inferences might be drawn as will be discussed later.

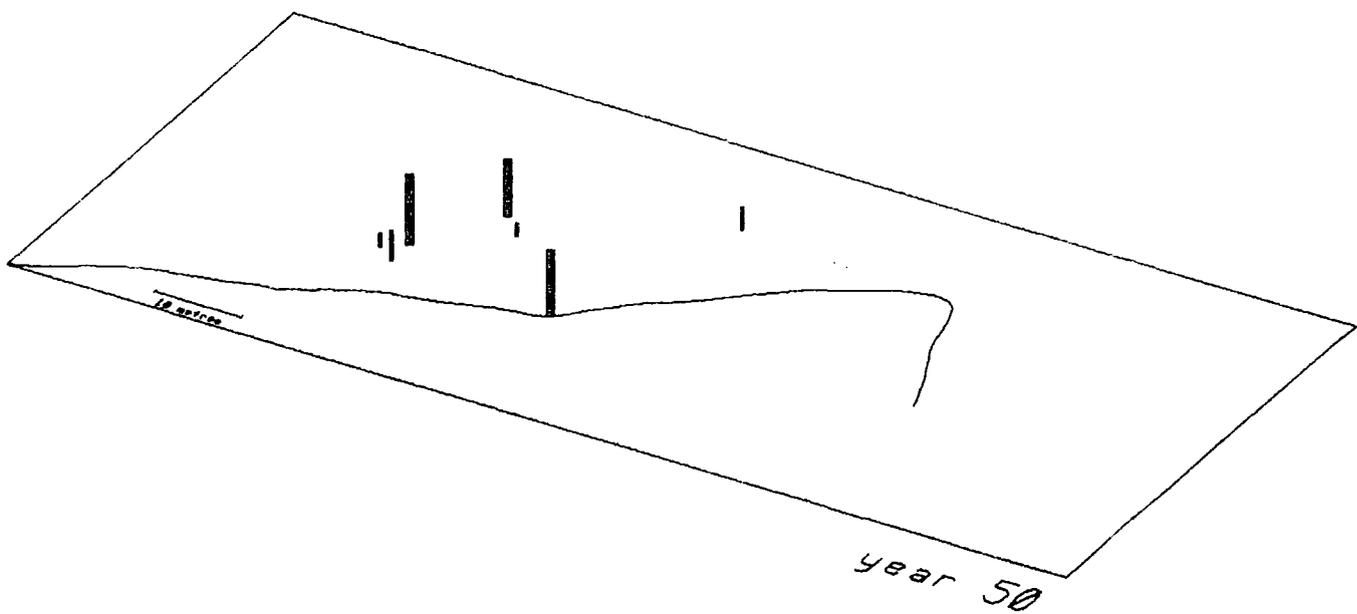## 4.8 Comparison with Lochstrathy

In terms of the first objective of this study, it is clear that *Pinus sylvestris* was present at Badanloch for about 400 years from around 4553 BP to 4161 BP. This is based on
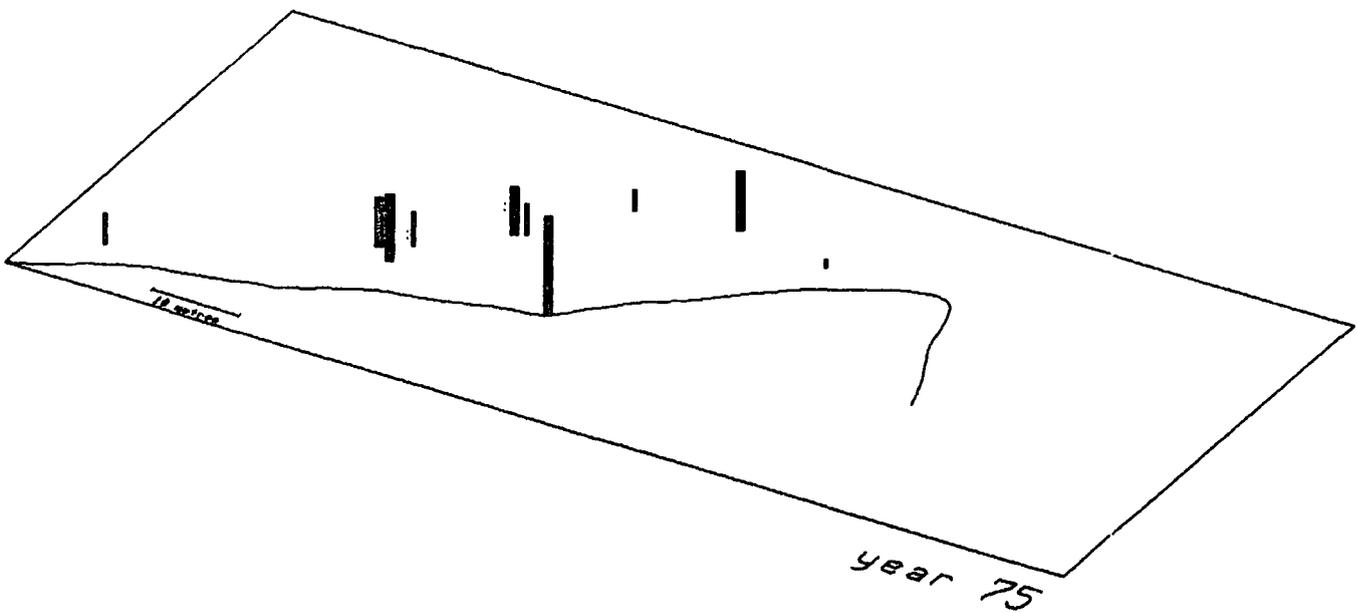
13

a
year 25

b
year 50

c
year 75

d

year 100

e

year 125

f

year 150

g

year 175

h

year 200

i

year 225

j

year 250

k

year 275

l

year 300

m

year 325

n

year 350

o

year 375
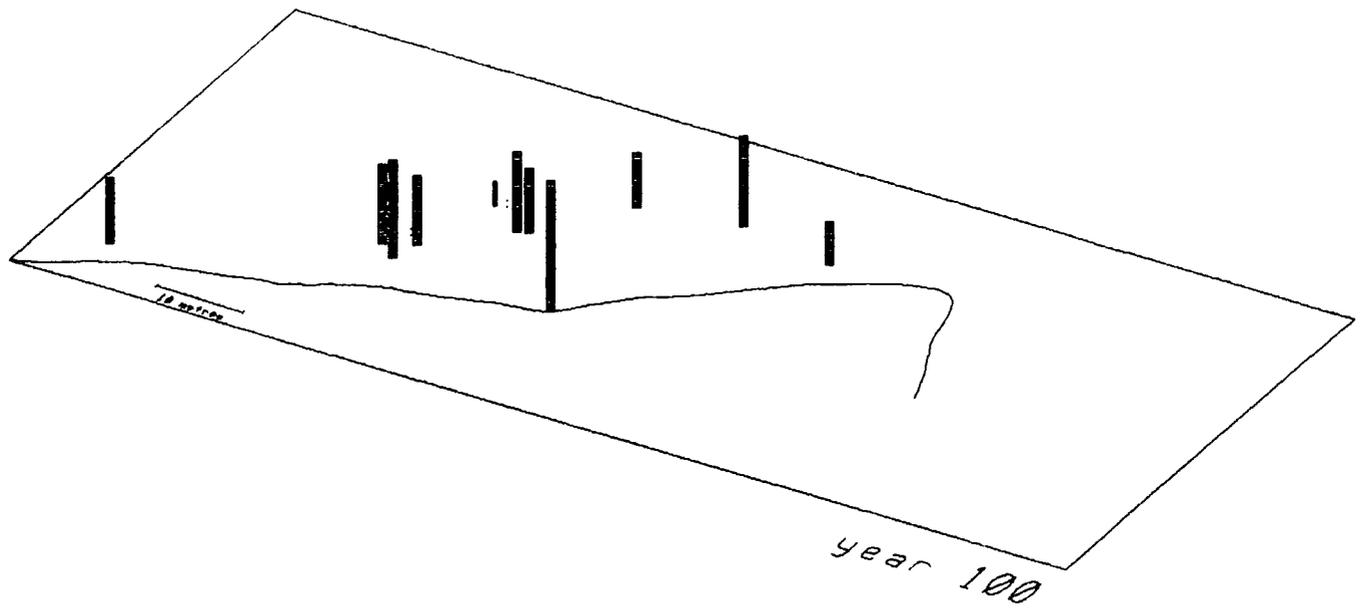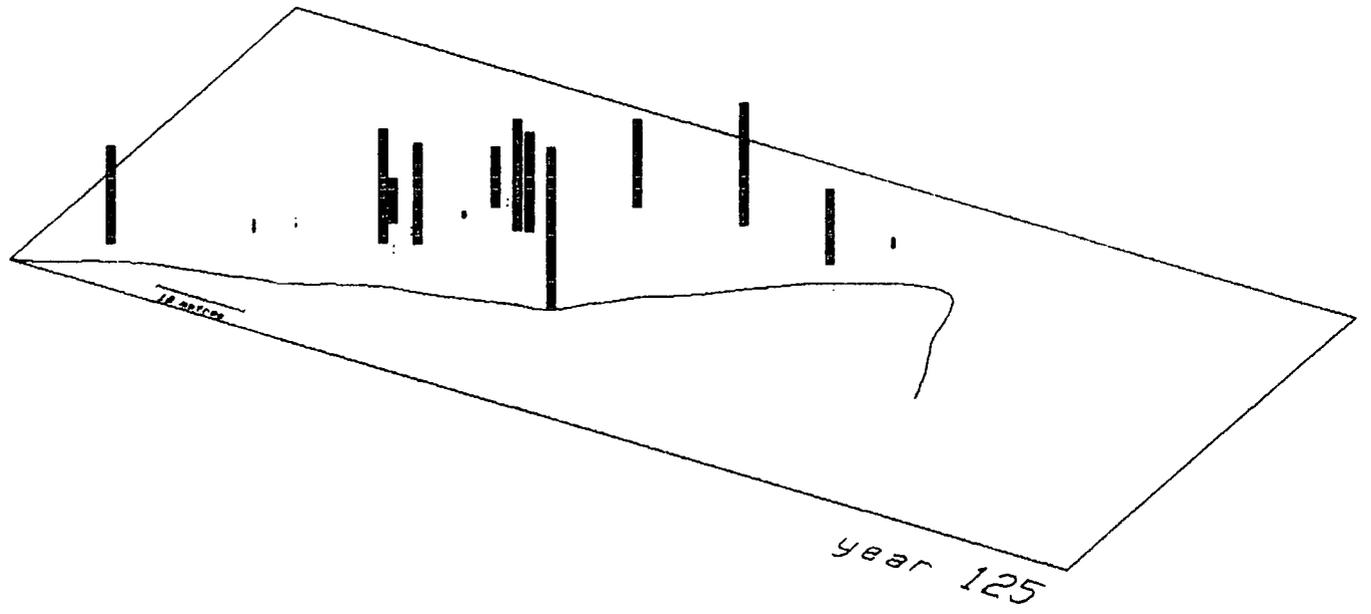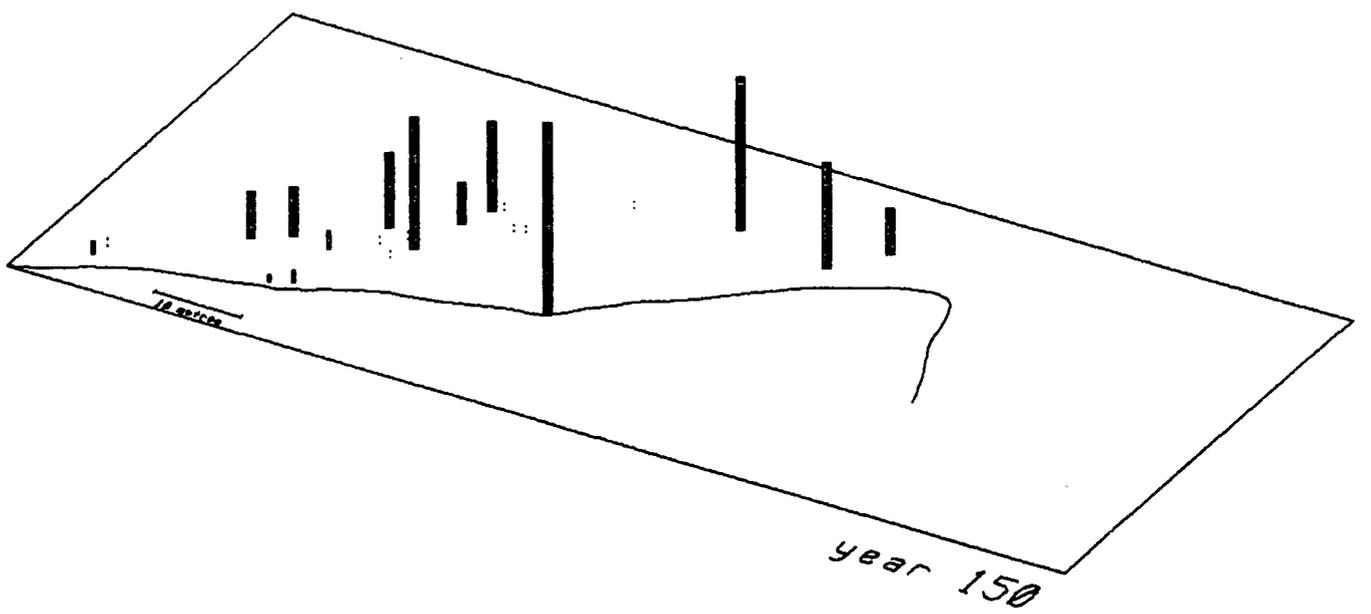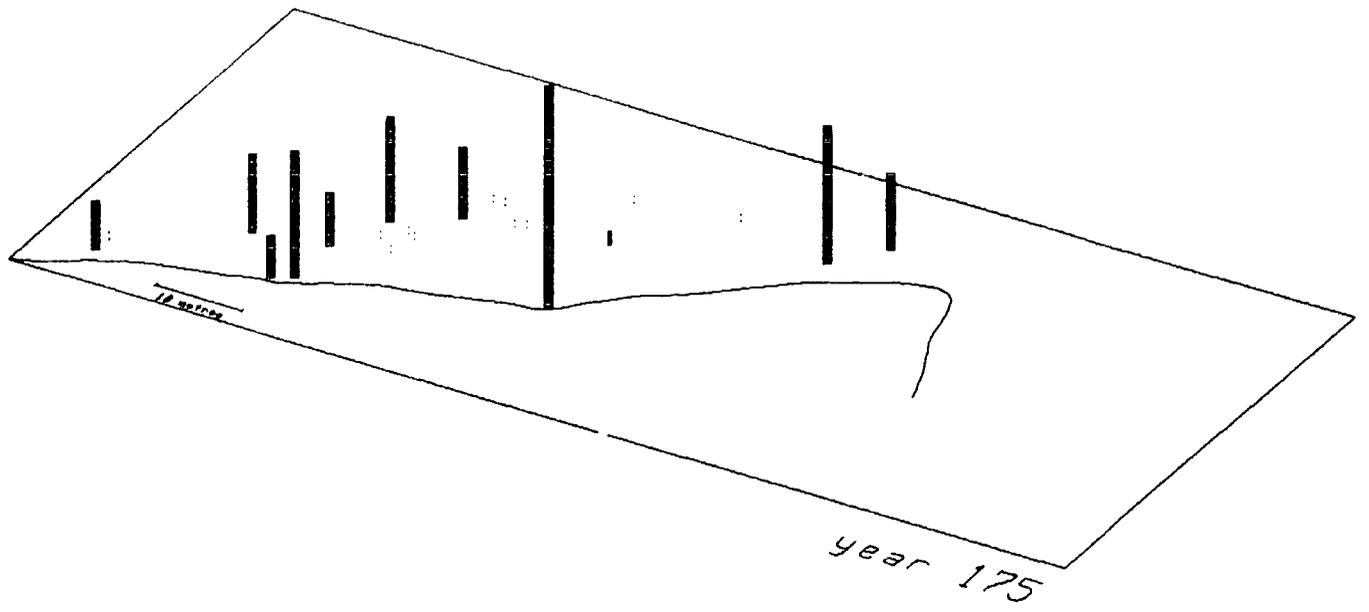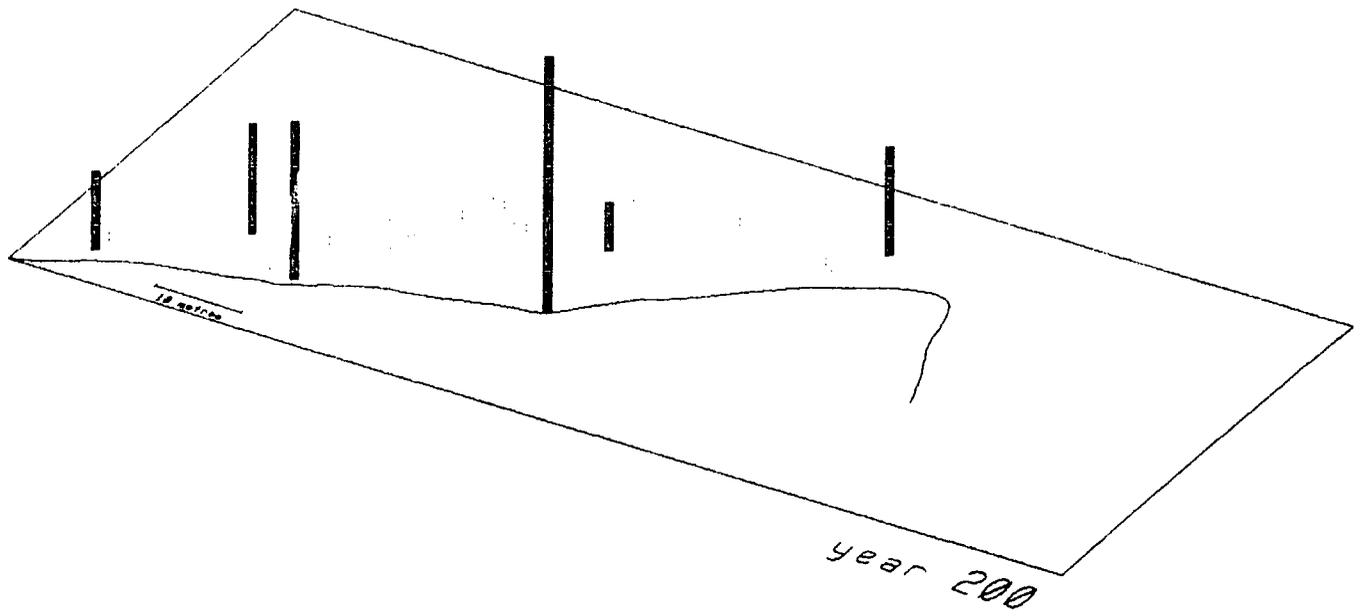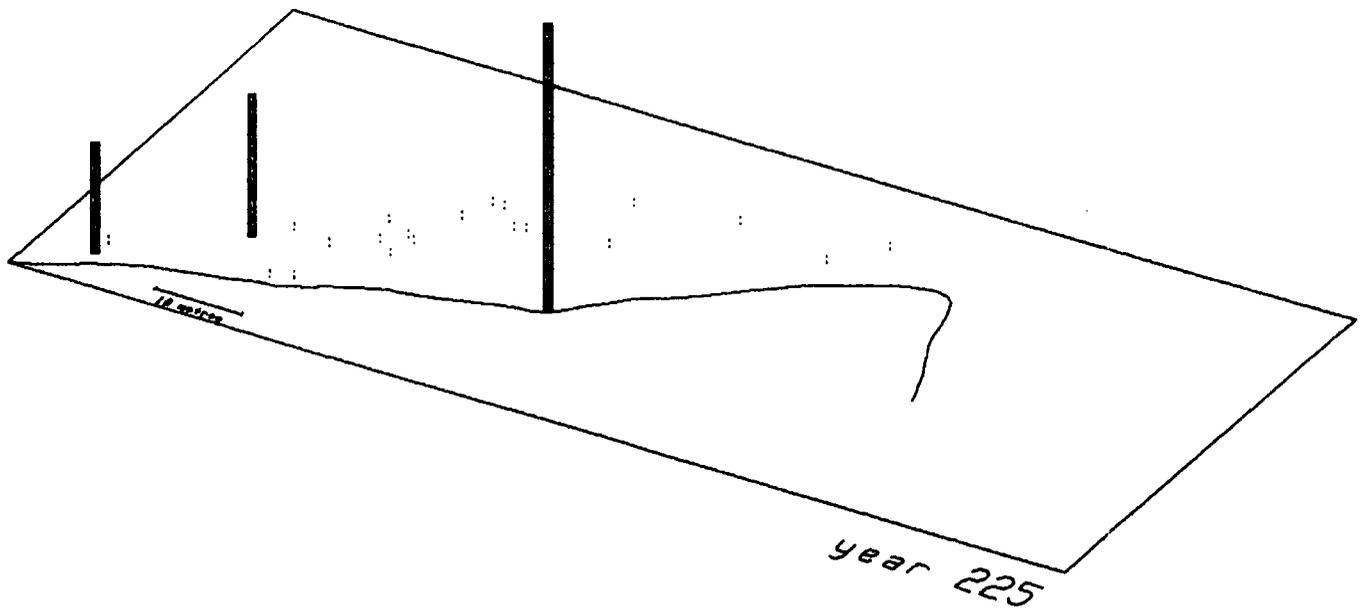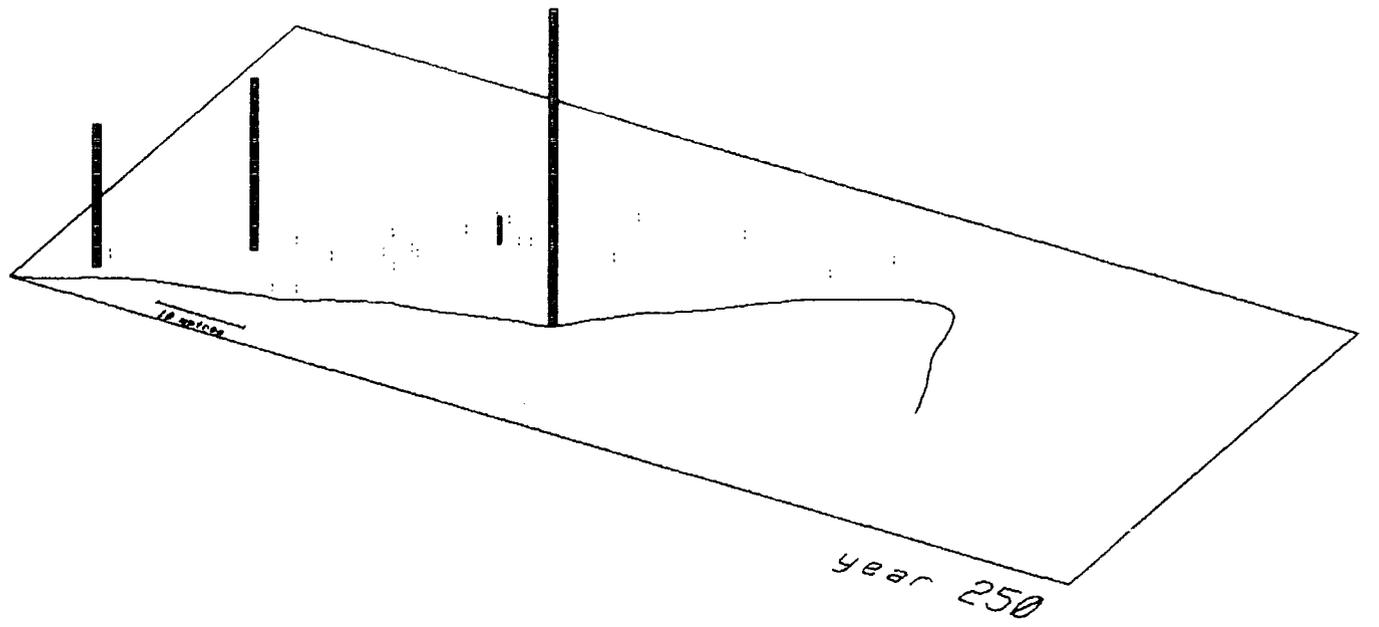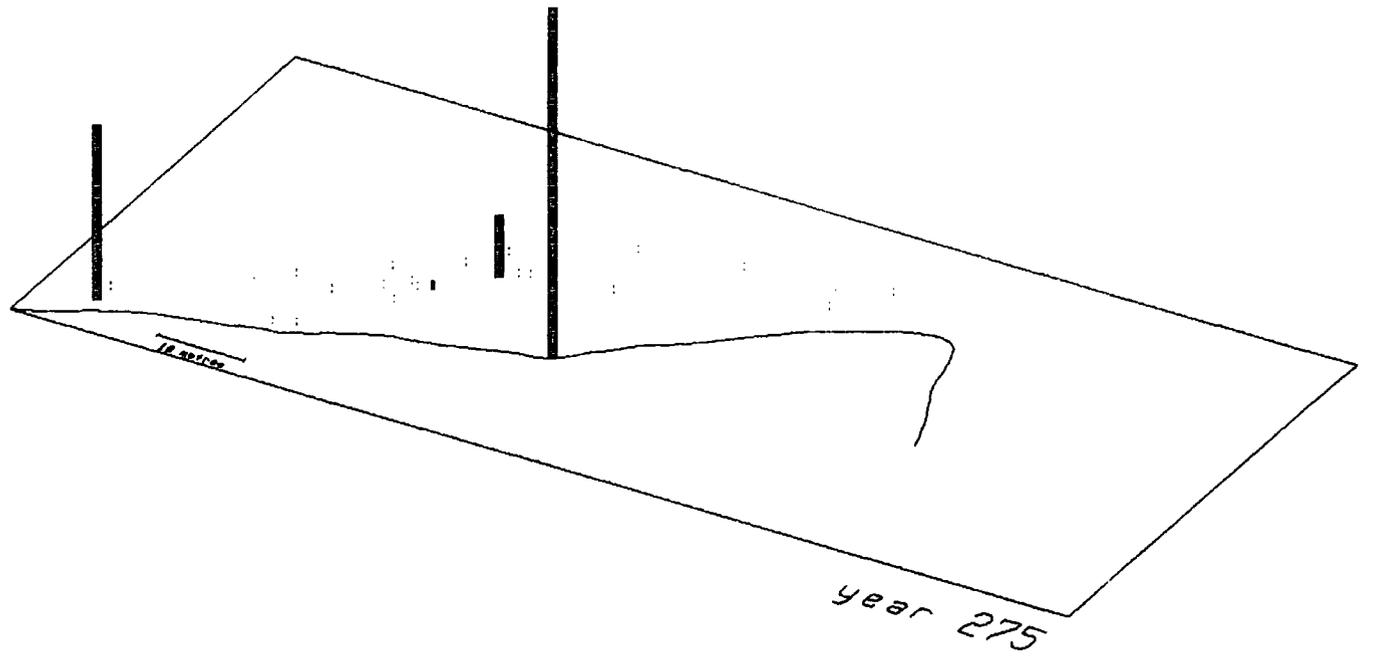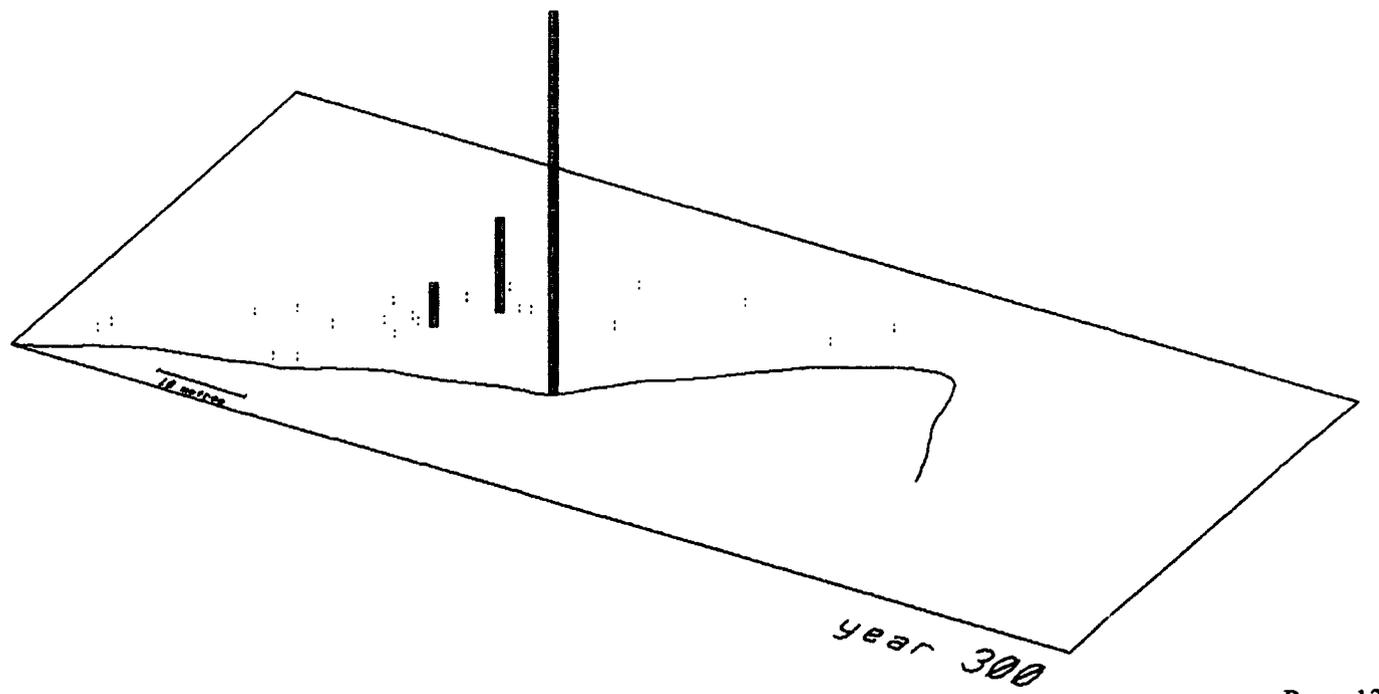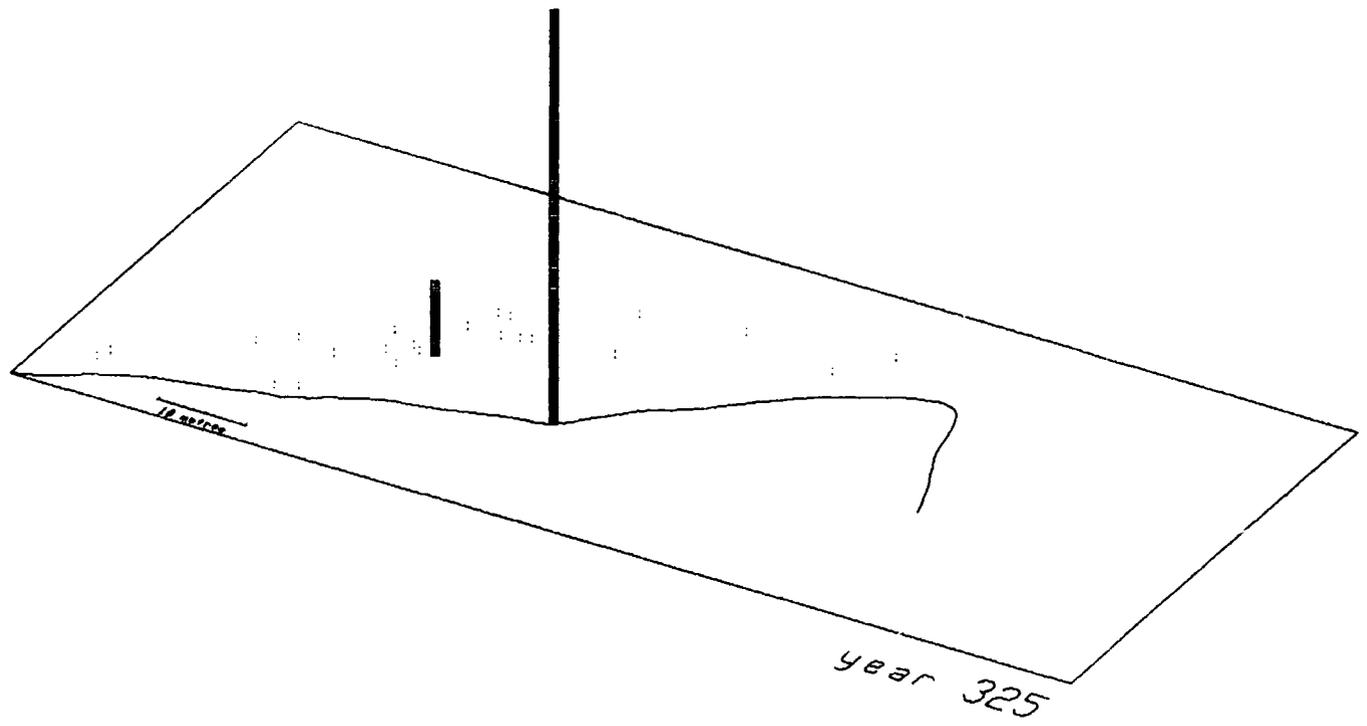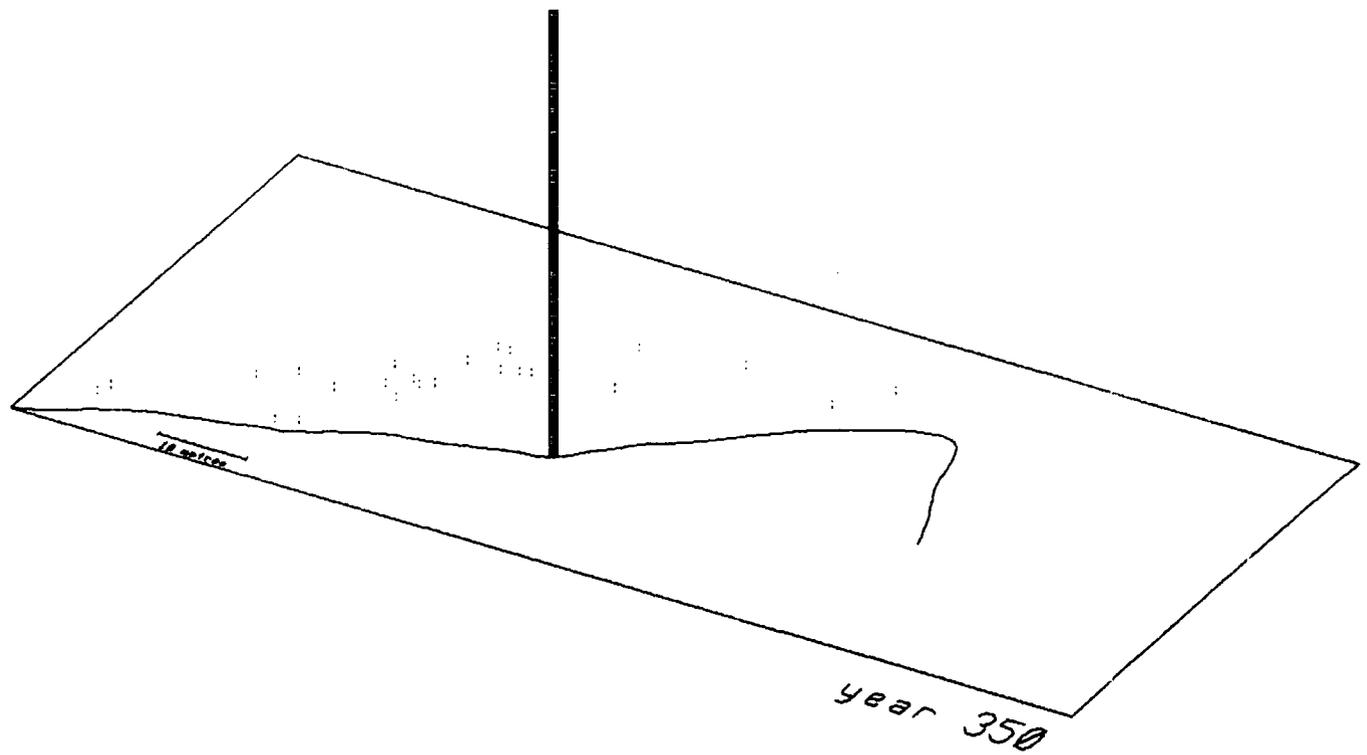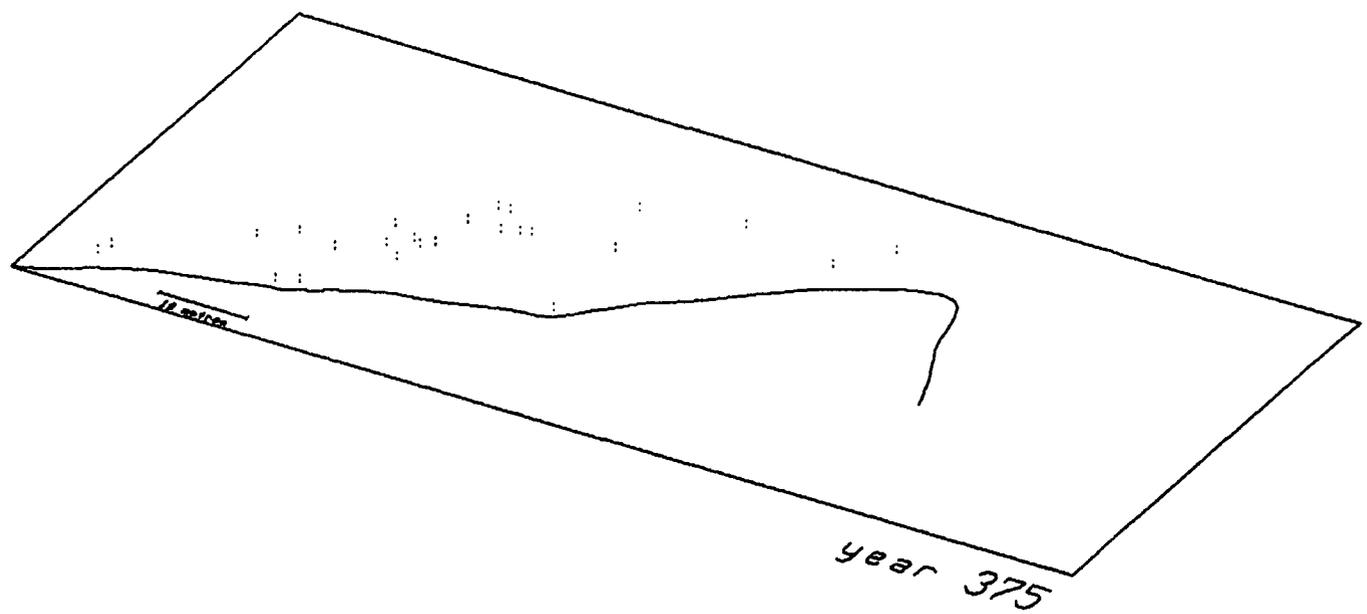
crossmatching to a single long lived specimen (BAD144) and therefore is a conservative estimate as clearly other trees must have occured before and after these limits. However, the rise and decline of the population is clearly shown (Fig. 18, page 12d) and it agrees closely with that found at Lochstrathy (Gear 1989, Gear and Huntley 1991); at Badanloch the beginning of the expansion being some 60 years earlier, and the decline about 15 years earlier. The Lochstrathy population shows 3 peaks, at approximately 4400 BP, 4350 BP and 4280 BP, the first and last coinciding with peaks at Badanloch, at site years 150 and 275 respectively. Though the difference in timing of the population rise at Badanloch and Lochstrathy is of the order of the standard error of each of the radiocarbon dates (±50), the coincidence of these peaks suggest that this difference may be real. Huntley (1991) suggests a maximum migration rate of 150-500 m year^{-1} for most trees, giving a distance range of 9-30 km for 60 years. This fits well with the 15 km that Lochstrathy lies to the north of Badanloch. Certainly the time spans of occupation of the two sites are very similar, suggesting wide-spread, probably climatic effects permitting the original colonisation and causing the ultimate decline of the *Pinus sylvestris* populations at both places.

The growth statistics for the two sites are also similar as shown in Table 3, though the mean lifespan at Badanloch seems to be greater, possibly because Lochstrathy is higher, about 160 m above sea level, and 15 km closer to the north coast. The bottom row of figures in the table represents an estimate for the maximum density of living trees per hectare reached at each of the sites. In the case of Lochstrathy this is calculated as roughly 50% of the total density (Gear 1989), but at Badanloch the figure is reached by multiplying the total density of stumps by the ratio of the maximum number of dated stumps alive at any one time (17 - see Fig. 18, page 12d) to the total number of all those dated (31). In all the Badanloch figures the data for BAD144 is omitted. Apart from the average lifespan of the trees the main difference between the Badanloch and Lochstrathy sites seems to be the greater evidence of fire at the latter, little if any being found at Badanloch (see 3.3).

5 DISCUSSION

There are two main aspects to the interpretation of the results of this project, the first being that of the ecology of the subfossil woodland with the reasons for its rise and decline, and the second being how this relates to an understanding of wider climatic changes in the north of Scotland and in north-west Europe.

14

LOCHSTRATHY

	A	B	C	D	BADANLOCH
Mean no. of rings	57.0	54.0	64.9	63.1	89.2
Mean annual incr.	0.788	0.595	0.738	0.843	0.771
Total stumps per ha.	386.99	248.32	530.50	224.11	431.47
Estimated max no. of stumps living at any one time	193	124	265	112	237

Table 3 Lochstrathy and Badanloch - growth statistics

In terms of the ecology of the woodland it seems clear that the trees at Badanloch were growing under stress towards the edge of their range, even when conditions were at their best. This is born out by a number of factors, the first being the low average lifespan found at the site, 89 years as opposed to the 140-190 years found in modern Scottish woods (Steven and Carlisle 1959), or around 100-130 years found at other sites in Scotland and Ireland where subfossil pine has colonised peat at roughly the same date (Bridge et al. 1990, McNally and Doyle 1984a).

Also indicative of stress is the high degree of distortion found in many of the samples from Badanloch, not all of this attributable to having to take samples lower in the tree than is ideal for dendrochronological analysis. Linked to this is the small average annual increment recorded from both the Badanloch and Lochstrathy sites, between 0.5 and 0.8 mm, again much lower than a modern site in Ireland on peat, where typical values of 2-3 mm are found (McNally and Doyle 1984a). These authors found that annual increments for subfossil trees at Glashabaun in Ireland growing at about the same time as those at Badanloch were on average about half of those for modern trees. In terms of height, the only piece of evidence found at Badanloch was a tree-trunk of about 5 metres in length (Plate 5), which probably represented the bulk of the tree. This trunk appears to have had branches for most of its length, a growth form which Steven and Carlisle (1959) consider to be partly genetic in origin, but partly attributable to age, young trees having a more conical form than older ones. Also dense stocking may produce this effect, but this seems not to have been the case at this site where densities are on the low side (see 4.6). McNally and Doyle (1984a) describe subfossil trunks of about the same overall length from the peat at Glashabaun, suggesting that the trunk at Badanloch might be typical of the growth attained on the site, though some of the stumps in the middle distance of Plate 6 appear to be the remains of larger trees. In this context it is worth noting that the maximum diameter of BAD144, with an age of 357 years was only 40 cm, the minimum being about 25 cm, and other, younger samples had diameters out of proportion to their age, for example BAD113, age 132, diameter 16 cm, and BAD116A, age 99, diameter about 18 cm. In modern trees Steven and Carlisle (1959) found that age and size in *Pinus sylvestris* were often not closely correlated, and that in long lived specimens the annual growth increment became very small (of the order of 20 rings per cm). Plates 7 and 8 show the section from BAD144, Plate 8 showing the very narrow rings (as many as 50 per cm) on radius D from about ring 185 onwards. This may partly be due to the age of the tree as Steven and Carlisle indicated, but the rapid change in growth rate suggests the onset of external stress as the main factor (Bridge et al. 1990). The smallest average ring width found in the Badanloch study was 0.33 mm (30 per cm) in a tree

15

Plate 5   5 m subfossil trunk from Badanloch – base away from camera

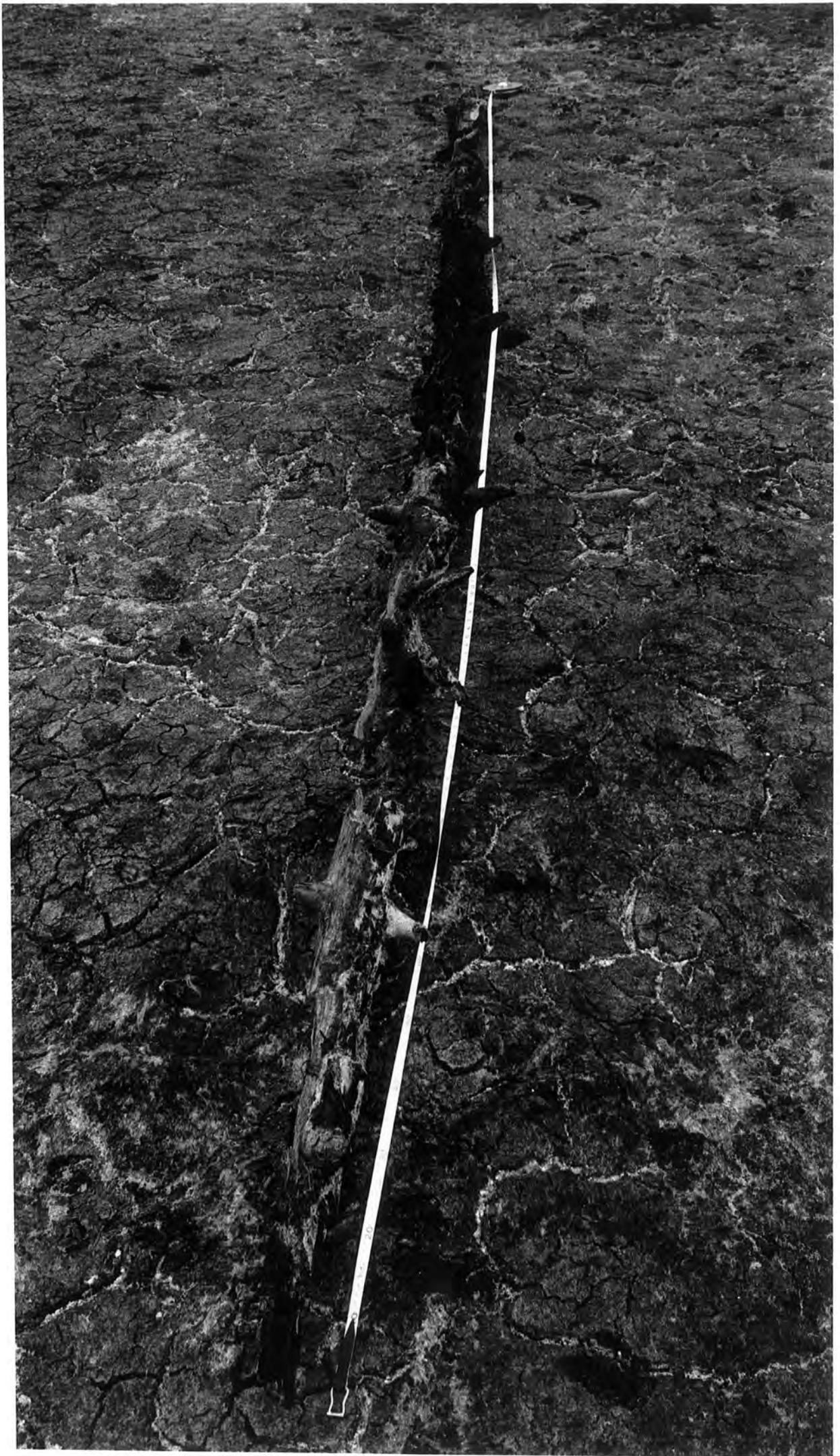Plate 6   Badanloch looking N, 2 large stumps in middle distance

Plate 7   BAD144 section – scale in mm

Plate 8   BAD144 section – narrow rings at end of "D" radius – scale in mm
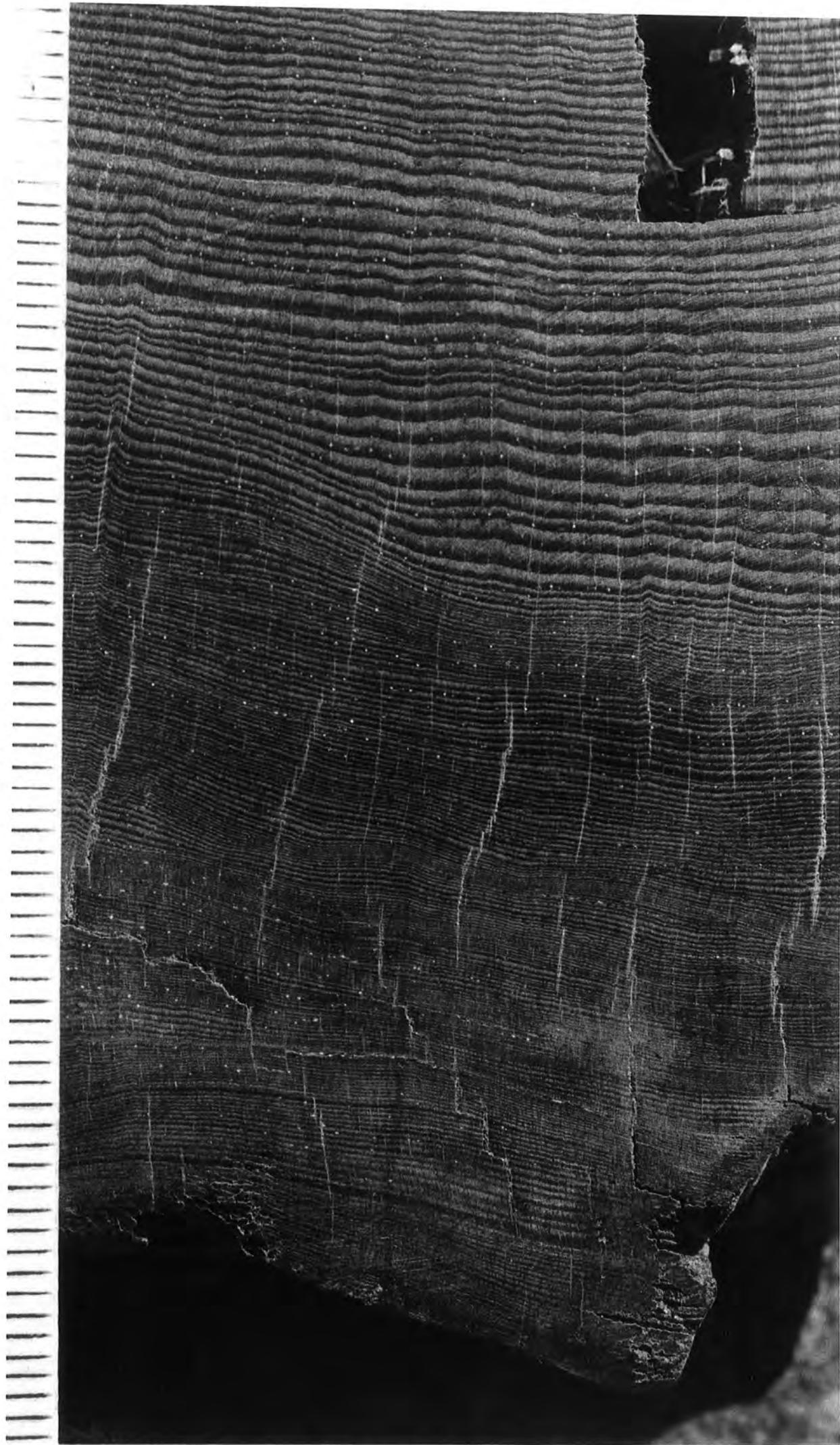
with an age of 119 years (BAD272). Significantly this was the last crossmatched tree alive on the site, well into the wood's decline.

Growth at the edge of a species' range implies climate as the main cause of stress. However there is some suggestion that edaphic factors may contribute to this in the case of *Pinus sylvestris* growing on peat. McVean (1963a) points to lack of phosphorus being important, suggesting this as a cause of lack of mycorrhizal activity as well as having a direct influence on the growth of the pines. Waterlogging may also prevent the formation of mycorrhizal associations, and certainly the horizontal root structures at Badanloch would bear this out (Plate 9), there being little evidence of the fibrous root growth associated with mycorrhiza. Carlisle and Brown (1968) identify this horizontal root structure with poorly drained habitats and it may be that the occasional tap root at Badanloch (Plate 10) is a response to wind exposure rather than drainage (the conical top shown in this plate is typical of the stump shape before decay was stopped by peat cover).

The climatic requirements outlined by the same authors seem fairly broad, the principal ones being mean temperatures of 10.5°C over four summer months for seed ripening and 8.5°C over the same period for vegetative growth. Carlisle and Brown (1968) also point out that Scots Pine will tolerate winter temperatures as low as - 26.7°C. Generally, *Pinus sylvestris* appears to prefer a more continental climate, and it seems that changes between this and a more oceanic regime with its higher rainfall are the key to changes in *Pinus* distribution in the north of Scotland, pine invading peat surfaces as they dried out. In this connection it is worth noting that at Badanloch there is a layer of birch beneath the pine (visible in Plate 9), which suggests that an increase in continentality of climate may have favoured a subsequent invasion of pine, birch preferring more oceanic conditions (Steven and Carlisle 1959). Alternatively, McNally and Doyle (1984b) suggest that the establishment of birch scrub may be an important seral stage in the developement of pine on bog surfaces, the pine supplanting the birch. However, birch-pine interactions are complex (Bennett 1984) and either may dominate depending on edaphic and climatic circumstances.

It is apparent both from the work of Gear (1989), summarised in Gear and Huntley (1991), and the present study that the cause of the decline in Scots Pine at Lochstrathy and Badanloch was the failure of the trees to regenerate, mortality through senescence remaining fairly constant. A number of factors may account for this, affecting both the setting of seed and the survival of seedlings.

Plate 9   Stump interstratified in peat edge – traces of birch underneath
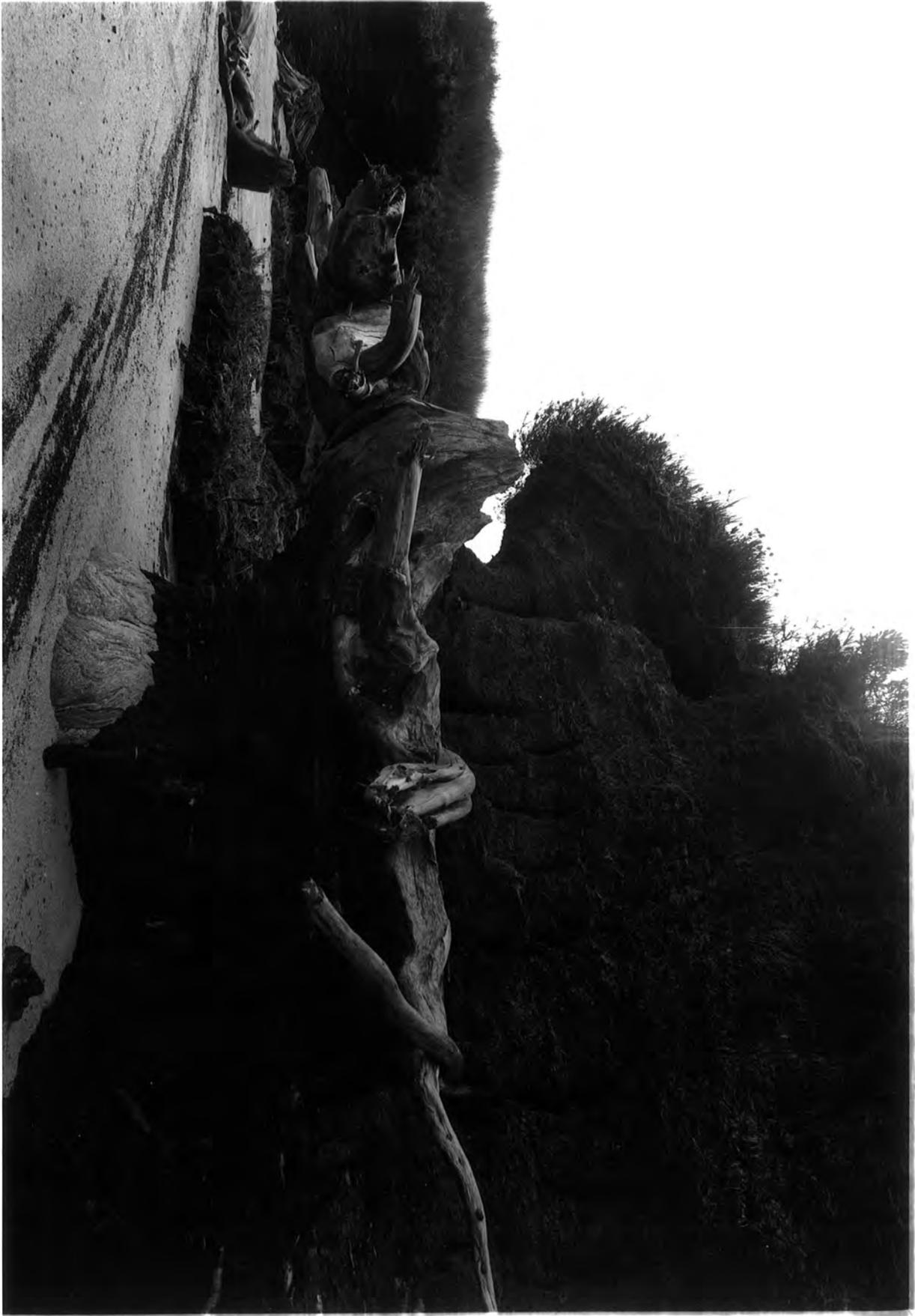
Plate 10   Subfossil stump showing tap-root

The setting of seed is described by McVean (1963) who points out that cone crops vary quite widely from year to year, quoting figures of 300 cones per tree in good years as opposed to below 25 in bad ones, and suggesting that good crops occur every 4 or 5 years or so. He also 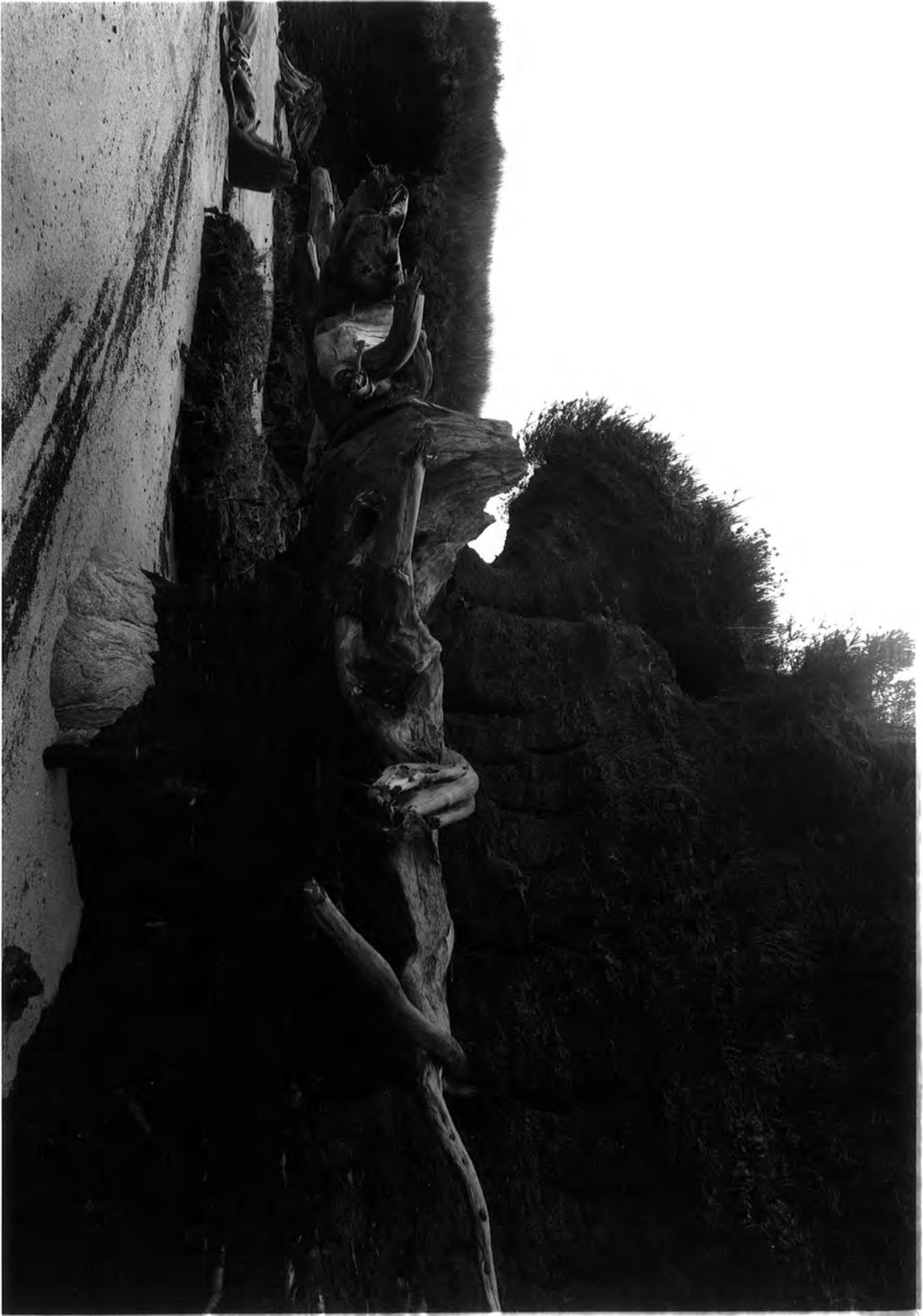gives a radius of about 100 m for most seedlings from the parent tree, but quotes examples of pines in the Cairngorms occuring more than 2 km from their nearest neighbour. McVean also gives the optimum temperature for germination as about 21°C and points out the beneficial effect of light on this process.

The same author then lists the principal causes of mortality of the seedlings. Both waterlogging and dessication can kill the seedling outright, the former producing anaerobic conditions around the roots, the latter occuring where the peat surface is too hard for the fairly blunt seedling radicle to penetrate and reach moisture. Other causes may be grazing and competition for nutrients and light with other plants.

Looking at the Badanloch site, it seems that major recruitment occured in three phases (Fig. 18, page 12d). The first of these occurs early on in the history of the site (around 75 site years) and may represent a response to the dying of the first generation of trees as suggested in 4.6 above. Similarly, the second phase occurs after a 75 year interval probably reflecting a similar process. Both these phases occur during the expansion of pine at Badanloch, in the period of higher growth increments shown in the BAD144 curves in Fig. 14, page 11b. The 3-D plots of Figs. 20a-o (pages 13a-e) show the pattern of this regeneration clearly, the original few trees giving rise to seedlings around them, these possibly benefitting from the increased litter under their parents (McVean 1963b). There is a suggestion that further colonisation occurs down the prevailing wind to the north-east, but in the absence of dating for other stumps on the site this must remain speculation. However it does seem clear that the overall distribution is fairly patchy as the wood on the site develops, with two generations each reaching an average age of 80-100 years, a few odd trees persisting to a much greater age. This is the structure described as "semi-irregular" by Steven and Carlisle (1959) and was found by them to be typical of native pine woods both in Scotland and in other countries. It is also the structure reflected in Figs 10a and b (page 10a), a normally distributed majority of trees around an age class of 100 or so, with a few much older individuals. Fig 10b represents the age structure at Clashgour A, a site at an altitude of 180 m on Rannoch Moor investigated by Bridge et al. (1990). Their description of the site and their attribution of their failure to crossmatch any samples to low ring numbers and distortion both point to similar conditions as those prevailing at Badanloch.

Returning to the third phase of recruitment, this is a much smaller one and occurs 125 years later, well into the decline of growth increments and numbers of trees alive on the site. This phase also coincides with the last phase of recruitment found at Lochstrathy by Gear (1989). Gear and Huntley (1991) also note peaks in *Sphagnum* spores in a fine resolution pollen study made at Lochstrathy, and these, allowing for the systematic discrepancy of 700 years that they recognise between their radiocarbon dates for peat and subfossil timber, match well with the periods of decline in recruitment at Lochstrathy and Badanloch. This would strongly suggest increased waterlogging as the primary cause for the decline in pine at these sites, and this is born out by the means of preservation of the stumps. At Badenloch they can be seen buried up to 1.5 metres deep (Plate 9, page 16a) showing that peat growth continued rapidly after their demise, overwhelming the stumps before they had time to decay. This continuing developement of the blanket bog could only have been brought about by the considerable increase in rainfall associated with an increase in the oceanicity of the climate. Bridge et al. (1990), quoting work by Dubois and Ferguson on deuterium:hydrogen ratios in subfossil pine stumps, identify "pluvials" or wet periods in the Cairngorms, one episode of which occurs between 4250-3870 BP, the period of pine decline on the peat bogs of the far north, and may therefore confirm further an increase in oceanicity of climate.

In terms of larger scale effects the general decline in pine around 4000 BP has long been recognised, as discussed in the introduction to this study. That the decline was gradual in Scandanavia but rapid in the British Isles was also recognised (Bennett 1984), but as most studies were based on conventional broad resolution palynological sampling at about 200-400 year intervals, short term events were missed and the subfossil stumps in north Scotland ascribed to a sparse scattering of trees. The work of Gear (1989), combining dendrochronological study with fine resolution pollen studies and radiocarbon dating, revealed a brief 400 year expansion of *Pinus sylvestris* northwards which was previously unsuspected. The retreat southwards of the pine forest at the end of this was shown to tally both in extent (about 70 km) and time with a similar shift in range margin in Finnish Lapland (Gear and Huntley 1991), as well as the general decline at around 4000 BP noted above. Gear and Huntley supposed therefore that these changes were part of a broad-scale change in atmospheric circulation and went on to point out the importance of the Scottish pine expansion as an indication of how rapidly vegetation could respond to changing climate.

6 CONCLUSIONS

The main conclusion to be drawn from this study is that it confirms the findings of Gear (1989) at Lochstrathy. This it does in terms of overall dating of the pine expansion, and in terms of the population dynamics of the two subfossil woodlands, showing similarities in population rise and fall overall as well as in detail. In view of the separation of the two sites, this would seem to confirm that the influences affecting them were part of a general climatic pattern and not purely local variations. In this connection it is to be regretted that the timing difference found in the rise of *Pinus sylvestris* at the two sites was not significant in terms of the standard deviations on the radiocarbon dates as this would have confirmed the migration rate of the trees. Further dendrochronological and radiocarbon dating of subfossil pine stumps over a larger area of the north of Scotland is needed to elucidate this.

This study has also demonstrated the potential usefulness of the combination of dendrochronology and accurate site mapping for assessing the structure of sub-fossil woodlands. Again further study incorporating larger numbers of samples over a wider area, ideally coupled with a fine resolution pollen study, would be desirable, particularly as the rejection rate in terms of crossmatching is rather high with trees growing under stress at the edge of their range.

From a wider viewpoint the studies at Lochstrathy and Badanloch, revealing as they do the effects of rapid broadscale climatic changes, confirm the importance of this work in assessing and predicting the consequences of modern climatic changes and their potential influence on vegetation (Gear and Huntley 1991).

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APPENDIX

Ring data processing programs (written & compiled in MS QuickBasic)

1 CONVERT

PRINT : PRINT " This utility converts .EPC files to files in .01 mm. and saves them with the same file name but no extension."

REM inputs factor for conversion and filename for processing

```
PRINT : PRINT : PRINT " CONVERSION FACTORS"
PRINT : PRINT "   x25 eyepiece, x0.6 objective - 8"
PRINT : PRINT "   x25 eyepiece, x1.6 objective - 3.125"
PRINT : PRINT "   x8  eyepiece, x4   objective - 2.5"
PRINT : PRINT "   x8  eyepiece, x7   objective - 1.4"
PRINT : INPUT " Enter factor for conversion ... ", factor
PRINT : PRINT " Enter name of file to convert, with path if in a
different directory"
INPUT " - don't include the .EPC extension ... ", filehead$
filetitle$ = filehead$ + ".epc"
OPEN filetitle$ FOR INPUT AS £1
OPEN filehead$ FOR OUTPUT AS £2


REM writes new file

writeloop:
DO
    INPUT £1, ringct
    ctring = ringct * factor
    IF ringct = -1 THEN ctring = -1
    WRITE £2, ctring
LOOP UNTIL ringct = -1
INPUT £1, ringct
IF ringct = -1 THEN
WRITE £2, ringct
GOTO finish
ELSE
ctring = ringct * factor
```

```
WRITE £2, ctring
END IF
GOTO writeloop
finish:
CLOSE £2
CLOSE £1
PRINT : PRINT " Converted file now written"
END
```

2   RINGPLOT

```
CLEAR : SCREEN 2
PRINT : PRINT "TREE RING QUICK PLOTTER"
PRINT : PRINT "This program counts and plots tree ring widths for up
to 3 counts."
PRINT : PRINT "The range may be fixed at a selected number or
automatically scaled to the        largest of the 3 sets of data."


REM loads file for processing and counts rings for each radius

datload:
PRINT : PRINT "Enter Drive letter for data   "
INPUT "or press <enter> only for C:\DENDRO\DATA\ - ", indlet$
IF indlet$ = "" THEN GOTO letter
PRINT : PRINT "Enter path in form \dir\dir\...dir\   "
INPUT "or press enter only for root directory - ", indpath$
PRINT : PRINT "Insert floppy disk for data if required"
PRINT : PRINT "Press space bar when ready": PRINT
WHILE INKEY$ <> " ": WEND
indirspec$ = indlet$ + ":" + indpath$
GOTO dirlist
letter:
indirspec$ = "C:\DENDRO\DATA\"
dirlist:
filelst$ = indirspec$ + "*."
PRINT : PRINT : FILES filelst$
PRINT : INPUT "Enter name of file required from list ... ", filechse$
```

```
filetitle$ = UCASE$(filechse$) + "."
filespec$ = indirspec$ + filetitle$
OPEN filespec$ FOR INPUT AS £1
count = 0
DO
   INPUT £1, number
   count = count + 1
LOOP UNTIL number = -1
counta = count - 1
INPUT £1, number
IF number = -1 THEN GOTO filend
count = 1
DO
   INPUT £1, number
   count = count + 1
LOOP UNTIL number = -1
countb = count - 1
INPUT £1, number
IF number = -1 THEN GOTO filend
count = 1
DO
   INPUT £1, number
   count = count + 1
LOOP UNTIL number = -1
countc = count - 1
filend:
CLS : PRINT : PRINT "File - "; filetitle$
PRINT : PRINT "Ring totals ..."
PRINT : PRINT "A - "; counta, "B - "; countb, "C - "; countc
CLOSE £1

REM choice of fixed or auto ranged display and input of fixed range
value

PRINT : PRINT "Press F for fixed range or A for auto ... "
DO
   range$ = INKEY$
```

```
LOOP UNTIL range$ = "f" OR range$ = "F" OR range$ = "a" OR range$
= "A"
IF range$ = "f" OR range$ = "F" THEN
PRINT : INPUT "Enter length of fixed range required ... ", rangeno
END IF
IF countb = 0 THEN GOTO plothold

REM inputs values for relative offset of ring plots if required

offset:
PRINT : PRINT "CURVE OFFSET - moves selected curve to left ..."
PRINT : PRINT "Enter offset (+ve integers only) required for A curve,"
INPUT "or <Enter> only for none ... ", offseta
PRINT : PRINT "Enter offset (+ve integers only) required for B curve,"
INPUT "or <Enter> only for none ... ", offsetb
IF countc = 0 THEN GOTO plotstart
PRINT : PRINT "Enter offset (+ve integers only) required for C curve,"
INPUT "or <Enter> only for none ... ", offsetc
GOTO plotstart
plothold:
PRINT : PRINT "Press space bar to continue ... "
WHILE INKEY$ <> " ": WEND

REM defines and loads arrays from file with ring data plus offset
values

plotstart:
CLS : PRINT : PRINT "CURVE PLOTTING ..."
PRINT : PRINT "Press Shift + PrtSc to print display, Space Bar to clear
it and end."
PRINT : PRINT "- please wait ..."
IF range$ = "f" OR range$ = "F" THEN dimsiz = rangeno: GOTO jumpsiz
IF counta > countb THEN dimsiz = counta ELSE dimsiz = countb
IF dimsiz < countc THEN dimsiz = countc
IF offseta = 0 AND offsetb = 0 AND offsetc = 0 THEN GOTO skipsiz
jumpsiz:
dimsiz = dimsiz + offseta + offsetb + offsetc
skipsiz:
```

```
DIM ring(1 TO dimsiz + 1, 1 TO 3)
OPEN filespec$ FOR INPUT AS £1
FOR a = 1 + offsetb + offsetc TO counta + offsetb + offsetc + 1
 INPUT £1, ring(a, 1)
NEXT a
IF countb = 0 THEN GOTO loadend
FOR b = 1 + offseta + offsetc TO countb + offseta + offsetc + 1
 INPUT £1, ring(b, 2)
NEXT b
IF countc = 0 THEN GOTO loadend
FOR c = 1 + offseta + offsetb TO countc + offseta + offsetb + 1
 INPUT £1, ring(c, 3)
NEXT c
loadend:
CLOSE £1


REM plots curves on screen

SLEEP 2: CLS
PRINT filechse$; "    Totals: A -"; counta; " B -"; countb; " C -";
countc; "  Offsets: A -"; offseta; " B -"; offsetb; " C -"; offsetc
FOR height = 65 TO 197 STEP 6€
LINE (0, height)-(639, height)
    IF dimsiz > 200 THEN GOTO five
    FOR tick = 1 TO 640 STEP (630 / dimsiz)
      LINE (tick - 1, height)-(tick - 1, height - 2)
    NEXT tick
five:
    FOR tick5 = 1 TO 640 STEP (630 / dimsiz) * 5
      LINE (tick5 - 1, height)-(tick5 - 1, height + 2)
    NEXT tick5
NEXT height
FOR x = 2 + offsetb + offsetc TO counta + offsetb + offsetc
    LINE ((x - 1) * 630 / dimsiz, (61 - CINT(ring(x - 1, 1) / 10)))-(x *
630 / dimsiz, (61 - CINT(ring(x, 1) / 10)))
NEXT x
IF countb = 0 THEN GOTO finish
FOR y = 2 + offseta + offsetc TO countb + offseta + offsetc
```

```
    LINE ((y - 1) * 630 / dimsiz, (127 - CINT(ring(y - 1, 2) / 10)))-(y
* 630 / dimsiz, (127 - CINT(ring(y, 2) / 10)))
NEXT y
IF countc = 0 THEN GOTO finish
FOR z = 2 + offseta + offsetb TO countc + offseta + offsetb
    LINE ((z - 1) * 630 / dimsiz, (193 - CINT(ring(z - 1, 3) / 10)))-(z *
630 / dimsiz, (193 - CINT(ring(z, 3) / 10)))
NEXT z
finish:
WHILE INKEY$ <> " ": WEND


REM program ends - choice of rerun or replot with same data


CLS
PRINT : PRINT "Press 1 to go to curve offset entry."
PRINT : PRINT "Press 2 to re-run from start."
PRINT : PRINT "Press 3 to end."
DO
exit$ = INKEY$
LOOP UNTIL exit$ = "1" OR exit$ = "2" OR exit$ = "3"
IF exit$ = "1" THEN
ERASE ring
GOTO offset
ELSEIF exit$ = "2" THEN
CLS : CLEAR
GOTO datload
END IF
END



3  RINGSTND


CLS : PRINT : PRINT "  STANDARD RING PLOTTER"
PRINT : PRINT "    This program standardises tree ring files, plots
them, and writes a file of standardised ring widths."


REM selects data file and loads it, counts rings in each radius
```

```
datload:
CLEAR
PRINT : PRINT "    Enter Drive letter for data    "
INPUT "    or press <enter> only for C:\DENDRO\DATA\ - ", indlet$
IF indlet$ = "" THEN GOTO letter
PRINT : PRINT "    Enter path in form \dir\dir\...dir\   "
INPUT "    or press enter only for root directory - ", indpath$
PRINT : PRINT "    Insert floppy disk for data if required"
PRINT : PRINT "    Press space bar when ready": PRINT
WHILE INKEY$ <> " ": WEND
indirspec$ = indlet$ + ":" + indpath$
GOTO dirlist
letter:
indirspec$ = "C:\DENDRO\DATA\"
dirlist:
filelst$ = indirspec$ + "*."
PRINT : PRINT : FILES filelst$
PRINT : INPUT "Enter name of file required from list ... ", filechse$
filetitle$ = UCASE$(filechse$) + "."
newtitle$ = UCASE$(filechse$) + ".STD"
filespec$ = indirspec$ + filetitle$
newspec$ = indirspec$ + newtitle$
OPEN filespec$ FOR INPUT AS £1
count = 0
DO
  INPUT £1, number
  count = count + 1
LOOP UNTIL number = -1
counta = count - 1
INPUT £1, number
IF number = -1 THEN GOTO filend
count = 1
DO
  INPUT £1, number
  count = count + 1
LOOP UNTIL number = -1
countb = count - 1
INPUT £1, number
```

```
IF number = -1 THEN GOTO filend
count = 1
DO
   INPUT £1, number
   count = count + 1
LOOP UNTIL number = -1
countc = count - 1
filend:
CLS : PRINT : PRINT "  File being processed - "; filetitle$
CLOSE £1


REM dimensions array and reads in data. Calculates mean and standard
deviation for each radius. Calculates standardised values and reads
them into array.


IF counta > countb THEN dimsiz = counta ELSE dimsiz = countb
IF dimsiz < countc THEN dimsiz = countc
DIM ringwidth(1 TO dimsiz + 1, 1 TO 6)
OPEN filespec$ FOR INPUT AS £1
FOR a = 1 TO counta
   INPUT £1, ringwidth(a, 1)
   meana = meana + ringwidth(a, 1)
NEXT a
amean = meana / counta
INPUT £1, ringwidth(counta + 1, 1)
FOR a = 1 TO counta
   sqmeana = sqmeana + (ringwidth(a, 1) - amean) ^ 2
NEXT a
sdeva = SQR(sqmeana / (counta - 1))
FOR a = 1 TO counta
   ringwidth(a, 2) = (ringwidth(a, 1) - amean) / sdeva
NEXT a
ringwidth(counta + 1, 2) = -1
IF countb = 0 THEN GOTO calcend
FOR b = 1 TO countb
   INPUT £1, ringwidth(b, 3)
   meanb = meanb + ringwidth(b, 3)
NEXT b
```

```
bmean = meanb / countb
INPUT £1, ringwidth(countb + 1, 3)
FOR b = 1 TO countb
 sqmeanb = sqmeanb + (ringwidth(b, 3) - bmean) ^ 2
NEXT b
sdevb = SQR(sqmeanb / (countb - 1))
FOR b = 1 TO countb
   ringwidth(b, 4) = (ringwidth(b, 3) - bmean) / sdevb
NEXT b
ringwidth(countb + 1, 4) = -1
IF countc = 0 THEN GOTO calcend
FOR c = 1 TO countc
   INPUT £1, ringwidth(c, 5)
   meanc = meanc + ringwidth(c, 5)
NEXT c
cmean = meanc / countc
INPUT £1, ringwidth(countc + 1, 5)
FOR c = 1 TO countc
 sqmeanc = sqmeanc + (ringwidth(c, 5) - cmean) ^ 2
NEXT c
sdevc = SQR(sqmeanc / (countc - 1))
FOR c = 1 TO countc
   ringwidth(c, 6) = (ringwidth(c, 5) - cmean) / sdevc
NEXT c
ringwidth(countc + 1, 6) = -1
calcend:
CLOSE £1

REM option to write standardised values to disk

PRINT : PRINT "  Press 1 to write standardised values as file, 2 to
continue ..."
DO
filing$ = INKEY$
LOOP UNTIL filing$ = "1" OR filing$ = "2"
IF filing$ = "2" THEN GOTO displaystat
OPEN newspec$ FOR OUTPUT AS £2
FOR a = 1 TO counta + 1
```

```
    WRITE £2, ringwidth(a, 2)
NEXT a
IF countb = 0 THEN GOTO endwrite
FOR b = 1 TO countb + 1
    WRITE £2, ringwidth(b, 4)
NEXT b
IF countc = 0 THEN GOTO endwrite
FOR c = 1 TO countc + 1
    WRITE £2, ringwidth(c, 6)
NEXT c
endwrite:
WRITE £2, -1
CLOSE £2
ERASE ringwidth

REM displays radius statistics

displaystat:
PRINT : PRINT : PRINT "  Standardisation complete"
PRINT : PRINT : PRINT "  RING TOTALS"
PRINT : PRINT "    File - "; newtitle$
PRINT : PRINT "    A - "; counta, "    Mean - "; amean, "Standard
deviation - "; sdeva
PRINT : PRINT "    B - "; countb, "    Mean - "; bmean, "Standard
deviation - "; sdevb
PRINT : PRINT "    C - "; countc, "    Mean - "; cmean, "Standard
deviation - "; sdevc
PRINT : PRINT : PRINT "  Press space bar to continue -"
WHILE INKEY$ <> " ": WEND

REM range selection and range value input

CLS : PRINT : PRINT "  To continue plotting press F for fixed range or
A for auto ... "
DO
    range$ = INKEY$
LOOP UNTIL range$ = "f" OR range$ = "F" OR range$ = "a" OR range$
= "A"
```

```
IF range$ = "f" OR range$ = "F" THEN
PRINT : INPUT "  Enter length of fixed range required ... ", rangeno
END IF
IF countb = 0 THEN GOTO plothold


REM relative curve offset option


offset:
PRINT : PRINT "  CURVE OFFSET - moves selected curve to left -"
PRINT : PRINT "    Enter offset (+ve integers only) required for A
curve,"
INPUT "   or <Enter> only for none ... ", offseta
PRINT : PRINT "    Enter offset (+ve integers only) required for B
curve,"
INPUT "   or <Enter> only for none ... ", offsetb
IF countc = 0 THEN GOTO plotstart
PRINT : PRINT "    Enter offset (+ve integers only) required for C
curve,"
INPUT "   or <Enter> only for none ... ", offsetc
GOTO plotstart
plothold:
PRINT : PRINT : PRINT "  Press space bar to continue -"
WHILE INKEY$ <> " ": WEND


REM defines array and loads it with standardised values and offset
values


plotstart:
CLS : PRINT : PRINT "  CURVE PLOTTING"
PRINT : PRINT "    Press Shift + PrtSc to print display, Space Bar to
clear it and end."
PRINT : PRINT "    - please wait"
IF range$ = "f" OR range$ = ./F" THEN dimsiz2 = rangeno: GOTO
jumpsiz
IF counta > countb THEN dimsiz2 = counta ELSE dimsiz2 = countb
IF dimsiz2 < countc THEN dimsiz2 = countc
IF offseta = 0 AND offsetb = 0 AND offsetc = 0 THEN GOTO skipsiz
jumpsiz:
```

```
dimsiz2 = dimsiz2 + offseta + offsetb + offsetc
skipsiz:
DIM ring(1 TO dimsiz2 + 1, 1 TO 3)
IF filing$ = "1" THEN OPEN newspec$ FOR INPUT AS £1
FOR a = 1 TO counta + 1
  IF filing$ = "1" THEN INPUT £1, ring(a + offsetb + offsetc, 1) ELSE
ring(a + offsetb + offsetc, 1) = ringwidth(a, 2)
NEXT a
IF countb = 0 THEN GOTO loadend
FOR b = 1 TO countb + 1
  IF filing$ = "1" THEN INPUT £1, ring(b + offseta + offsetc, 2) ELSE
ring(b + offseta + offsetc, 2) = ringwidth(b, 4)
NEXT b
IF countc = 0 THEN GOTO loadend
FOR c = 1 TO countc + 1
  IF filing$ = "1" THEN INPUT £1, ring(c + offseta + offsetb, 3) ELSE
ring(c + offseta + offsetb, 3) = ringwidth(c, 6)
NEXT c
loadend:
IF filing$ = "1" THEN CLOSE £1


REM plots standardised values on screen

SLEEP 2: SCREEN 2: CLS
PRINT newtitle$; "    Totals: A -"; counta; " B -"; countb; " C -";
countc; "  Offsets: A -"; offseta; " B -"; offsetb; " C -"; offsetc
FOR height = 65 TO 197 STEP 66
   LINE (0, height)-(639, height)
   LINE (0, height - 34)-(639, height - 34), , , &H8080
   IF dimsiz2 > 200 THEN GOTO five
     FOR tick = 1 TO 640 STEP (630 / dimsiz2)
       LINE (tick - 1, height)-(tick - 1, height - 2)
     NEXT tick
five:
     FOR tick5 = 1 TO 640 STEP (630 / dimsiz2) * 5
       LINE (tick5 - 1, height)-(tick5 - 1, height + 2)
     NEXT tick5
NEXT height
```

```
LOCATE 3, 1: PRINT "+": LOCATE 6, 80: PRINT "A": LOCATE 6, 1: PRINT
"-"
LOCATE 11, 1: PRINT "+": LOCATE 15, 80: PRINT "B": LOCATE 15, 1:
PRINT "-"
LOCATE 19, 1: PRINT "+": LOCATE 23, 80: PRINT "C": LOCATE 23, 1:
PRINT "-"
FOR x = 2 + offsetb + offsetc TO counta + offsetb + offsetc
     LINE ((x - 1) * 630 / dimsiz2, (31 - ring(x - 1, 1) * 8))-(x * 630 /
dimsiz2, (31 - ring(x, 1) * 8))
NEXT x
IF countb = 0 THEN GOTO finish
FOR y = 2 + offseta + offsetc TO countb + offseta + offsetc
     LINE ((y - 1) * 630 / dimsiz2, (97 - ring(y - 1, 2) * 8))-(y * 630 /
dimsiz2, (97 - ring(y, 2) * 8))
NEXT y
IF countc = 0 THEN GOTO finish
FOR z = 2 + offseta + offsetb TO countc + offseta + offsetb
     LINE ((z - 1) * 630 / dimsiz2, (163 - ring(z - 1, 3) * 8))-(z * 630 /
dimsiz2, (163 - ring(z, 3) * 8))
NEXT z
finish:
WHILE INKEY$ <> " ": WEND

REM program ending and rerun options

CLS
PRINT : PRINT "  Press 1 to go to curve offset entry."
PRINT : PRINT "  Press 2 to re-run from start."
PRINT : PRINT "  Press 3 to end."
DO
exit$ = INKEY$
LOOP UNTIL exit$ = "1" OR exit$ = "2" OR exit$ = "3"
IF exit$ = "1" THEN
ERASE ring
GOTO offset
ELSEIF exit$ = "2" THEN
CLS
GOTO datload
```

END IF
END

4 CURVSMTH

```
start:
CLS : CLEAR : SCREEN 0
PRINT : PRINT "ROLLING MEAN PLOTTER FOR CURVE SMOOTHING"

REM selection of files, counts the rings in each radius, displays
results.  Inputs value for rolling mean required.

datload:
PRINT : PRINT "Enter Drive letter for data   "
INPUT "or press <enter> only for C:\DENDRO\DATA\ - ", indlet$
IF indlet$ = "" THEN GOTO letter
PRINT : PRINT "Enter path in form \dir\dir\...dir\   "
INPUT "or press enter only for root directory - ", indpath$
PRINT : PRINT "Insert floppy disk for data if required"
PRINT : PRINT "Press space bar when ready": PRINT
WHILE INKEY$ <> " ": WEND
indirspec$ = indlet$ + ":" + indpath$
GOTO dirlist
letter:
indirspec$ = "C:\DENDRO\DATA\"
dirlist:
filelst$ = indirspec$ + "*.STD"
PRINT : PRINT : FILES filelst$
PRINT : INPUT "Enter name of file required from list (.STD assumed)...
", filechse$
filetitle$ = UCASE$(filechse$) + ".STD"
filespec$ = indirspec$ + filetitle$
newspec$ = indirspec$ + UCASE$(filechse$) + ".SMT"
OPEN filespec$ FOR INPUT AS £1
count = 0
DO
    INPUT £1, number
```

```
    count = count + 1
LOOP UNTIL number = -1
counta = count - 1
INPUT £1, number
IF number = -1 THEN GOTO filend
count = 1
DO
   INPUT £1, number
   count = count + 1
LOOP UNTIL number = -1
countb = count - 1
INPUT £1, number
IF number = -1 THEN GOTO filend
count = 1
DO
   INPUT £1, number
   count = count + 1
LOOP UNTIL number = -1
countc = count - 1
filend:
CLS : PRINT : PRINT "File - "; filetitle$
PRINT : PRINT "Ring totals ..."
PRINT : PRINT "A - "; counta, "B - "; countb, "C - "; countc
CLOSE £1
PRINT : INPUT "Enter number of rings for rolling mean ...", smthmean


REM defines array, loads it with standardised values, calculates rolling
mean and reads into array.


IF counta > countb THEN dimsiz = counta ELSE dimsiz = countb
IF dimsiz < countc THEN dimsiz = countc
DIM standring(1 TO dimsiz + 1, 1 TO 6)
check = smthmean / 2
IF check = FIX(check) THEN first = smthmean / 2 ELSE first =
(smthmean + 1) / 2
OPEN filespec$ FOR INPUT AS £1
FOR a = 1 TO counta
   INPUT £1, standring(a, 1)
```

```
NEXT a
INPUT £1, standring(counta + 1, 1)
lasta = counta - FIX(smthmean / 2)
FOR a = first TO lasta
  suma = 0
    FOR inc = 1 TO first - 1
      suma = suma + standring(a - (first - inc), 1) + standring(a + inc,
1)
    NEXT inc
  IF check = FIX(check) THEN
    suma = suma + standring(a, 1) + standring(a + first, 1)
  ELSE
    suma = suma + standring(a, 1)
  END IF
  standring(a, 4) = suma / smthmean
NEXT a
IF countb = 0 THEN GOTO calcend
FOR b = 1 TO countb
  INPUT £1, standring(b, 2)
NEXT b
INPUT £1, standring(countb + 1, 2)
lastb = countb - FIX(smthmean / 2)
FOR b = first TO lastb
  sumb = 0
    FOR inc = 1 TO first - 1
      sumb = sumb + standring(b - (first - inc), 2) + standring(b +
inc, 2)
    NEXT inc
  IF check = FIX(check) THEN
    sumb = sumb + standring(b, 2) + standring(b + first, 2)
  ELSE
    sumb = sumb + standring(b, 2)
  END IF
  standring(b, 5) = sumb / smthmean
NEXT b
FOR c = 1 TO countc
  INPUT £1, standring(c, 3)
NEXT c
```

```
INPUT £1, standring(countc + 1, 3)
lastc = countc - FIX(smthmean / 2)
FOR c = first TO lastc
   sumc = 0
     FOR inc = 1 TO first - 1
        sumc = sumc + standring(c - (first - inc), 3) + standring(c + inc,
3)
     NEXT inc
   IF check = FIX(check) THEN
     sumc = sumc + standring(c, 3) + standring(c + first, 3)
   ELSE
     sumc = sumc + standring(c, 3)
   END IF
   standring(c, 6) = sumc / smthmean
NEXT c
calcend:
CLOSE £1


REM option to write rolling mean values to disk

PRINT : PRINT "   Press 1 to write smoothed values as file, 2 to
continue ..."
DO
filing$ = INKEY$
LOOP UNTIL filing$ = "1" OR filing$ = "2"
IF filing$ = "2" THEN GOTO plotstart
OPEN newspec$ FOR OUTPUT AS £2
FOR a = first TO lasta
   WRITE £2, standring(a, 4)
NEXT a
WRITE £2, -1
IF countb = 0 THEN GOTO endwrite
FOR b = first TO lastb
   WRITE £2, standring(b, 5)
NEXT b
WRITE £2, -1
IF countc = 0 THEN GOTO endwrite
FOR c = first TO lastc
```

```
    WRITE £2, standring(c, 6)
NEXT c
WRITE £2, -1
endwrite:
WRITE £2, -1
CLOSE £2


REM inputs radius to plot


plotstart:
PRINT : PRINT "Select radius for plotting (A, B or C)..."
DO
rad$ = INKEY$
LOOP UNTIL rad$ = "A" OR rad$ = "a" OR rad$ = "B" OR rad$ = "b" OR
rad$ = "C" OR rad$ = "c"
IF rad$ = "A" OR rad$ = "a" THEN
plotcount = counta
arr = 1
ELSEIF rad$ = "B" OR rad$ = "b" THEN
plotcount = countb
arr = 2
ELSE
plotcount = countc
arr = 3
END IF
IF plotcount = 0 THEN
CLS
PRINT : PRINT "Radius choice not in original file, please redo - "
GOTO plotstart
END IF


REM selects fixed or auto range, inputs value for fixed range


PRINT : PRINT "Press F for fixed range or A for auto ... "
DO
    range$ = INKEY$
LOOP UNTIL range$ = "f" OR range$ = "F" OR range$ = "a" OR range$
= "A"
```

```
IF range$ = "a" OR range$ = "A" THEN
range = plotcount
GOTO startdraw
END IF
scales:
PRINT : INPUT "Enter scale length for plot ... ", range
PRINT : INPUT "Enter start of range required ... ", strtplot
PRINT : INPUT "Enter end of range required ... ", endplot
IF (endplot - strtplot) > range THEN
PRINT : PRINT "Range selected > scale length. Please redo."
GOTO scales
END IF
startdraw:
IF range$ = "a" OR range$ = "A" THEN
strtplot = 1
endplot = plotcount
END IF

REM plots standardised and rolling mean values

CLS : PRINT : PRINT "CURVE PLOTTING ..."
PRINT : PRINT "Press Shift + PrtSc to print display, Space Bar to clear
it and end."
PRINT : PRINT "- please wait ..."
SLEEP 1: SCREEN 2: CLS
day$ = MID$(DATE$, 4, 3): mnth$ = MID$(DATE$, 1, 3): year$ =
MID$(DATE$, 7, 4)
engdat$ = day$ + mnth$ + year$
LOCATE 5, 1: PRINT filetitle$; "       "; engdat$; "      Radius - ";
UCASE$(rad$); "   Rolling mean = "; smthmean
LOCATE 24, 1: PRINT "Range: "; strtplot; " - "; endplot
FOR height = 100 TO 166 STEP 66
   LINE (0, height)-(639, height)
   LINE (0, height - 34)-(639, height - 34), , , &H8080
   IF range > 200 THEN GOTO five
      FOR tick = 1 TO 640 STEP (630 / range)
         LINE (tick - 1, height)-(tick - 1, height - 2)
      NEXT tick
```
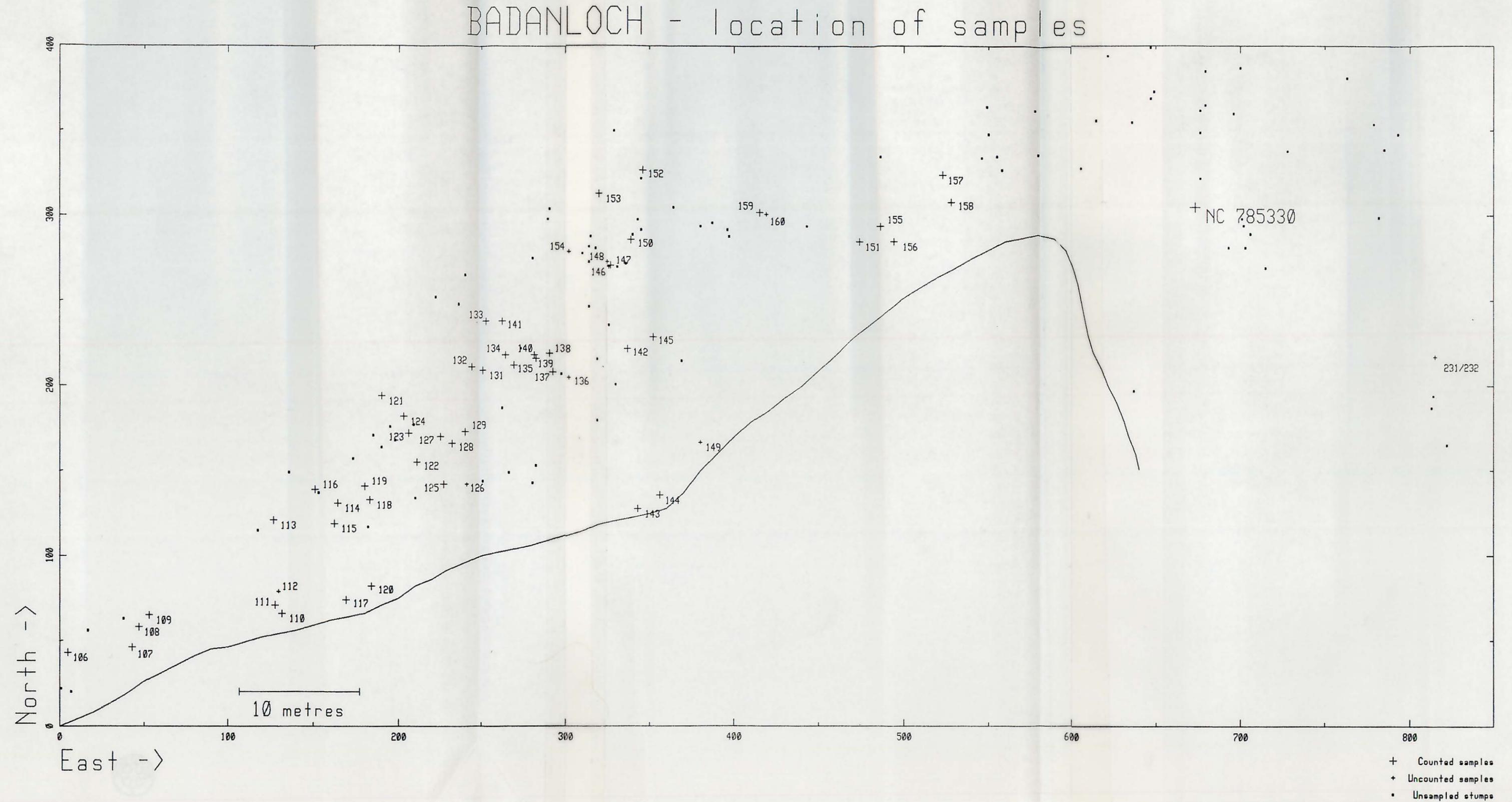
```
five:
    FOR tick5 = 1 TO 640 STEP (630 / range) * 5
        LINE (tick5 - 1, height)-(tick5 - 1, height + 2)
    NEXT tick5
NEXT height
FOR x = strtplot + 1 TO endplot
    LINE ((x - strtplot) * 630 / range, (66 - standring(x - 1, arr) *
8))-((x - (strtplot - 1)) * 630 / range, (66 - standring(x, arr) * 8))
NEXT x
FOR y = strtplot + 1 TO endplot
    LINE ((y - strtplot) * 630 / range, (132 - standring(y - 1, arr + 3)
* 8))-((y - (strtplot - 1)) * 630 / range, (132 - standring(y, arr + 3) *
8))
NEXT y
WHILE INKEY$ <> " ": WEND


REM program end and rerun options

CLS
PRINT : PRINT "  Press 1 to re-run."
PRINT : PRINT "  Press 2 to end."
DO
exit$ = INKEY$
LOOP UNTIL exit$ = "1" OR exit$ = "2"
IF exit$ = "1" THEN
CLS
GOTO start
END IF
END
```

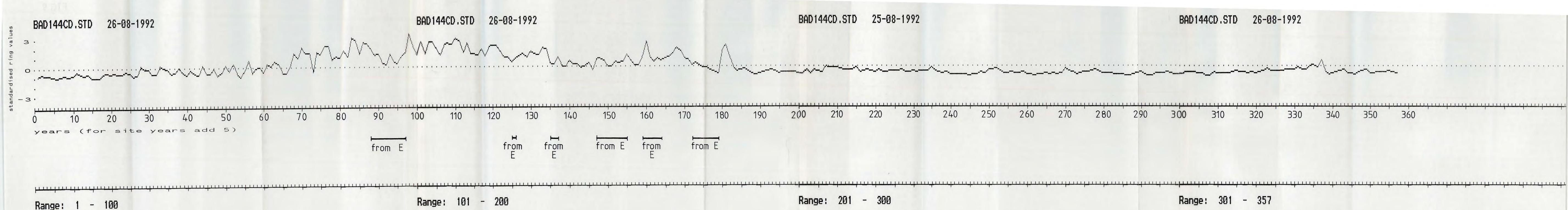Figure 7 Plan of sample locations at Badanloch

BADANLOCH - location of samples

NC 785330

231/232

10 metres

North ->

East ->

+   Counted samples
+   Uncounted samples
·   Unsampled stumps

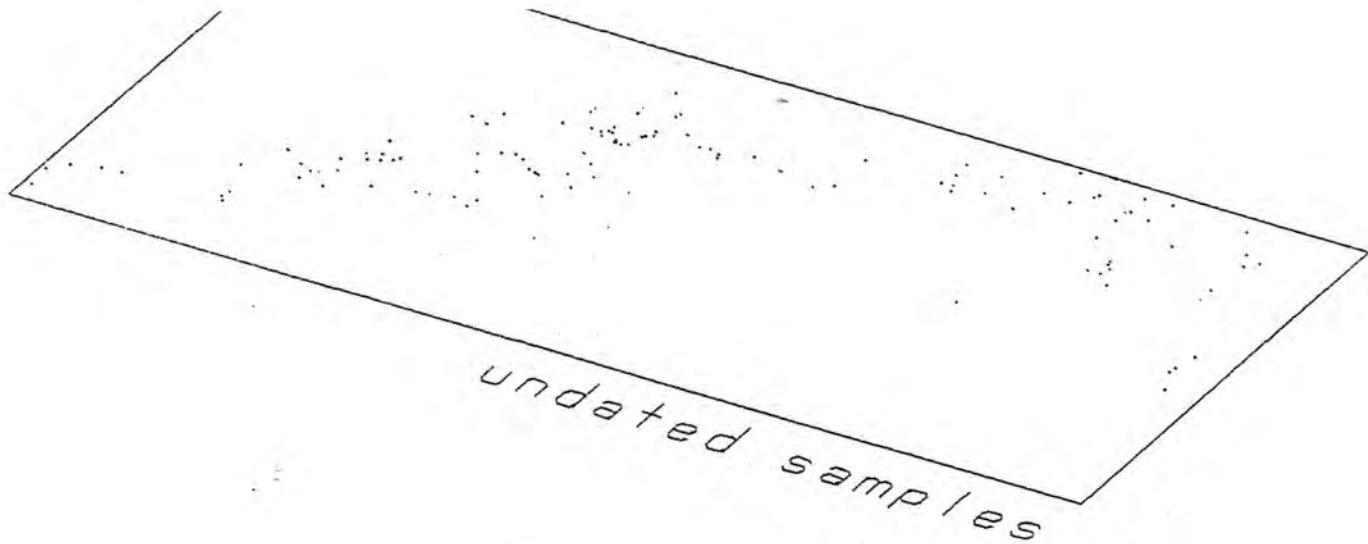Figure 9 BAD144CD - final standardised main sequence for crossmatching

FIG 20p

undated samples

Figure 20 p Overlay showing undated tree positions for Fig. 20 a-o