Dendrochronological Investigations of Scots Pine from the North-West Cairngorms Region, Scotland

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Report Introduction

This report describes recent, ongoing and future dendrochronological (See Appendix A for a definition of Dendrochronology) research in the region of the North-West Cairngorms. The Cairngorms, as well as the Glen Affric region, provide the most promising areas where living pine chronologies may be extended using either historical material (e.g. beams from buildings) and preserved material in lochs. By developing such extended chronologies back in time, it will not only be possible to reconstruct past climatic conditions for the Scottish Highlands for potentially many centuries, but these data will also enable a long term study of forest dynamics for these regions over time and will allow an assessment of how the pine woodland ecosystem has adapted to past climatic changes and management practices. Such information could be employed to inform refinement of management strategies of this important resource for the future.

Overall Project Introduction

Large scale, annually resolved reconstructions of past temperatures for the last 1000 years (Mann et al. 1999; Briffa 2000; Esper et al. 2002; D'Arrigo et al. 2006) are important to not only provide information on past climatic variability (IPCC 2007), but also to constrain climate model scenarios for the 21st century and aid attribution studies (Hegerl et al. 2007). Such large scale reconstructions however, are derived from relatively few proxy series (most tree-ring data sources) which are sparsely located and are unable to provide detailed spatial climatic information. There is therefore a need to produce new, long temperature reconstructions for regions where currently little or no proxy data exist.

In the United Kingdom, dendroclimatology (See Appendix A for a definition) is problematic due to either weak or mixed climatic signals, as noted in long (> 1000 years) English oak records (Kelly et al. 2002), or the inability of extending temperature sensitive living Scots pine (*Pinus sylvestris* L.) records in the Highlands of Scotland which only go back ~200-300 years (Hughes et al. 1984; Fish 2007 – see later).

This report describes ongoing dendrochronological research undertaken at the University of St. Andrews (in collaboration with Forest Research and AOC Archaeology) that aims to rectify the current paucity of long TR based proxy records in the United Kingdom. Due to the presence of preserved pine material in both buildings and lake/bog sediments, as well as the strong climatic signal that can be extracted from Scots pine tree-ring data, Scotland provides a potentially important target region for developing a long climatic reconstruction for at least the last 1000 years.

Dendroclimatology and Scots Pine in Scotland

Schweingruber et al. (1978, 1979) showed in their seminal studies that the maximum density of annual conifer rings, measured using x-ray microdensitometry, yields a strong and consistent proxy of past summer temperatures. Using data obtained from ring-width (RW) and maximum latewood density (MXD) from several pine sites throughout the Highlands of Scotland, Hughes et al. (1984) showed it was possible to reconstruct summer temperatures from AD 1721- AD 1975. Figure 1a highlights the strong calibration using the original Hughes et al. (1984) data (locations shown in Figure 1b) where the linear combination of both RW and MXD parameters explains 65% of the temperature variance.

Despite the clear potential of using Scots pine for dendroclimatic reconstruction, one of the elusive aims for working with pine in Scotland is extending the living pine chronologies back in time, as has been done with oak (Crone and Mills 2002). Carbon dating of sub-fossil pine material found preserved in peat bogs has, however, been used to provide information on the spatial and temporal distribution of pine in Scotland over the last ~ 8000 years (Ward et al. 1987; Bridge et al. 1990; Gear and Huntley, 1991). However, dendrochronological techniques could not be applied to the samples in these studies due to the relatively short length (due to decay) of the samples (~100 years) and the fact that many of the samples were taken from the root stock of the trees (the stems being rotted away) where the tree rings are highly distorted.

Scots pine has existed in some areas of Scotland for about 8000 years (Bennett 1995; Shaw and Tipping 2006). The present distribution of pine is much reduced compared to its maximum extent around 5700 years ago and the remaining pine woodlands are protected by government policy and non intervention management so that they are theoretically self-sustaining in perpetuity (Colin Edwards, Forest Research, pers. comm). Palynological analysis in the Scottish Highlands has shown that pine has grown continuously for the last ~ 8000 years in the Glen Affric and Cairngorm regions (Shaw and Tipping 2006, Figure 1b). These regions are therefore important critical areas for locating sub-fossil pine remains as it may be possible to find relevant sample material covering this whole period.

The key to extending the Scottish living pine chronologies therefore lies NOT in using incomplete, distorted pine samples from peat bogs, but finding sources of complete stems where clearly-defined, long TR sequences can be found. In Scandinavia, very long (> 5000 years) pine RW chronologies have been developed using sub-fossil wood preserved in the sediments of small lakes (Eronen et al. 2002; Gunnarson and Linderholm 2002; Grudd et al. 2002; Linderholm and Gunnarson 2005;

Grudd 2008). To date, no equivalent attempt has been made in Scotland to find pine material in small lochans.

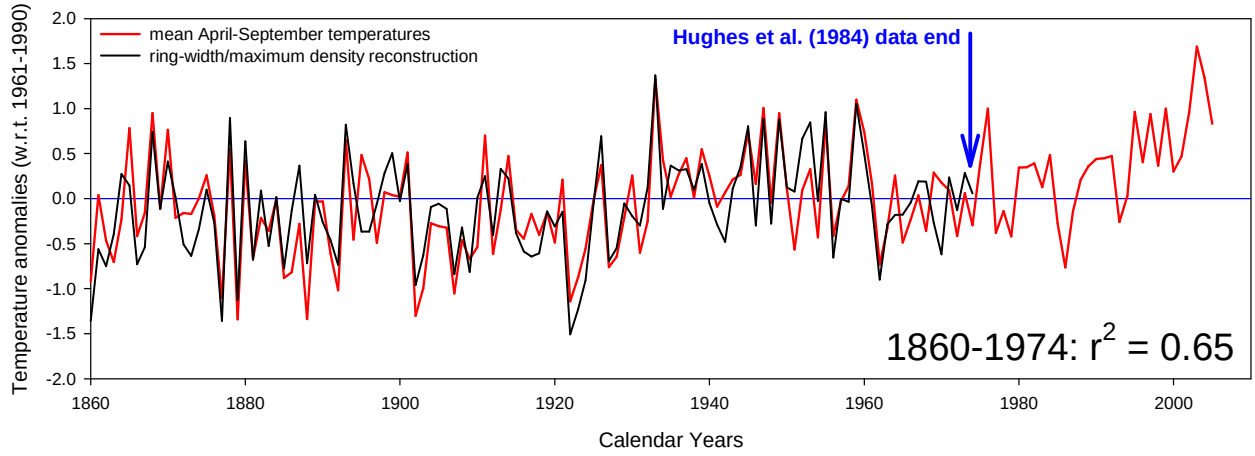

Figure 1a: *Calibration (1860-1974) results between the combined (using linear multiple regression) ring-width and maximum data derived from Scotland and April-September mean temperatures.*

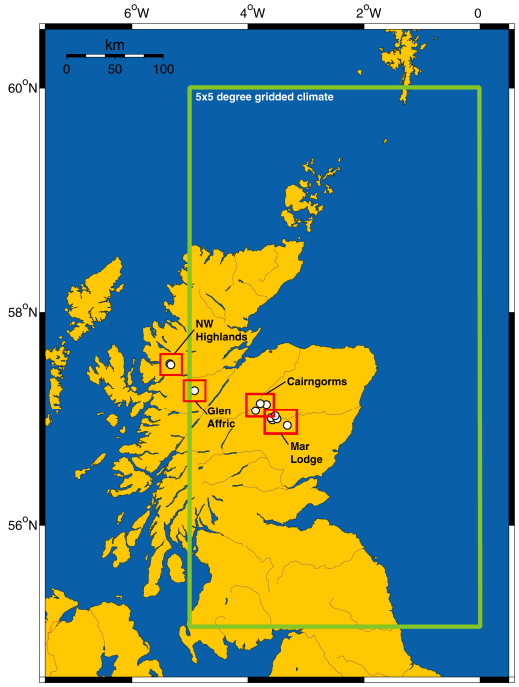

Figure 1b: *Location map of existing living pine network. The Hughes et al. (1984) study used samples taken from the NW Highlands, Glen Affric and Mar Lodge regions. The Cairngorm samples are recent additions (Fish 2007). Green box denotes the gridded temperature data utilised for the calibration in Figure 1a.*

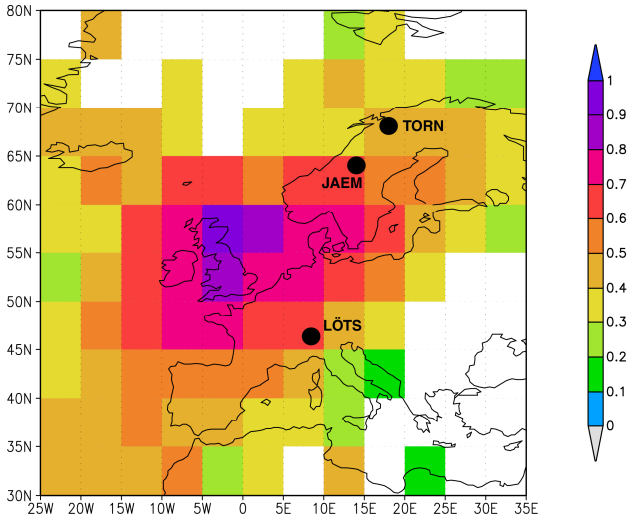

Figure 1c: *Spatial correlations (1860-1974 for April-September) between the relevant grid over Scotland (Figure 1a) with gridded (5x5 degrees) temperatures over Europe (Brohan et al. 2006). The dots show the locations of the only millennial long tree-ring based reconstructions in Europe: TORN = Torneträsk (Grudd 2008); JAEM = Jaemtland (Gunnarson and Linderholm 2002; Linderholm and Gunnarson 2005); LÖTS = Lötschental (Büntgen et al. 2005, 2006).*

Climatologically, Scotland is distinct from mainland Europe due to its proximity to the North Atlantic. The influence of the North Atlantic Oscillation (NAO) is especially strong upon Scottish climate (Cook et al. 2002; Folland et al. in press). Figure 1c shows a spatial correlation map between gridded temperatures relevant to Scotland (Figure 1b) and gridded land/sea temperatures across Europe for April-September mean temperatures (the reconstructed season in Figure 1a). Also

shown are the locations of the existing 1000+ year long TR based reconstructions of past summer temperatures in Europe. Acquiring a similar TR based palaeoclimate reconstruction from Scotland would not only fill an important spatial gap within the European region, but will also provide important information on the past behaviour of the NAO.

The Scottish Pine Project: Recent Work and Current Status

In 2007, an MSc student from the University of Edinburgh (Terri Fish – supervised by Rob Wilson and Colin Edwards of Forest Research) undertook dendroecological analysis to examine senescence rates of Scots pine in Scotland (with a focus on the Glen Affric region). The main aim of this work was to assess how long the currently living trees had before the onset of senescence. Samples of living and dead trees were taken to determine not only the ages of the living trees but also the age of the dead trees at death. Tree-ring data were also utilised from various other sites throughout the Highlands (divided into four regions - Figure 1b) to determine the applicability of the results from Glen Affric to the remainder of the country. The North-West Cairngorm region was represented by three sites, Loch Morlich (MOR), Rothiemurchus (ROTHIE) and Glen Feshie (FESHIE). Summary information for the individual trees sampled at these sites is detailed in Appendix B while their locations are shown in Appendix C (Figures C2, C3 and C4). Figure 2 shows the mean stand age for each site studied by Fish (2007) across the Highlands.

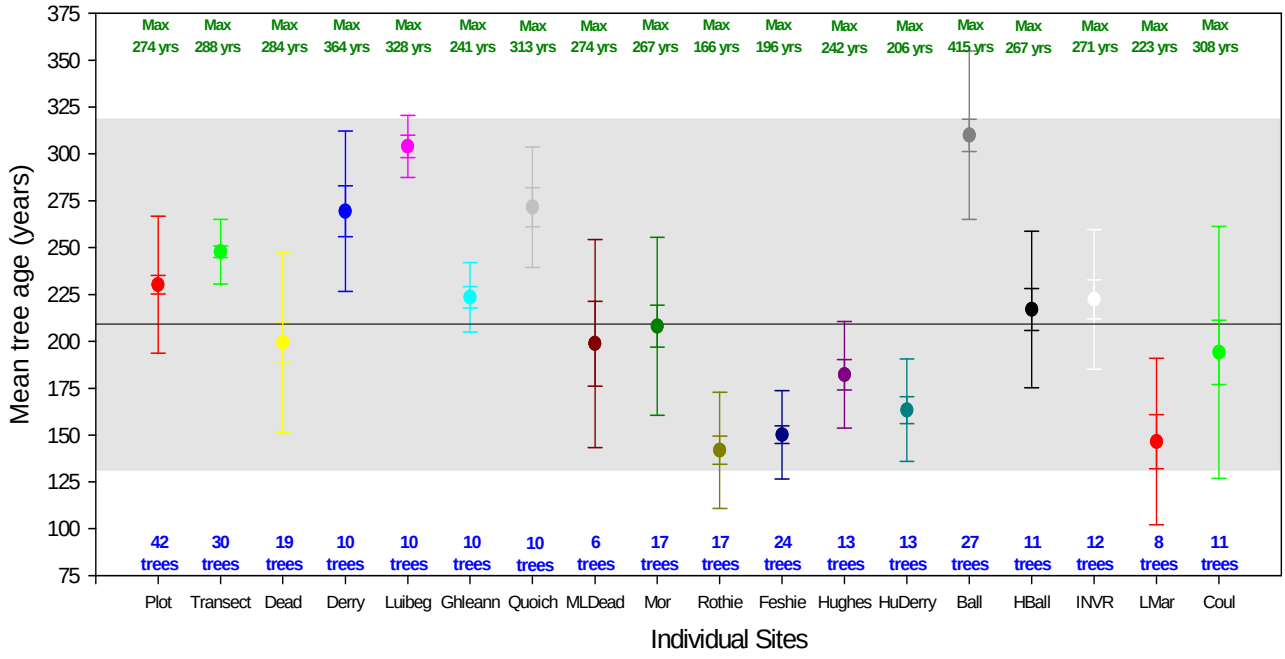

Figure 2: *Mean stand age (with error estimates) for each site studied by Fish (2007). Plot, Transect and Dead are all located within Glen Affric; Derry, Luibeg, Ghleann, Quoich, MLDead, Hughes, HuDerry, Ball, Hball, Invr are located on the Mar Lodge Estates and region around Ballochbuie; Mor, Rothie and Feshie are located in the NW Cairngorms; LMar and Coul are located in the NW Highlands. Upper values show the age of the oldest individual sampled, while lower values indicate how many trees were sampled at each site (courtesy of Terri Fish).*

The overall mean stand age for mature pine trees in Scotland is 214 (±37) years. All four regions fall within 50 years of this countrywide mean, with the NW Highlands averaging 204 (±42) years, Glen Affric averaging 229 (±24) years, the Cairngorm Mountains averaging 174 (±39) years and Mar Lodge averaging 243 (±43) years. While some sites (i.e. Ballochbuie and Glen Derry) contain a few old trees in excess of 350 years (Figure 2), these are not the norm. The pine trees sampled in the Rothiemurchus Estate are probably some of the youngest trees sampled by Fish (2007) throughout Scotland and may simply reflect the high growth rates of these trees compared to other sites sampled. Figure 3 shows the mean tree diameter (cm) as a function of mean tree age which clearly highlights the higher growth rates of the ROTHIE sites compared to FESHIE and MORLICH. It is interesting to note that despite their relatively young age, the ROTHIE trees are amongst some of the largest sampled.

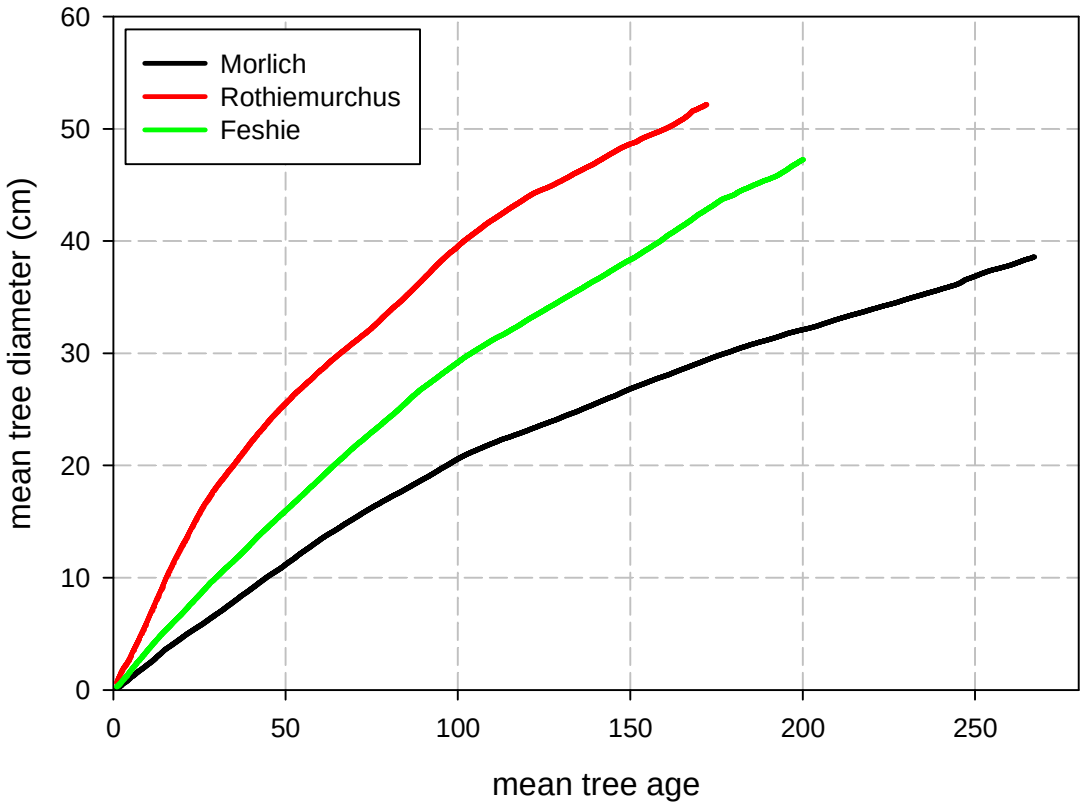

Figure 3: *Mean tree diameter for the ROTHIE, FESHIE and MORLICH sites as a function of mean tree age.*

Fish (2007) concluded that there appears to be little evidence at this time to show that the pine trees in Scotland are nearing senescence and death. To better examine senescence rates of Scots pine, future work must focus on updating the network of tree-ring chronologies across Scotland. This is currently one of my research aims over the coming years.

The research by Fish (2007) clearly identified that living pine trees alone cannot be relied upon to provide a particularly long tree-ring based reconstruction of past climate. Therefore, alternative sources of preserved wood are needed. As mentioned earlier, there are potentially two sources of preserved pine material - beams from historical structures and preserved tree stems in loch sediments. The former option is being explored by Drs. Coralie Mills and Anne Crone (AOC Archaeology) while the latter is the main focus of the St. Andrews work. Both organisations are collaborating closely together as both data-sets will be mutually beneficial.

For the search for sub-fossil material, initial surveys are being undertaken in regions where it is known that pine has grown continuously for many thousands of years (e.g. The Cairngorms and Glen Affric; Figure 1b). In June 2008, a survey of lochs was made through the North-West Cairngorms (see Appendix C for detailed information). A few sub-fossil pine stems were found in many small lochans (even ones above the present tree-line). However, a particularly abundant amount of material was noted in Loch an Eilein and Loch Gamhna in the Rothiemurchus Estate (OS coordinates: NH8907 – see Figure 4). A preliminary reconnaissance sampling field trip was undertaken in September 2008 to acquire samples for carbon dating to ascertain the rough time frame that the material represents. In total, 25 samples have been collected, many of which contain over 150 rings (Figure 5). One noteworthy observation is the green colour that some of the samples (especially those from Loch an Eilein) developed after contact with the air. Discussions with colleagues in Scandinavia (Håkan Grudd of Stockholm University and Risto Jalkanen of the Finnish Forest Research Institute, pers. comm.) suggest that these samples could well be over 1000 years old. Funding has recently been obtained from the Natural Environment Research Council to undertake carbon dating on these samples.

Conclusion

It is very early days in the Scottish pine project. To develop a >1000 year long pine chronology will not be realised from acquiring samples from one of two lochans. The success of the project will rely on successfully sampling/dating multiple buildings, and acquiring many pine samples from many lochs throughout the Highlands. The initial samples from the Rothiemurchus Estate are very encouraging however, and we should have dating results (from dendrochronological and/or carbon dating methods) by the spring of 2009. Permission dependent, we plan to return to Loch an Eilein and Loch Gamhna in 2009 to undertake a more complete sampling as well as undertaken further surveys in the region (specifically Loch Morlich and Lochan Uaine) as well as Glen Affric.

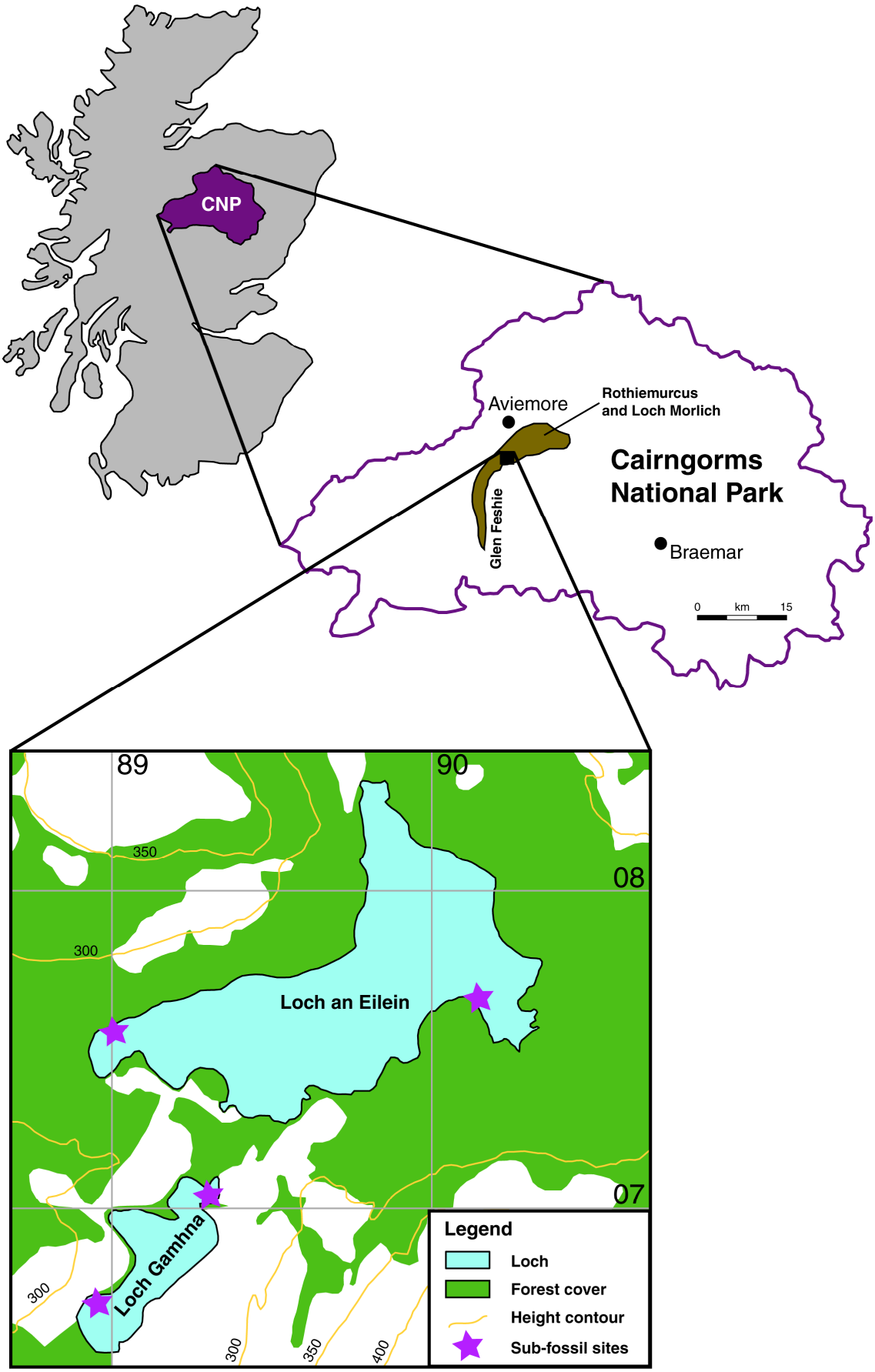

Figure 4: *Location map of sub-fossil pine sites around Loch an Eilein and Loch Gamhna in relation to the Cairngorms National Park and Scotland. The samples from Loch an Eilein were taken from the easterly location. More sub-fossil logs were noted in the September 2008 fieldtrip, but no samples have yet been taken from this location. A more complete survey of the Loch an Eilein south shore is still needed.*

Figure 5: *Preliminary sub-fossil pine test samples taken from Loch an Eilein and Loch Gamhna in September 2008.*

Appendix A

Dendrochronology and Dendroclimatology

At the simplest level, dendrochronology is the science of dating tree rings and interpreting the information within them. The crucial term is ‘dating’. Unlike many other palaeoclimate disciplines, dendrochronology allows the correct identification of each growth ring to an exact calendar year through the process of pattern matching sequences of wide and narrow rings. This process is known as crossdating and is schematically shown in Figure A1. Initially a chronology is derived from living trees (where the year of sampling is known) and then through careful comparison (visually and statistically) of the ring-width sequences, the living chronology can be extended using preserved material from either buildings (e.g. beams) or sub-fossil material (i.e. material preserved in sediments).

Dendroclimatology is concerned with identifying relationships between climate and measured parameters from annual rings (e.g. ring-width, maximum density, stable isotopes etc) and so allowing the development of tree-ring based palaeoclimatic reconstructions. A statistical model is derived using the overlap between the tree-ring and climate data and the temporal stability of this model is assumed to hold through time and is used to reconstruct past climate prior to the period covered by the instrumental data.

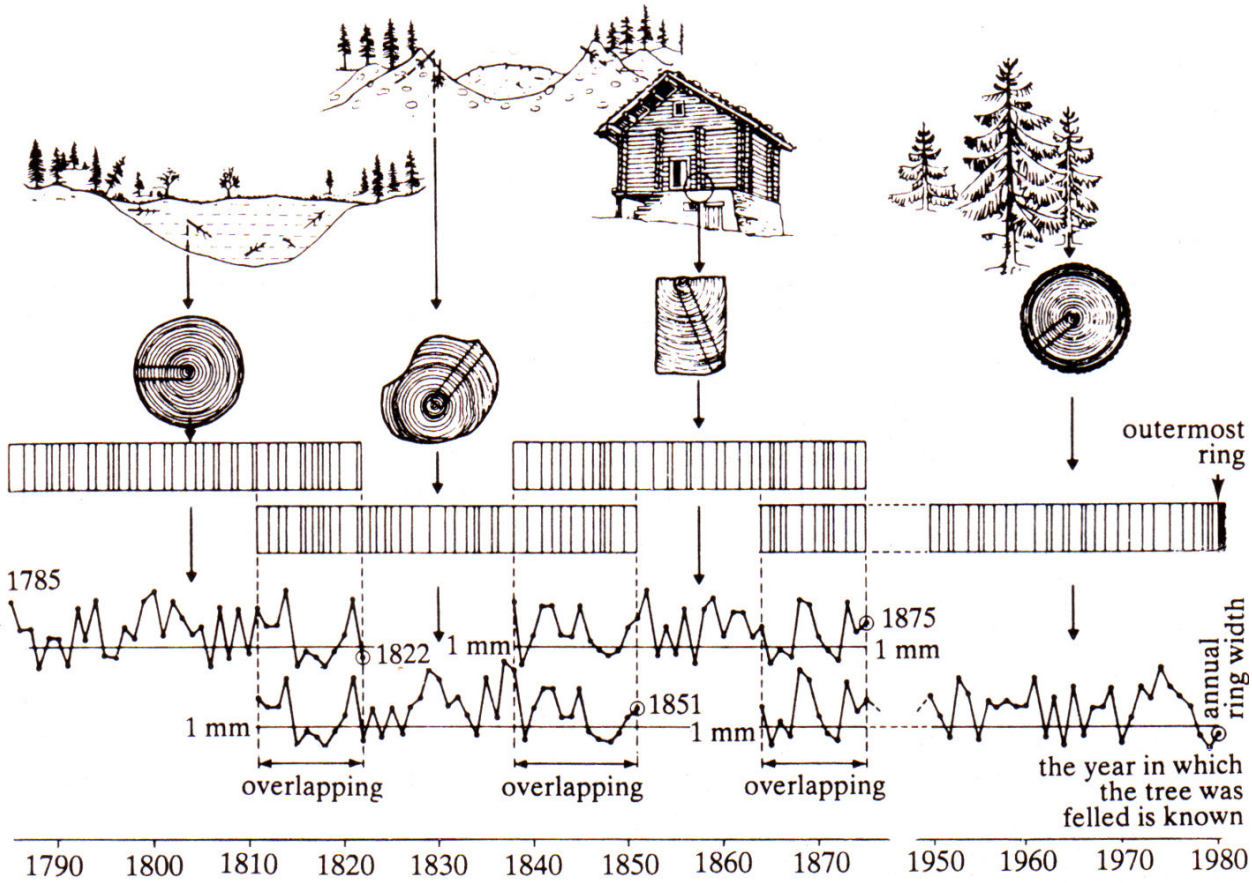

Figure A1: *Schematic representation of the procedure of crossdating.*

Appendix B

Cairngorm Region

The following tables list the time periods covered by each sample and the estimated pith offset values (i.e. number of rings missing between the first year of the sample and the centre of the tree). Included, as well, are the estimated sapwood counts. The mean sapwood count was utilized to estimate the age of the trees sampled that had no or partially complete sapwood. In all instances, the estimated sapwood count was derived from complete samples except where denoted by brackets. In these instances, a mean sapwood count of 81 (±4) years (mean sapwood count estimate, Fish (2007)) was used while the number of actual remaining sapwood rings was placed in brackets. Internal correlation is the Pearson's correlation coefficient (measure of coherence) between each series and the mean of all other from the site. Values in red are not significant at the 95% confidence limit.

Table B1. *Summary information for ring-width series measured from the MOR site in the Cairngorm Mountains. Estimates in brackets denote actual count of sapwood rings.*

Series	First Year	Last Year	Number of years	Pith offsets	Sapwood count	Est. age	Est. year of death	Internal Correlation		Series	First Year	Last Year	Number of years	Pith offsets	Sapwood count	Est. age	Est. year of death	Internal Correlation
GLM01A	1766	2006	241	4	111	245	2007	0.43		GLM10A	1749	2006	258	8	83	266	2007	0.46
GLM02A	1764	2006	243	6	116	249	2007	0.63		GLM11A	1887	2006	120	14	71	134	2007	0.52
GLM03A	1802	2006	205	4	104	209	2007	0.45		GLM12A	1780	2006	227	22	59	249	2007	0.47
GLM04A	1788	2006	219	15	95	234	2007	0.44		GLM13A	1802	2006	205	14	120	219	2007	0.56
GLM05A	1775	2006	232	7	98	239	2007	0.47		GLM14A	1808	2006	199	43	108	242	2007	0.53
GLM06A	1740	2006	267	0	115	267	2007	0.52		GLM15A	1898	2006	109	15	44	124	2007	0.34
GLM07A	1775	2003	229	11	71 (3)	240	2004	0.54		GLM16A	1775	2006	232	15	109	247	2007	0.58
GLM08A	1763	2006	244	0	107	244	2007	0.59		GLM17A	1874	2006	133	13	80	146	2007	0.33
GLM09A	1833	2006	174	--	84	174	2007	0.50										

Table B2. *Summary information for ring-width series measured from the ROTHIE site in the Cairngorm Mountains.*

Series	First Year	Last Year	Number of years	Pith offsets	Sapwood count	Est. age	Est. year of death	Internal Correlation
RTM01A	1898	2006	109	--	68	109	2007	0.38
RTM02A	1845	2006	162	1	67	163	2007	0.21
RTM03A	1859	2006	148	--	67	148	2007	0.53
RTM04A	1854	2006	153	11	94	164	2007	0.43
RTM05A	1850	2006	157	7	83	164	2007	0.44
RTM06A	1937	2006	70	8	70	78	2007	0.69
RTM07A	1879	2006	128	--	55	128	2007	0.38
RTM08A	1940	2006	67	9	36	76	2007	0.15
RTM09A	1853	2006	154	7	45	161	2007	0.33
RTM10A	1852	2006	155	13	93	168	2007	0.55
RTM11A	1841	2006	166	5	89	171	2007	0.47
RTM12A	1852	2006	155	--	88	155	2007	0.56
RTM13A	1849	2006	158	5	101	163	2007	0.39
RTM14A	1841	2006	166	6	93	172	2007	0.48
RTM15A	1852	2006	155	11	68	166	2007	0.40
RTM16A	1845	2006	162	6	57	168	2007	0.54
RTM17A	1860	2006	147	14	73	161	2007	0.64

Table B3. *Summary information for ring-width series measured from the FESHIE site in the Cairngorm Mountains. Estimates in brackets denote actual count of sapwood rings.*

Series	First Year	Last Year	Number of years	Pith offsets	Sapwood count	Est. age	Est. year of death	Internal Correlation
FSH01A	1811	2006	196	4	60	200	2007	0.26
FSH02A	1841	2004	164	15	84 (2)	179	2005	0.44
FSH03A	1875	2004	130	7	44 (2)	137	2005	0.36
FSH04A	1842	2006	165	11	72	176	2007	0.60
FSH05A	1916	2006	91	12	67	103	2007	0.55
FSH06A	1851	2006	156	14	88	170	2007	0.35
FSH07A	1853	2006	154	9	71	163	2007	0.61
FSH08A	1833	2006	174	0	77	174	2007	0.47
FSH09A	1853	2006	154	5	69	159	2007	0.55
FSH10A	1873	2001	129	14	83 (5)	143	2002	0.45
FSH11A	1888	2006	119	11	77	130	2007	0.60
FSH12A	1858	2006	149	5	67	154	2007	0.64
FSH13A	1867	2006	140	4	61	144	2007	0.47
FSH14A	1900	2006	107	15	77	122	2007	0.70
FSH15A	1861	2004	144	10	76 (2)	154	2005	0.54
FSH16A	1848	2006	159	10	92	169	2007	0.54
FSH17A	1854	2006	153	1	78	154	2007	0.34
FSH18A	1874	2006	133	--	86	133	2007	0.57
FSH21A	1822	2006	185	15	87	200	2007	0.41
FSH22A	1849	2006	158	--	92	158	2007	0.39
FSH23A	1839	2006	168	--	44	168	2007	0.29
FSH24A	1844	2006	163	--	70	163	2007	0.15
FSH25A	1854	2006	153	8	98	161	2007	0.48
FSH26A	1847	2006	160	--	81	160	2007	0.39

Appendix C

NW Cairngorms Lochan Survey

This Appendix briefly details the reconnaissance survey (mountain bike, walking and fell running) of potentially relevant small lochans in the NW Cairngorms for finding preserved pine stems in lake sediments.

Figure C1 shows the three regions described. Separate maps for each region provide further location details of the lochs and lochans examined.

All OS grid coordinates are relevant to the OS Outdoor Leisure 3 map for the Cairngorms region.

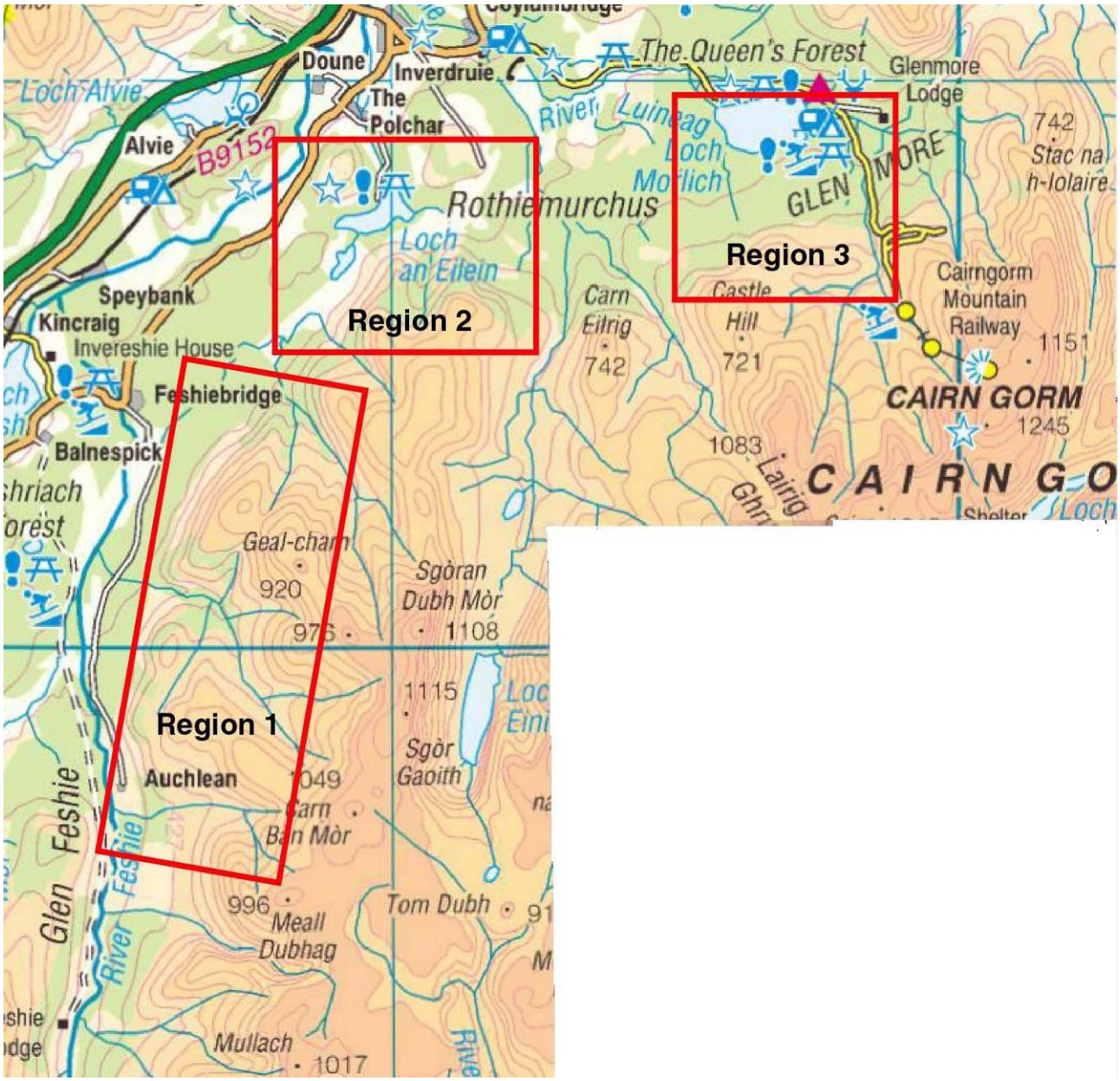

Figure C1: *Location of the three regions visited.*

Region 1

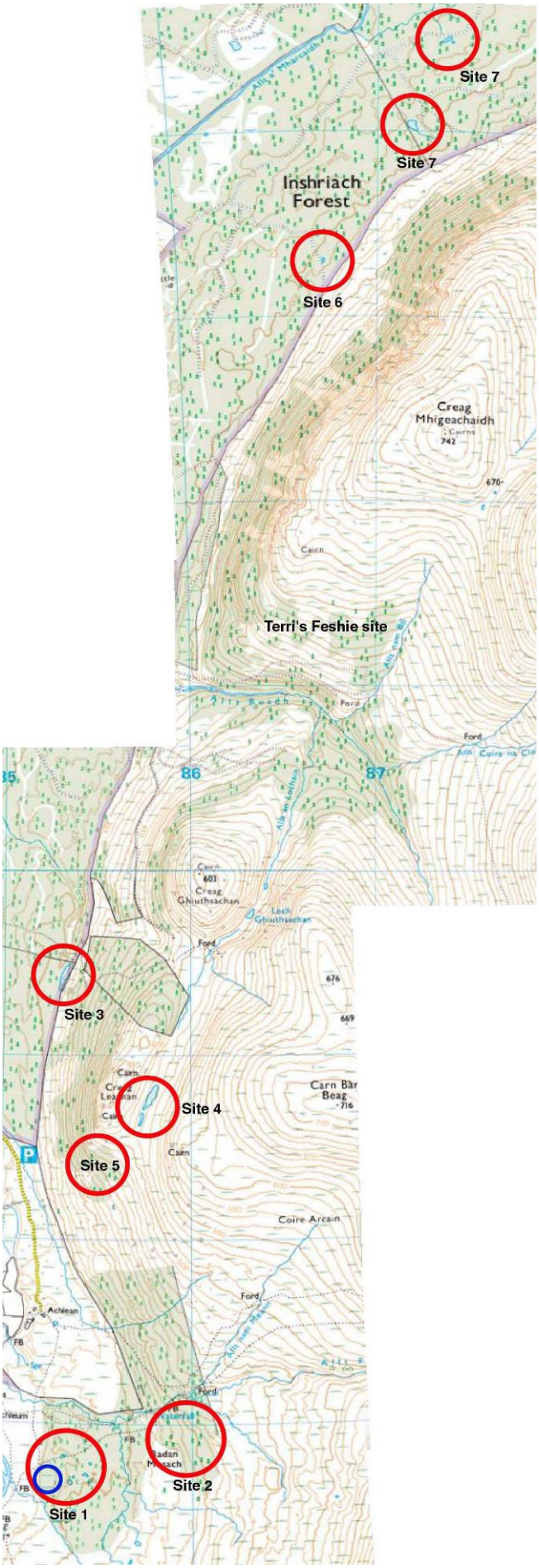

Figure C2: *Detailed map of sites in Region 1*

Site 1:
Modern pine plantation with multiple small lochans.
Most of these are almost ‘in-filled’ and are essentially bogs.
Certainly of no use with regards to finding relatively ‘recent’ pine material. I define ‘recent’ as material that could be anytime from the last 500-1000 years.

Area highlighted by blue circle denotes a once sizeable lake (now a bog) which could theoretically be a source of older (early-mid Holocene) pine logs. Of course, how to dig down and survey such a site is an interesting question.

Site 2:
Badan Mosach (858969)
This site is a very promising natural pine stand. I sampled one tree and it was at least 200-250 years old. Very slow growth rates. I am sure there will be other old trees.
There were also many dead standing stems.
Developing a chronology from this location would help fill in a gap between the Mar Lodge and NW Cairngorm living sites.
This pine stand was sampled in September 2008 and the samples are awaiting processing.

Site 3:
Lake (see photo 1) on border between pine plantation to west and partially natural pine stand to east.
No obvious evidence of pine stems within lake. However, to properly survey the lake, one would have to go and rummage in the sediment. However, no obvious ‘recent’ stems, which is my current main focus, could be seen.

Photo 1

Site 4:
Lake (~520m) above present day forest but under theoretical tree-line. A few small pine saplings were dotted around.
This lake needs a proper survey (i.e. wet suit needed), but there was indeed evidence for pine stems in this lake (see Photo 2).

Photo 2:

Site 5:
Natural pine site on slope going down from previous sites.
Lots of dead standing stems, but trees were not particularly old (150-200 yrs max). Similar ages to Terri Fish's Feshie site that we sampled last year to the north (see Figure C2).

Sites 6-8:
Small lochans in modern pine plantations. Generally not very exciting. Most are now bogs.
Most promising is Site 7 (Figure C2 - the southern most one – the northerly site should be labelled Site 8) which has a rocky bottom (Photo 3). No evidence of any pine stems in lake, although again, a rummage in the sediments might turn something up although due to rocky bottom, the sediment might not be that well developed. Some relict rotten large dead stems suggest that the area was clear cut probably about 50 years ago.

Photo 3: Note suffering 13 year old field assistant.

Region 2

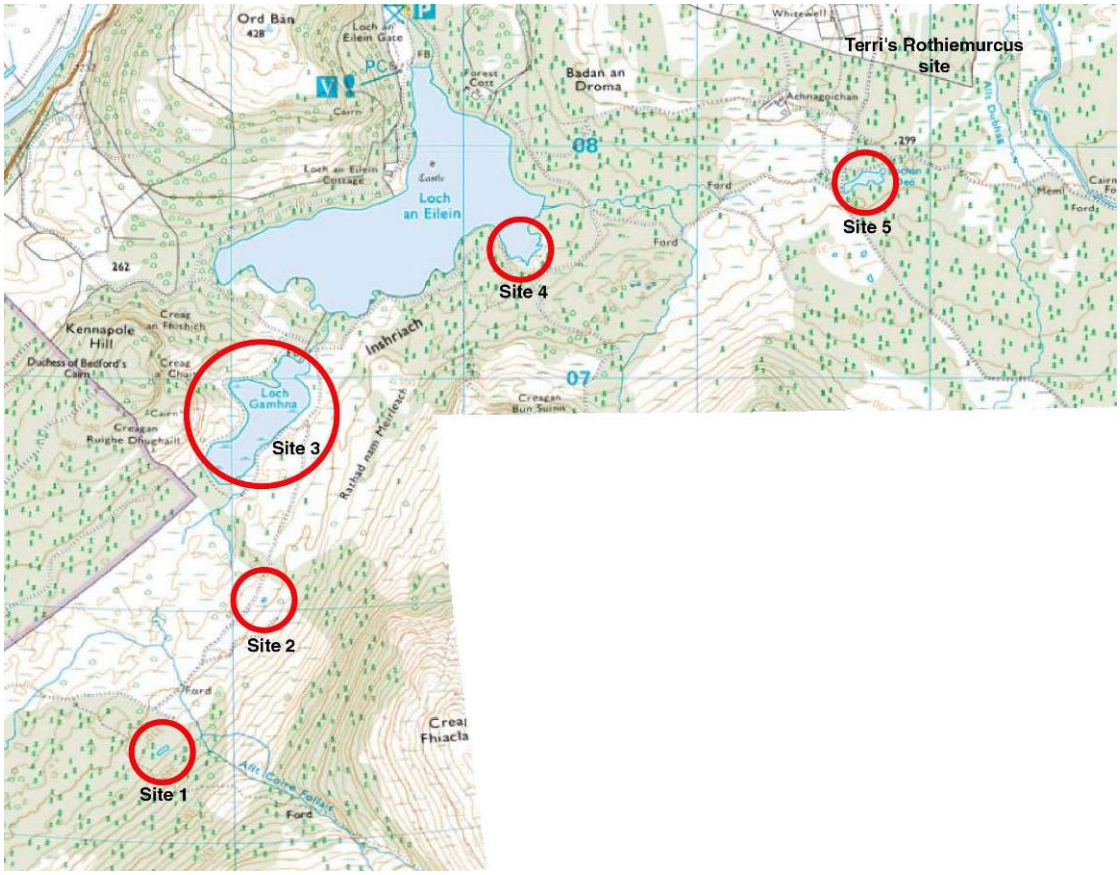

Figure C3: *Detailed map of sites in Region 2*

Site 1:
Another rocky bottomed lake with minimal sediment (Photo 4). This will never be useful as it obviously periodically dries out (as now). Notice the dead pine tree that has however fallen into the lake.
Living tree ages in this region are nothing special (~150 years in age).

Photo 4:

Site 2:
Very small, almost totally in-filled Lochan. No real use.

Site 3:
Now things start getting interesting.
Loch Gamhna really does have a lot of potential.
We went around the whole lake and dead stems could be seen in most locations.
Some are too close to the surface (Photo 5) and are probably rotten due to contact with the air, but there are many stems (Photo 6) which appear well preserved.
This was exactly the sort of situation that I saw in Finland when I was there a few years ago.

Photo 5: Surface exposed stems in Loch Gamhna

Photo 6: Large stems in Loch Gamhna

Site 4:
Scouting the southern shore of Loch an Eilein showed at the eastern end that there is a relatively sheltered bay (903076) which appears to be a pine stem hot spot. It just looks excellent.
See Photos 7-10.

So - both Loch Gamhna and Loch an Eilein are our key candidates for acquiring preserved pine material. The pine trees around these lakes, although large, are not that old (150-200 years or so), probably due to the lower elevations (~300m) and higher growth rates. However, Fish (2007) showed that the temperature signal in these low elevation sites is stronger than the high elevation sites.

Preliminary sub-fossil samples were taken from these Lochs in September 2008. See main report for details. Cores were also taken from living trees around the areas where the sub-fossil material was sampled. These living samples await processing and measurement.

Site 5:
This lochan is located just SW of Terri's Rothiemurcus site.
Another rocky bottomed loch with a couple of small pine stems noted in the sediments. There was evidence that these had been cut, so I am not sure how natural these were.
Pine trees around this lake have maximal ages of ~160 years.

Some smaller lochans further to the south showed no evidence of pine stems.

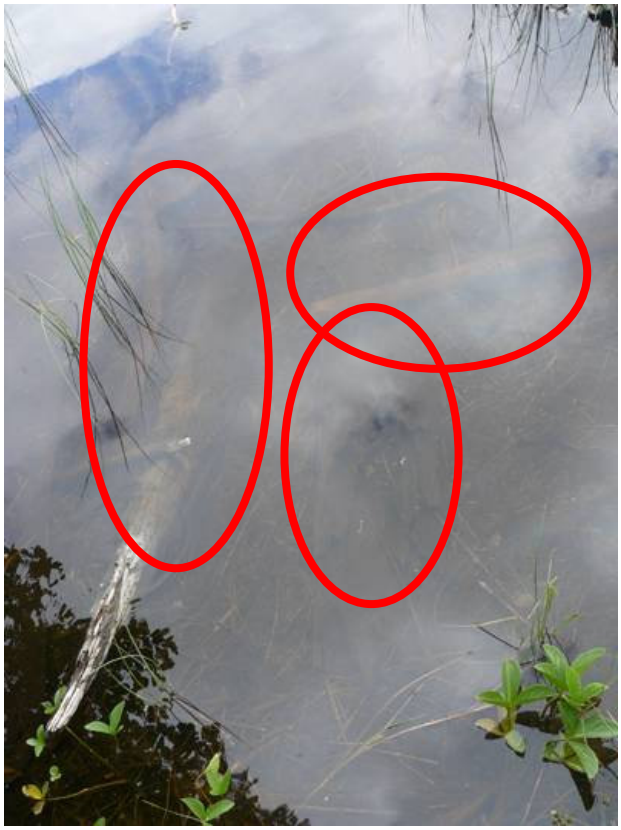

Photo 7

Photo 9

Photo 8

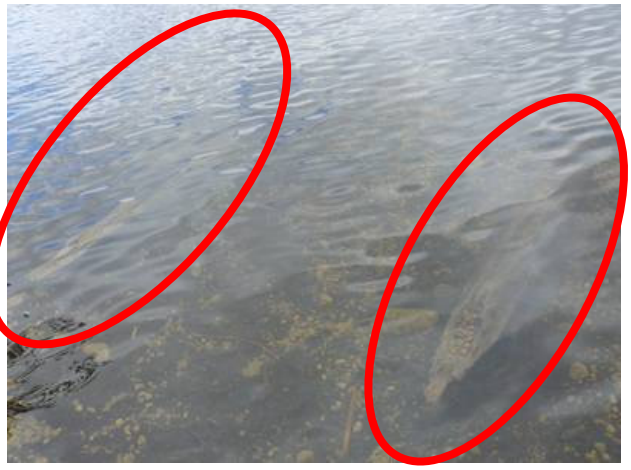

Photo 10

Region 3

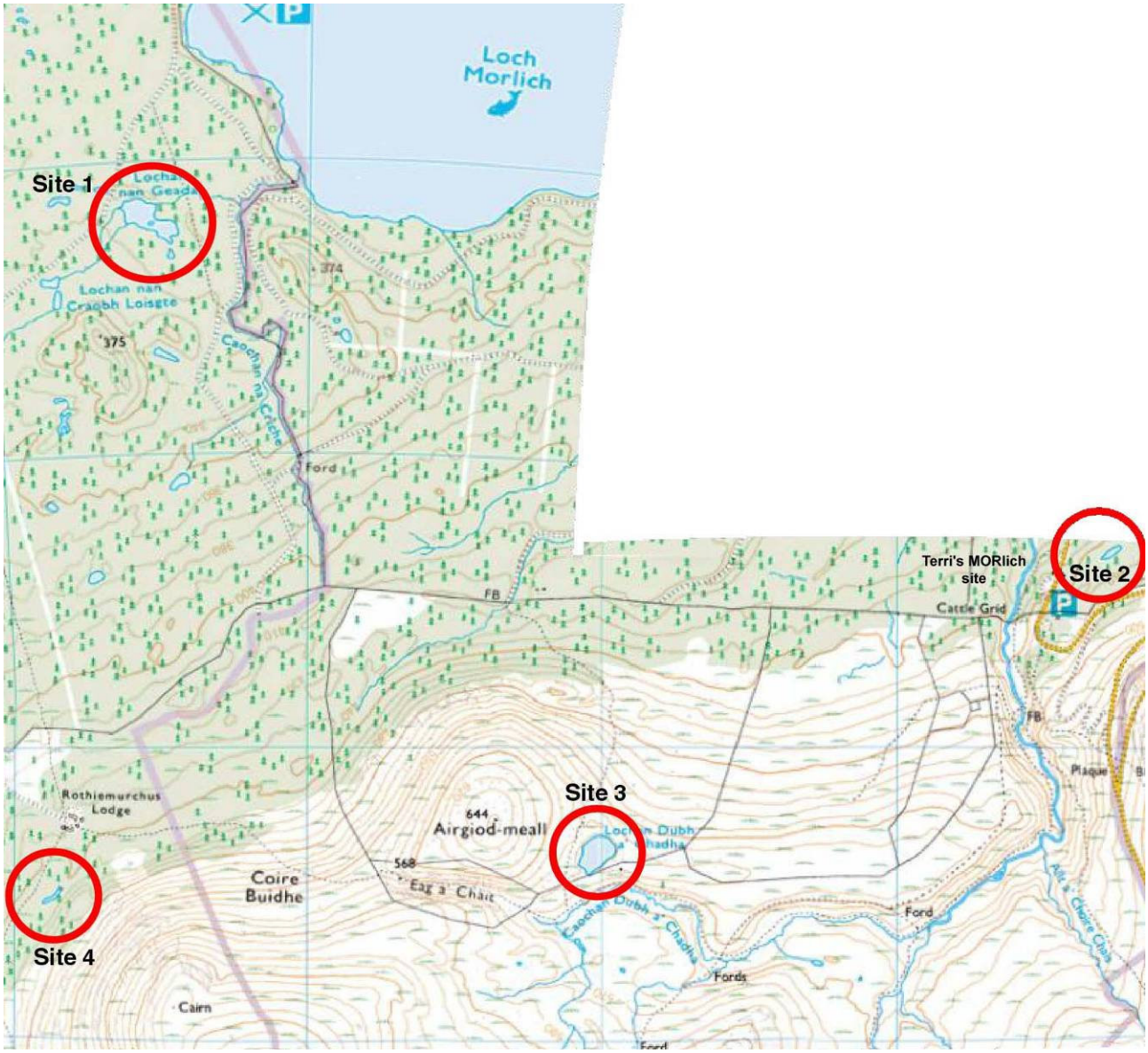

Figure C4: *Detailed map of sites in Region 3*

Site 1:
The area to the SW of Loch Morlich is currently mostly young pine plantations. However, I did pop up and have a look at Lochan nan Geadas. Despite being in a plantation, some older pines have been left around the loch shore. However, I saw no evidence of pine stems in the lake sediments. That does not mean they are not there, but one would have to rummage around in the sediment.

There are a whole host of small lochans in this area that would be worth looking at in the future. I was running out of time.

Post September discussion with individuals at the Scottish Woodlands Discussion Group has highlighted that Loch Morlich itself holds great promise. This loch will be surveyed in 2009.

Site 2:
Small lochan just east of Terri's Morlich site.
Location appears ideal, but saw no evidence of pine stems in the sediments.
Still might be worth a further look in the future.

Site 3:
Lochan Dubh Chadha - Reasonable sized Lochan above (~550m) current local tree-line although some small pine saplings are scattered around.

In the SW corner of the lochan, there was some evidence of pine stems (and roots etc) in the peat at that end (Photo 11). Again, as with a similar lake in Region 1 (site 4), the age of these stems is probably related to when this region was last forested.

Photo 11:

Site 4:
Last but not least. The small loch SW of Rothiemurcus lodge.
Nice DAMN!! (Photo 12). Might be worth contacting the lodge to see if this was a smaller natural lake at some earlier stage.

Photo 12:

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