

CHARCOAL PRODUCTION DURING THE NORSE AND EARLY MEDIEVAL PERIODS IN EYJAFJALLAHREPPUR, SOUTHERN ICELAND

M J Church[1,2] • A J Dugmore[3] • K A Mairs[3] • A R Millard[1] • G T Cook[4] • G Sveinbjarnardóttir[5] • P A Ascough[6] • K H Roucoux[7]

ABSTRACT. Timber procurement and the use of woodlands are key issues in understanding the open landscapes of the Norse and Medieval periods in the North Atlantic islands. This paper outlines evidence for the timing and mechanisms of woodland use and deforestation in an area of southern Iceland, which is tracked through the mapping and analysis of charcoal production pits. Precise dating of the use of these charcoal production pits within a Bayesian framework is demonstrated through the combination of tephrochronology, sediment accumulation rates, and multiple radiocarbon dates on the archaeological charcoal. Two phases of charcoal production and woodland exploitation have been demonstrated, the first within the first 2 centuries of settlement (cal AD 870–1050) and the second phase over 100 yr later (cal AD 1185–1295). The implications for using charcoal as a medium for ^{14}C dating in Iceland and the wider North Atlantic are then explored. Archaeobotanical analysis of the charcoal sampled from the pits has indicated that birch roundwood was the dominant wood used, that the roundwood was stripped from larger shrubs/trees in late spring/early summer, and that certain sizes and ages of roundwood were harvested. Finally, the timing of the charcoal production is placed into the wider debate on deforestation across Iceland during the Norse and early Medieval periods.

INTRODUCTION

Timber procurement and the use of woodlands are key issues in the Norse and Medieval periods in the North Atlantic islands (Simpson et al. 2003; Dugmore et al. 2005), necessitating a successful balance to be struck between a) demand for wood for fuel, roofing and furnishings, and boat-building and charcoal production for metalworking and b) supply of timber in marginal environments. The demand for wood and timber meant pristine forest in Iceland was subject to substantial clearance during the settlement period. This paper outlines evidence for the timing and mechanisms of Norse deforestation in an area of southern Iceland, which is tracked through the mapping and analysis of charcoal production pits.

The first human colonization of Iceland, known as *landnám* (Old Norse, meaning "land-take"), occurred relatively recently and is dated to around AD 870 (Sveinbjörnsdóttir et al. 2004). Various researchers have estimated through computer modeling and palynology that approximately 15–40% of the land surface of Iceland was covered in birch (*Betula* sp.) woodland at landnám, much of it concentrated in the coastal lowlands (Hallsdóttir 1995; Bergþórrson 1996; Ólafsdóttir et al. 2001; Wastl et al. 2001). Present coverage of birch woodland in Iceland is less than 1% and much of this is a result of active plantation during the 20th century (Ólafsdóttir et al. 2001). One of the key research questions when assessing the impact of human settlement on the Icelandic environment is the timing of this deforestation. It has been argued from palynological evidence that this deforestation occurred very rapidly during the first centuries after landnám, primarily to create extensive grasslands for grazing and hay production (Einarsson 1961, 1963; Hallsdóttir 1987, 1996; Zutter 1997; Hallsdóttir and Caseldine 2005). This model would create a timber deficit, requiring the suc-

[1]Department of Archaeology, Durham University, United Kingdom.
[2]Corresponding author. Email: m.j.church@durham.ac.uk.
[3]Institute of Geography, University of Edinburgh, United Kingdom.
[4]Scottish Universities Environmental Research Centre, Radiocarbon Dating Laboratory, East Kilbride, United Kingdom.
[5]Institute of Archaeology, University College London, United Kingdom.
[6]Department of Geography, St. Andrews University, United Kingdom.
[7]Department of Geography, Leeds University, United Kingdom.

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cessful formation of complex trade networks and active management of the remaining woodland. Charcoal production for extracting iron from iron ore and metal-working was one of the main uses of wood in Iceland during the past 1100 yr, and charcoal production pits have been found in various parts of the country (Dugmore et al. 2006; McGovern et al. 2007). Medieval estate documents and documents such as the Grágás, a collection of medieval laws compiled in the latter half of the 13th century, indicate that these pits were produced within or immediately adjacent to birch woodland. Therefore, detailed sampling and dating of the charcoal from these pits will provide a proxy record for woodland presence, use, and clearance.

An interdisciplinary project investigating the human impact on the environment and human adaptation to environmental change is ongoing within the district of Eyjafjallahreppur in southern Iceland. The western part of the study area is defined by the Markarfljót River to the west and north and the Eyjafjöll Mountains to the east (Figure 1). Various lines of evidence have been combined to investigate the human-environment interaction in the area, including geomorphology, tephrochronology, archaeology, and contemporary literature-based research (Dugmore et al. 2006; Mairs et al. 2006; Sveinbjarnardóttir et al. 2006). An aspect of this research has been to investigate the timing and mechanisms of the use of woodland and deforestation through the analysis of a number of charcoal production pits recently discovered in the area, and the results are presented here.

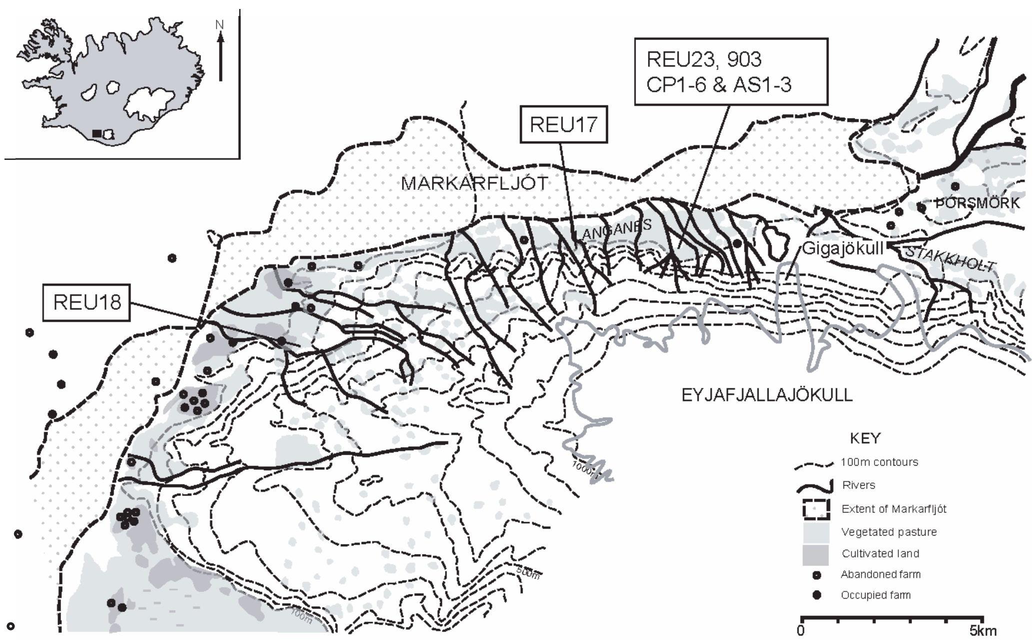

Figure 1 Location map of study area

RESEARCH AIMS

Three related aims were formulated prior to the research:

1. To assess the mechanisms of wood procurement, possible woodland management, and deforestation through analysis of the archaeobotanical remains recovered from the charcoal production pits;
2. To date the use of the charcoal production pits through an integrated dating approach combining radiocarbon dating and tephrochronology within a Bayesian framework;

3. To assess the results from the charcoal production pits within the wider context of deforestation within Iceland.

These aims were investigated through the integrated use of the methods outlined below.

METHODS

Field Sampling

Figure 1 presents the location of the 12 charcoal production pits discovered in the study area. Most of the pits (site codes = REU23, 903 CP1-6, and 903 AS1-3) were discovered in eroding fluvial sections in an area called Langanes, approximately 40 km from the coast and 1 km west of Gigajökull, a small valley glacier extending from the main Eyjafjallajökull icecap. REU17 was accidentally discovered further west along the Markarfljót Valley during a test-pit dug for tephrochronological and geomorphic analysis. REU18 represents a charcoal production pit found on the margins of the landnám farm of Syðsta Mörk at the head of the Markarfljót Valley, which is still occupied and farmed today. Table 1 outlines the summary archaeological details of each of the pits.

Table 1 Summary description of each site.

Site code	Description
REU17	Pit with charcoal discovered during geomorphology survey and sectioned in 2003.
REU18	Charcoal sample provided by farmer from charcoal pit found in 1990s in Syðsta Mörk.
REU23	Pit with charcoal; complete cross-section exposed in fluvial section in 2002.
903CP1	Pit with charcoal; complete cross-section exposed in fluvial section in 2003.
903CP2	Edge of pit with charcoal exposed in fluvial section in 2004.
903CP3	Pit with charcoal; complete cross-section with 2 charcoal fills exposed in fluvial section in 2004.
903CP4	Edge of pit with charcoal exposed in fluvial section in 2004.
903CP5	Pit with charcoal; complete cross-section exposed in fluvial section in 2003.
903CP6	Edge of pit with charcoal exposed in fluvial section in 2004.
903AS1	Ash and charcoal spread (spoil from a pit) appearing in fluvial section in 2003.
903AS2	Ash and charcoal spread (spoil from a pit) appearing in fluvial section in 2003.
903AS3	Ash and charcoal spread (spoil from a pit) appearing in fluvial section in 2004.

Each pit was recorded and sampled using standard archaeological excavation procedures, with the section cleaned, photographed, and drawn, paying particular attention to the relationship between the archaeological contexts and the associated tephras. This part of Eyjafjallahreppur is an excellent area for geochronological research because a very detailed tephrochronology has been developed for the region (Dugmore 1989; Dugmore and Buckland 1991; Dugmore and Erskine 1994; Larsen 1996), supported by geochemical analysis of individual glass shards in key tephras (Dugmore et al. 2000, 2006). Figure 2 presents a typical cross-section from one of the pits recorded in the eroding fluvial sections in Langanes. The pit cuts, and therefore is later than, the Eldjá 933 tephra, which has been dated to cal AD 933 (maximum counting error of 1 yr) when correlated to the DYE-3, GRIP, and NGRIP Greenland ice cores (Vinther et al. 2006). Remains of the spoil from the pit and the firing process are seen on each side of the pit (Context 6), overlying a small amount of natural soil accumulation immediately above the Eldjá 933 tephra. The basal charcoal fill of the pit (Context 4) represents either the desired end product of the charcoal production or the remnants of charcoal left after the larger charcoal pieces were removed for use elsewhere. This layer was bulk sampled for ^{14}C and archaeobotanical analysis. The basal fill and pit was then filled back in by human action with the mixed remains of soil dug from the pit and the turf used to cover the wood during the charcoal production (Context 3). Natural soil accumulation then occurs across all of the archaeological remains culminating in the tephra falls of Hekla 1341 and Katla 1500, both dated by correlation to historical records (Dugmore 1989). The use of the pit can therefore be constrained chronologically, by the tephras, to between AD 933 and 1341. Tephrochronology can also be used to estimate the time lapse between the use and abandonment of the site and the fall of Hekla 1341 by measuring the natural sediment accumulation overlying the pit spoil. For example, in the example presented in Figure 2, a series of sediment thickness measurements (60 in total) were taken between the top of the spoil and the bottom of Hekla 1341, at the point where the spoil thins out to the left of the pit. An average was then calculated with an associated standard deviation. Immediately adjacent to the left of the spoil was over 20 m of eroding fluvial section that exposed the natural sediment accumulation between Eldjá 933 and Hekla 1341. Another series of sediment thickness measurements (135 in total) were taken from this natural section to estimate the local sediment accumulation rate with associated standard deviation, which was then used to estimate the time lapse from the abandonment of the site to the fall of Hekla 1341.

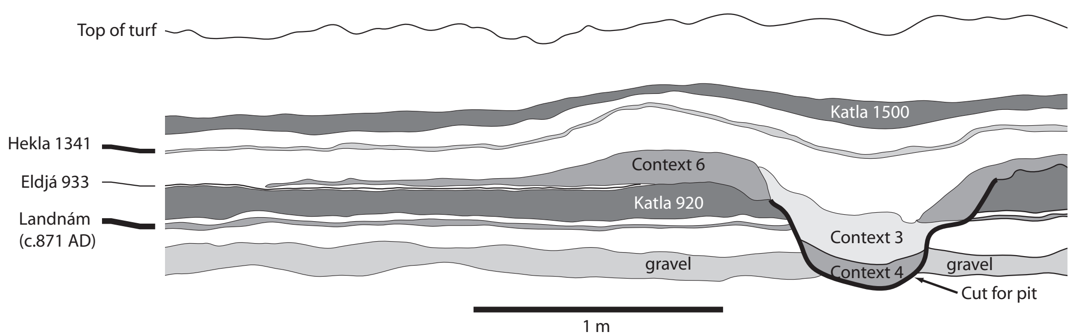

Figure 2 Section drawing of charcoal pit 903 CP1

Bulk Sample Processing

The bulk samples for ^{14}C and archaeobotanical analysis were processed using a Siraf-type wet sieve tank (Kenward et al. 1980), using 1.0- and 0.3-mm sieves for the flot and a 1.0-mm sieve net to catch the residue. The material was air-dried and both the flot and residue fully sorted under 6–20× magnification. Charcoal was sorted only from the >4-mm fraction, because identification is very difficult below this size (Pearsall 2000). All plant macrofossil identifications were checked against the botanical literature (Long 1929; Beijerinck 1947; Berggren 1969, 1981; Schweingruber 1990; Anderberg 1994) and modern reference material from collections in the Department of Archaeology at Durham University. Nomenclature follows Stace (1994), with ecological information taken from Kristinsson (1998). When the sorted charcoal assemblages were large, 50 fragments of charcoal were randomly selected for identification from the sorted remains, using a riffle box following the methodology of van der Veen and Fieller (1982). The charcoal fragments were generally identified to genus, with the number of fragments and weight for each genus recorded. The fragments were also categorized into roundwood or timber and the number of rings noted. Roundwood charcoal pieces were then systematically removed from the remainder of the sorted charcoal for identification, in order to produce data on the size and age of the wood fragments burnt.

Dating and Statistical Analysis

Three charcoal samples were chosen for ^{14}C dating from each pit. The samples chosen consisted of birch roundwood (*Betula* sp.) as this was the dominant wood type in all of the pits (see Table 2), and the samples were submitted for analysis at the SUERC Radiocarbon Laboratory, East Kilbride, Scotland. Where possible, the outer ring and bark were chosen for accelerator mass spectrometry (AMS) dating, as this contained ^{14}C incorporated in the final 5 yr of growth before the death of the birch roundwood. A dating protocol was then designed for each of the charcoal production pits, with the age model calculated using the Bayesian function within OxCal v 3.10 (Bronk Ramsey 1995, 2001, 2005). An example of the code used for charcoal pit 903 CP1 (the section in Figure 2) can be seen in Figure 3. First, the lower tephra isochron was established for each pit using one of either the landnám tephra, dated AD 871 ± 2 by correlation to the GRIP ice core (Grönvold et al. 1995), or Eldjá 933. All of the pits cut Eldjá 933 except for REU18, which cut the landnám tephra. Secondly, the 3 ^{14}C dates were combined because the archaeobotanical material suggested that the charcoal came from living trees/shrubs that were harvested at the same point in time (see below). The contemporaneity of the dates was statistically assessed using a χ^2 test (Ward and Wilson 1978) and outliers then removed from the model, e.g. SUERC-2380 (see Table 3). The age offset associated with the sample was also modeled. For example, bark and a single outer ring were assigned an offset of 3 ± 1 yr, representing the 1–5 yr carbon turnover observed in the bark of modern birch (Atkinson 1992). Thirdly, the time lapsed between the top of the archaeological spoil and the bottom of Hekla 1341 was estimated using the sediment accumulation rate data collected. This sediment accumulation estimate was possible for 6 of the 12 sites, a function of the variability of the quality of the archaeological record and the natural soil sequence between each site (see Table 4). The sediment accumulation estimate was modeled in the OxCal program by utilizing the dose and dose-rate functions, usually used when modeling thermoluminescence dates. Finally, the upper tephra isochron modeled was Hekla 1341 for all of the pits.

RESULTS AND DISCUSSION

Charcoal Production and Woodland Management

Table 2 presents the summary archaeobotanical results from the 12 sites. Birch (*Betula* sp.) roundwood dominates all of the assemblages, with a few pieces of birch timber/rootwood and willow (*Salix* sp.) roundwood identified. Very low concentrations of smaller carbonized plant macrofossils were also recovered from the larger assemblages from basal fills of the charcoal pits (e.g. 903 CP1, 903 CP3, REU17, and REU23), including leaf fragments of Ling heather (*Calluna vulgaris* [L.] Hull.), moss leaf fragments, small culm nodes/bases, small rhizomes, and seeds from heath and grassland species. These plant macrofossils were likely to have been carbonized within the turfs used during the charcoal production process, because they reflect the suite of macrofossils expected when burning turf (Dickson 1998; Church et al. 2007).

Much of the birch roundwood still had pieces of bark attached and the larger assemblages also had many hundreds of birch leaf buds, many of which were just beginning to leaf. This indicates that the birch roundwood was harvested while the shrubs/trees were still alive; therefore, it can be assumed that the wood used for the charcoal production was used shortly after harvesting because the bark and buds were still very well preserved when the wood was charred in the pits, removing the possibility of "old wood" contamination for the ^{14}C dates. This phenomenon has been demonstrated in landnám sites in Iceland (Sveinbjörnsdóttir et al. 2004) and Iron Age sites in Atlantic Scotland (Ashmore 1999), and it is therefore very important to establish the archaeobotanical taphonomy of charcoal if used for ^{14}C dating in the North Atlantic. The equivalence of age of the death for the majority of the birch roundwood pieces in the charcoal assemblages meant that combining the 3 ^{14}C dates for each site was legitimate.

Table 2 Archaeobotanical identifications for each charcoal pit (a = abundant, p = present, F = fragment: charcoal mass in grams in parentheses).

Pit	903 AS1	903 AS2	903 AS3	903 CP1	903 CP2	903 CP3	903 CP3	903 CP4	903 CP5	903 CP6	REU17	REU18	REU23
Context	C.1	C.1	C.1	C.4	C.2	C.3	C.5	C.2	C.2	n/a	C.1	n/a	C.8
Context type	C spread	C spread	C spread	Basal fill	Basal fill	Middle fill	Basal fill	C spread	Basal fill	C spread	Basal fill	Basal fill	Basal fill
Charcoal													
Betula sp. timber	1F(0.03)			2F(0.12)		1F(0.08)	1F(0.05)	1F(0.05)					1F(0.03)
Betula sp. roundwood (not pith to bark)	24F(0.81)	13F(0.47)	12F(0.3)	33F(2.15)	27F(0.74)	21F(1.51)	32F(2.7)	16F(0.96)	27F(0.83)	3F(0.14)	21F(1.97)		37F(3.27)
Betula sp. roundwood (pith to bark)			3F(0.46)	3F(0.23)	11F(0.7)	9F(1.43)	7F(0.44)	2F(0.31)	3F(0.05)		20F(7.65)		8F(2.05)
Betula sp. rootwood (not pith to bark)				1F(0.05)	2F(0.07)						9F(0.92)		1F(0.6)
Betula sp. bark fragment	11F(0.38)	4F(0.07)	1F(0.01)	11F(0.99)	10F(0.18)	17F(0.61)	9F(0.32)	13F(0.33)	19F(0.4)				
Salix sp. roundwood (pith to bark)						2F(0.06)	1F(0.01)						1F(0.03)
Deciduous rootwood (pith to bark)	1F(0.04)								1F(0.03)				2F(0.04)
Indeterminate charcoal										1F(0.03)			
Total number of fragments identified	37	17	16	50	50	50	50	32	40	4	50	2	50
Proportion of assemblage identified (%)	100	100	100	<5	100	<5	<5	100	100	100	<5	100	<5
Carbonized plant macrofossils													
Betula sp. buds				a		a	a		p		a		a
Betula sp. fruit scales				p		p	p				p		p
Calluna vulgaris (L.) Hull. leaf fragment				1F		1F			7F				7F
Moss leaf fragment						2F			3F				4F
Mixed heath and grassland seeds				1		7	8				1		28
Monocotyledon culm node				1		1	2		1		2		
Monocotyledon culm base				1		1			1		13		1
Indeterminate rhizome							1				5		

Table 3 Conventional ^{14}C ages and $\delta^{13}C$ results for charcoal samples from Markarfljót charcoal pits. The combined age was produced using OxCal v 3.10 (Bronk Ramsey 1995, 2001, 2005) with the χ^2 test results in square brackets.

Measurement ID	Sample ID	Sample details	Age ^{14}C yr BP	$\delta^{13}C$
SUERC-2373	REU17 C.1 CS.A	*Betula* sp. roundwood bark	1095 ± 35	–29.6
SUERC-8209	REU17 C.1 CS.B	*Betula* sp. roundwood outer ring and bark	1115 ± 35	–29.3
SUERC-8210	REU17 C.1 CS.C	*Betula* sp. roundwood outer ring and bark	1090 ± 35	–26.5
Combined age for REU17 [*t* value = 0.3 ($\chi^2_{:0.05}$ = 6.0)]			1100 ± 20	
SUERC-2374	REU18 CS.A	*Betula* sp. roundwood outer 2 rings	1150 ± 40	–27.2
SUERC-8211	REU18 CS.B	*Betula* sp. roundwood outer 10 rings	1205 ± 35	–27.4
Combined age for REU18 [*t* value = 1.1 ($\chi^2_{:0.05}$ = 3.8)]			1182 ± 26	
SUERC-2375	REU23 C.8 CS.A	*Betula* sp. roundwood bark	935 ± 35	–27.2
SUERC-8212	REU23 C.8 CS.B	*Betula* sp. roundwood outer 5 rings and bark	960 ± 35	–27.5
SUERC-8216	REU23 C.8 CS.C	*Betula* sp. roundwood outer 5 rings and bark	940 ± 35	–26.9
Combined age for REU23 [*t* value = 0.3 ($\chi^2_{:0.05}$ = 6.0)]			945 ± 20	
SUERC-2376	903 CP1 C.4 CS.A	*Betula* sp. roundwood bark	1130 ± 35	–28.1
SUERC-8217	903 CP1 C.4 CS.B	*Betula* sp. roundwood outer ring and bark	1135 ± 35	–29.9
SUERC-8218	903 CP1 C.4 CS.C	*Betula* sp. roundwood outer ring and bark	1145 ± 35	–30.8
Combined age for 903 CP1 [*t* value = 0.1 ($\chi^2_{:0.05}$ = 6.0)]			1137 ± 20	
SUERC-8219	903 CP2 C.2 CS.A	*Betula* sp. roundwood outer 10 rings and bark	845 ± 35	–27.7
SUERC-8220	903 CP2 C.2 CS.B	*Betula* sp. roundwood outer 13 rings and bark	780 ± 35	–28.0
SUERC-8221	903 CP2 C.2 CS.C	*Betula* sp. roundwood outer 8 rings and bark	790 ± 35	–27.6
Combined age for 903 CP2 [*t* value = 2.0 ($\chi^2_{:0.05}$ = 6.0)]			805 ± 20	
SUERC-8222	903 CP3 C.5 CS.A	*Betula* sp. roundwood outer ring and bark	825 ± 35	–28.0
SUERC-8340	903 CP3 C.5 CS.B	*Betula* sp. roundwood outer 5 rings and bark	810 ± 35	–27.7
SUERC-8226	903 CP3 C.5 CS.C	*Betula* sp. roundwood outer 7 rings and bark	800 ± 35	–28.0
Combined age for 903 CP3 [*t* value = 0.3 ($\chi^2_{:0.05}$ = 6.0)]			812 ± 20	
SUERC-8227	903 CP4 C.2 CS.A	*Betula* sp. roundwood outer 5 rings and bark	990 ± 35	–26.6
SUERC-8228	903 CP4 C.2 CS.B	*Betula* sp. roundwood outer 5 rings and bark	1065 ± 35	–26.4
SUERC-8229	903 CP4 C.2 CS.C	*Betula* sp. roundwood outer 7 rings and bark	1075 ± 35	–27.3
Combined age for 903 CP4 [*t* value = 3.5 ($\chi^2_{:0.05}$ = 6.0)]			1044 ± 20	
SUERC-8230	903 CP5 C.2 CS.A	*Betula* sp. roundwood outer ring and bark	770 ± 35	–30.0
SUERC-8231	903 CP5 C.2 CS.B	*Betula* sp. roundwood outer 13 rings and bark	685 ± 35	–28.0
SUERC-8232	903 CP5 C.2 CS.C	*Betula* sp. roundwood outer 11 rings and bark	690 ± 35	–28.0
Combined age for 903 CP5 [*t* value = 3.7 ($\chi^2_{:0.05}$ = 6.0)]			715 ± 20	
SUERC-8236	903 CP6 CS.A	*Betula* sp. roundwood 5 rings	805 ± 30	–28.4
SUERC-8237	903 CP6 CS.B	*Betula* sp. roundwood 7 rings	790 ± 35	–28.2
SUERC-8238	903 CP6 CS.C	*Betula* sp. roundwood 6 rings	800 ± 35	–28.0
Combined age for 903 CP6 [*t* value 0.1 [($\chi^2_{:0.05}$ = 6.0)]			799 ± 19	
SUERC-2380	903 AS1 CS.A	*Betula* sp. roundwood outer 6 rings	960 ± 35	–26.0
SUERC-8239	903 AS1 CS.B	*Betula* sp. roundwood 10 rings	1050 ± 35	–27.5
SUERC-8240	903 AS1 CS.C	*Betula* sp. roundwood 14 rings	1080 ± 35	–27.8
Combined age for 903 AS1 including SUERC-2380 [*t* value = 6.3 ($\chi^2_{:0.05}$ = 6.0)]			1030 ± 20	
Combined age for 903 AS1 excluding SUERC-2380 [*t* value = 0.4 ($\chi^2_{:0.05}$ = 3.8)]			1065 ± 25	
SUERC-2381	903 AS2 CS.A	*Betula* sp. roundwood outer 11 rings	1005 ± 35	–27.6
SUERC-8241	903 AS2 CS.B	*Betula* sp. roundwood 15 rings	1110 ± 35	–27.0
SUERC-8242	903 AS2 CS.C	*Betula* sp. roundwood outer 11 rings	1075 ± 35	–27.8
Combined age for 903 AS2 [*t* value = 4.7 ($\chi^2_{:0.05}$ = 6.0)]			1064 ± 20	
SUERC-8246	903 AS3 CS.A	*Betula* sp. roundwood outer 10 rings and bark	795 ± 35	–27.7
SUERC-8247	903 AS3 CS.B	*Betula* sp. roundwood 19 rings and bark	785 ± 35	–27.0
SUERC-8248	903 AS3 CS.C	*Betula* sp. roundwood outer 5 rings and bark	795 ± 35	–26.6
Combined age for 903 AS3 [*t* value = 0.1 ($\chi^2_{:0.05}$ = 6.0)]			792 ± 20	

Table 4 Calendrical age models for charcoal pits, calculated using OxCal v 3.10 (Bronk Ramsey 1995, 2001, 2005). * = no sediment accumulation estimate possible.

Site	^{14}C only cal AD (2 σ)	^{14}C dates and tephra cal AD (2 σ)	^{14}C, tephras, and sediment accumulation estimate cal AD (2 σ)
REU17	890–990	932–995	932–995*
REU18	770–950	865–960	865–960*
REU23	1020–1160	1020–1160	1024–1043
903 CP1	820–980	932–973	948–987
903 CP2	1205–1270	1215–1275	1232–1249
903 CP3	1185–1270	1185–1270	1185–1270*
903 CP4	900–1030	984–1026	986–1024
903 CP5	1260–1295	1271–1297	1276–1295
903 CP6	1210–1270	1215–1270	1215–1270*
903 AS1	890–1020	945–1025	945–1025*
903 AS2	890–1020	960–1025	960–1025*
903 AS3	1215–1275	1220–1275	1248–1275

```
Plot
{
Sequence "903CP1"
{
Prior "Eldja933.14d"; Lower tephra limit = Eldjá 933
phase{
Combine "903CP1Comb" Combination of radiocarbon dates
{
R_Date "903CP1-CSA" 1130 35; Offset 3 1;
R_Date "903CP1-CSB" 1135 35; Offset 3 1;
R_Date "903CP1-CSC" 1145 35; Offset 3 1;
Year "1341"; Sediment accumulation estimate
Dose "0.4500";
error "0.0446";
C_Date "903CP1-sed" d158.6 d6.77;
};};
C_Date "H1341" 1341; Upper tephra limit
};
};
```

Figure 3 Code for age model for charcoal pit 903 CP1 in OxCal v 3.10 (Bronk Ramsey 1995, 2001, 2005) (**bold** = explanatory text).

The abundance of the birch leaf buds also suggests that the birch roundwood was harvested during late spring/early summer (Kristinsson 1998). A number of the larger pieces had evidence of disarticulation scars indicative of branch stripping. This implies that a form of coppicing may have been practiced during this time of year, with roundwood being harvested from larger bushes/trees that were being actively conserved. Figure 4 presents the ring counts and diameter sizes for birch roundwood (pith to bark) from 2 pits that are representative of the assemblages from the 2 phases. Caution must be exercised when analyzing these data as it is unclear whether the charcoal recovered was the desired charcoal product or the smaller pieces left after the bigger charcoal pieces had been removed. Also, the data presented are only from roundwood pieces that had pith to bark transverse sections from which accurate ring count and size estimates could be made; some larger pieces were not included in the analysis as they did not have complete pith to bark transverse sections. However, both pits show a unimodal distribution of the ring counts (and therefore ages) of the birch roundwood fragments identified. These distributions may indicate a deliberate selection of certain ages of roundwood from the bushes/trees, in particular parts of the birch such as the lower branches. Alternatively, it may indicate some form of periodic harvesting of preserved woodland.

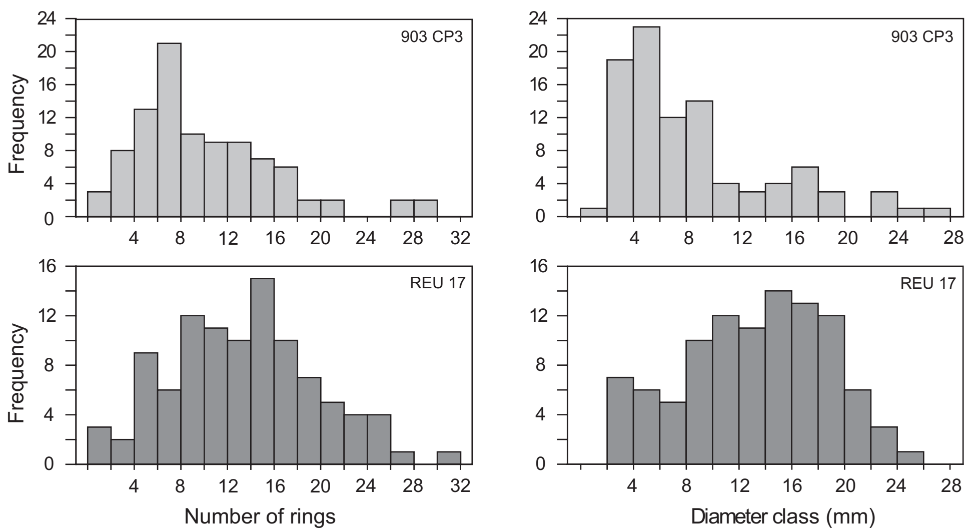

Figure 4 Ring counts and diameters of birch roundwood from charcoal pits REU17 and 903 CP3

Timing of Charcoal Production and Implications for Deforestation and Land Management

Table 3 presents the ^{14}C dates and results of the χ^2 tests for each of the pits. Only 1 set of ^{14}C dates failed the test (i.e. from 903 AS1) and in this case the outlier, SUERC-2380, was removed and the remaining 2 dates combined. The rest of the ^{14}C dates passed the χ^2 test, and so each of the sets of dates was combined within the model for each pit. Table 4 and Figure 5 present the age ranges of the 3 different levels of modeled data for each of the pits. The first level only modeled the combined ^{14}C dates; the second level modeled the combined ^{14}C dates and the tephra lower and upper isochrons; and the third level modeled the combined ^{14}C dates, the tephra lower/upper isochrons, and the sediment accumulation data. In general, increased precision was possible with each ascending level, with the 6 pits modeled using all 3 lines of chronological information, producing calibrated age ranges of 17–39 yr. This increased precision has produced an interesting picture of the timing of the use of the pits. The earliest dated pit, REU18, had a date range from cal AD 865–960 (2 σ) and was located at the head of Markarfljót Valley (Figure 1). A second suite of pits overlapped with the later range of REU18 and included REU17, located half-way up the valley, and 4 pits located in the group discovered at Langanes. All of these pits were dug later than Eldjá 933 and ranged in date from cal AD 932–1043 (2 σ). A hiatus of approximately 140 yr is then seen before a second phase of pit digging resumes in the same area at Langanes, ranging from cal AD 1185–1295 (2 σ).

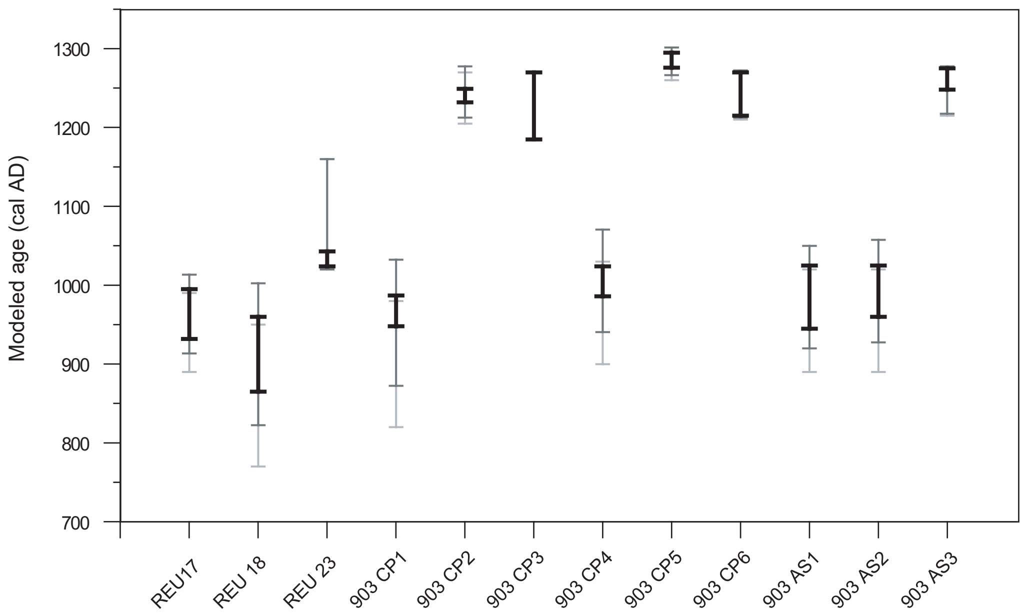

Figure 5 Modeled ages of charcoal pits. The light-gray date range represents the combined ^{14}C dates only; the darker gray date range represents the combined ^{14}C dates and tephra upper/lower isochrones; and the black date range represents the combined ^{14}C dates, the tephra upper/lower isochrons, and the sediment accumulation rate data.

A preliminary model of charcoal production and woodland use can therefore be proposed for the southern slopes of Markarfljót Valley. There was an initial phase of charcoal production and woodland use in the 2 centuries after landnám, with the earliest dated pit nearest the coast ending in the mid-11th century cal AD. The archaeobotanical remains from 2 of the pits (903 CP1 and REU17) include birch rootwood, indicating that some bushes/trees were being harvested in their entirety. This finding fits the traditional model of deforestation. Geomorphic survey of the area through tephra logging has revealed that extensive landscape erosion and degradation occurred during this period, an effect attributed to both deforestation and livestock grazing across the landscape (Mairs 2003; Dugmore et al. 2006; Mairs et al. 2006).

The 140-yr hiatus can be explained by a number of scenarios. It may indicate a changing use for the woodland away from charcoal production that would be archaeologically invisible. Alternatively, it could mean that the woodland was regenerating. There are multiple explanations for this phenomenon, including deliberate conservation of the woodland or settlement abandonment in the area. Evidence for both scenarios exists in the immediate landscape. For example, a series of landnám period farms has been located in the immediate area to the east of Gigajökull at Þorsmörk that have been shown to be abandoned by the end of the 12th century through survey of the archaeological remains (Sveinbjarnardóttir 1992) and geomorphic analysis (Dugmore et al. 2006). Alternatively, preserved mature birch woodland exists today at Þorsmörk and is said to have remained in the area since the

Medieval period, through contemporary literature-based analysis (Sveinbjarnardóttir 1992; Sveinbjarnardóttir et al. 2006). However, this is hard to verify as there is no potential for paleoecological reconstruction in the area because of the lack of suitable lakes or peat bogs.

The second period of charcoal production in the Langanes area occurred from the late 12th to late 13th centuries cal AD. This second phase implies the existence of woodland in the immediate area and renewed exploitation, demonstrating a more complex picture of woodland presence and use than previously indicated by the traditional model of settlement period deforestation. The nature of this woodland use is evident from the archaeobotanical analysis of the charcoal from the 5 charcoal pits in the second phase. Again, the wood was dominated by birch roundwood, with the recovery of hundreds of birch buds indicating harvesting in late spring/early summer and multiple disarticulation scars indicating branch stripping. These features appear to indicate a form of management of the woodland resource, but the timing and manner of the harvesting may have contributed to deforestation. Birch sap rises during this time of year and the branch stripping would have left open scars in the larger trunks/branches of the birch from which sap could have been lost, weakening the plant growing in its ecological limits and making it more susceptible to environmental/climatic degradation and human impact on the landscape. Figure 4 presents age and size data from birch (pith to bark) roundwood from 2 pits representative of the 2 phases. The size and age of the wood changed between the phases, with the greatest frequency for the age of the birch roundwood peaking at 15–16 yr for the earlier pit (REU17) and at 7–8 yr for the later pit (903 CP3). The size of the roundwood harvested also decreased from the greatest frequency of 15–16 mm in REU17 to 5–6 mm in 903 CP3. These data may indicate that smaller-diameter roundwood was being harvested at a younger age in the later phase, stemming from the over-exploitation of a diminishing resource. Geomorphic survey of the area through tephra logging has revealed that extensive landscape erosion and degradation occurred during this second period of woodland use (Mairs 2003; Dugmore et al. 2006; Mairs et al. 2006). Such degradation may relate to deforestation.

The second phase ended by cal AD 1300. No further evidence of charcoal production was seen in any of the eroding fluvial sections in the valley after the tephra fall of Hekla 1341. This lack of evidence implies that the area was fully deforested by this time, apart from the woodland at Þorsmörk that was maintained for use by the Bishopric of Skalholt (Sveinbjarnardóttir et al. 2006). Also, geomorphic research has indicated that the landscape stabilized after 1300 in the immediate area of Langanes and Þorsmörk (Dugmore et al. 2006), following settlement abandonment of the area (Sveinbjarnardóttir 1992) and possible stabilization of the landscape following the final phase of deforestation at Langanes.

In summary, the story of woodland use and deforestation is more complex than a simple felling of trees within the first 2 centuries after landnám; rather, a picture of slower depletion over 500 yr emerges with evidence of possible woodland management, conservation, and regeneration occurring within this time. This picture of phased clearance of birch woodland is also emerging from recent palynological work from a small lake (Helluvaðstjörn) 60 km inland from the coast at Mývatnssveit, northern Iceland, where the birch decline was gradual from landnám until about cal AD 1300 (Lawson et al. 2006, 2007). Also, thousands of charcoal pits have been located in Mývatnssveit through aerial survey and a series of pits were excavated and sampled in an area on a hill ridge at Hoskulsstaðir, 30 km inland halfway between Lake Mývatn and the coast (Church et al. 2006). Post-excavation analysis is still ongoing, but a single ^{14}C date of birch roundwood taken from the basal charcoal-rich fills of each pit (see Table 5) indicated a phase of woodland use from the early 11th to late 13th centuries cal AD.

Table 5 Conventional ^{14}C ages and $\delta^{13}C$ results for charcoal samples from Hoskulsstaðir charcoal pits. All samples were *Betula* sp. roundwood outer rings and bark. The dates were calibrated using OxCal v 3.10 (Bronk Ramsey 1995, 2001, 2005).

Measurement ID	Sample ID	Age ^{14}C yr BP	$\delta^{13}C$	Calibrated date AD (2 σ)
SUERC-8249	HOSK N CP1 C.11	925 ± 35	–29.0	1020–1190
SUERC-8341	HOSK N CP2 C.4	990 ± 35	–26.8	980–1160
SUERC-8342	HOSK N CP3 C.5	820 ± 35	–27.4	1160–1280
SUERC-8343	HOSK N CP5 C.4	890 ± 35	–27.4	1030–1220
SUERC-8344	HOSK N CP16 C.5	970 ± 35	–30.1	990–1160
SUERC-8345	HOSK N CP17L C.5	965 ± 35	–27.4	1010–1160
SUERC-8346	HOSK N CP17S C.24	945 ± 35	–30.1	1020–1170
SUERC-8350	HOSK N CP19 C.6	895 ± 35	–26.9	1030–1220
SUERC-8351	HOSK N CP23 C.7	935 ± 35	–26.8	1020–1180

CONCLUSIONS

A novel approach combining ^{14}C dating, tephrochronology, and sediment accumulation rate data within a Bayesian framework has increased the dating resolution normally possible for a series of charcoal production pits in Eyjafjallahreppur, southern Iceland. This approach has proved that charcoal can be used for dating archaeological sites in the North Atlantic, but only if the archaeobotanical taphonomy of the charcoal is fully understood.

Two phases of charcoal production and woodland exploitation have been demonstrated, the first within the first 2 centuries of settlement (about cal AD 870–1050) and the second phase more than 100 yr later (about cal AD 1185–1295). Archaeobotanical analysis of the charcoal sampled from the pits has indicated that birch roundwood was the dominant wood used, the roundwood was stripped from larger shrubs/trees in late spring/early summer, and certain sizes and ages of roundwood were harvested.

A model of phased woodland clearance in the area from about cal AD 870–1300 is presented that differs in nature and rate from the traditional deforestation model proposed for Iceland during the Norse and Medieval periods.

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REFERENCES

Anderberg A-L. 1994. *Atlas of Seeds: Part 4, Resedaceae–Umbelliferae*. Stockholm: Swedish Museum of Natural History. 281 p.

Ashmore PJ. 1999. Radiocarbon dating: avoiding errors by avoiding mixed samples. *Antiquity* 73(279):124–30.

Atkinson MD. 1992. *Betula pendula* Roth (B. *verrucosa* Ehrh.) and *B. pubescens* Ehrh. *Journal of Ecology* 80: 837–70.

Beijerinck W. 1947. *Zadenatlas der Nederlandsche Flora*. Wageningen: Veenman & Zonen. 316 p. In Dutch.

Berggren G. 1969. *Atlas of Seeds, Part 2, Cyperaceae*. Stockholm: Swedish Museum of Natural History. 107 p.

Berggren G. 1981. *Atlas of Seeds, Part 3, Salicaceae – Cruciferae*. Stockholm: Swedish Museum of Natural History. 260 p.

Bergþórrson P. 1996. Air temperature and plant growth. *Icelandic Agricultural Sciences* 10:141–64. In Icelandic with English summary.

Bronk Ramsey C. 1995. Radiocarbon calibration and analysis of stratigraphy: the OxCal program. *Radiocarbon* 37(2):425–30.

Bronk Ramsey C. 2001. Development of the radiocarbon program. *Radiocarbon* 43(2A):355–63.

Bronk Ramsey C. 2005. OxCal program v 3.10. http://www.rlaha.ox.ac.uk/oxcal/oxcal.htm.

Church MJ, Vésteinsson O, Einnarson Á, McGovern TH. 2006. Charcoal production pits at Hoskulsstaðir, Mývatnsveit. Unpublished report for the National Museum of Iceland, Durham University.

Church MJ, Peters C, Batt CM. 2007. Sourcing fire ash on archaeological sites in the Western and Northern Isles of Scotland, using mineral magnetism. *Geoarchaeology* 22(7):747–74.

Dickson CA. 1998. Past uses of turf in the Northern Isles. In: Coles G, Milles CM, editors. *Life on the Edge: Human Settlement and Marginality.* Oxford: Oxbow Books. p 105–9.

Dugmore AJ. 1989. Tephrochronological studies of Holocene glacier fluctuations in southern Iceland. In: Oerlemans J, editor. *Glacial Fluctuations and Climatic Change*. Dordrecht: Kluwer Academic Publishers. p 37–55.

Dugmore AJ, Buckland PC. 1991. Tephrochronology and late Holocene soil erosion in south Iceland. In: Maizels J, Caseldine C, editors. *Environmental Change in Iceland: Past and Present*. Dordrecht: Kluwer. p 147–59.

Dugmore AJ, Erskine CC. 1994. Local and regional patterns of soil erosion in southern Iceland. In: Stötter J, Wilhelm F, editors. *Environmental Change in Iceland, Münchener Geographische Abhandlungen* Reihe B, Band B12. p 63–79.

Dugmore AJ, Newton AJ, Larsen G, Cook GT. 2000. Tephrochronology, environmental change and the Norse settlement of Iceland. *Environmental Archaeology* 5:21–34.

Dugmore AJ, Church MJ, Buckland PC, Edwards KJ, Lawson I, McGovern TH, Panagiotakopulu E, Simpson IA, Skidmore P, Sveinbjarnardóttir G. 2005. The Norse *landnám* on the North Atlantic islands: an environmental impact assessment. *Polar Record* 41(1): 21–37.

Dugmore AJ, Church MJ, Mairs K-A, Newton AJ, Sveinbjarnardóttir G. 2006. An over-optimistic pioneer fringe? Environmental perspectives on medieval settlement abandonment in Þórsmörk, south Iceland. In: Arneborg J, Grønnow B, editors. *The Dynamics of Northern Societies*. Copenhagen: National Museum of Denmark. p 333–44.

Einarsson T. 1961. Pollenanalytische Untersuchungen zur spät-und postglazialen Klimagesch Islands. Sonderveröffentlichungen des Geologischen Institutes der Universität Köln, 6. 52 p. In German.

Einarsson T. 1963. Pollen analytical studies on the vegetation and climate history of Iceland in Late and Post-Glacial times. In: Löve A, Löve D, editors. *North Atlantic Biota and Their History.* Oxford: Pergamon Press. p 355–65.

Grönvold K, Óskarsson N, Johnsen SJ, Clausen HB, Hammer CU, Bond G, Bard E. 1995. Ash layers from Iceland in the Greenland GRIP ice core correlated with oceanic and land sediments. *Earth and Planetary Science Letters* 135(1–4):149–55.

Hallsdóttir M. 1987. Pollen analytical studies of human influence on vegetation in relation to the landnám tephra layer in southwest Iceland [PhD dissertation]. Lund: Lundqua Thesis 18.

Hallsdóttir M. 1995. On the pre-settlement history of Icelandic vegetation. *Icelandic Agricultural Sciences* 9: 17–29. In Icelandic with English summary.

Hallsdóttir M. 1996. Frjógreining, Frjókorn sem heimild um landnámið. In: Grímsdóttir GÁ, editor. *Um Landnám á Íslandi*. Reykjavík: Fjórtán erindi. p 123–34. In Icelandic.

Hallsdóttir M, Caseldine CJ. 2005. The Holocene vegetation history of Iceland, state-of-the-art and future research. In: Caseldine C, Russel A, Harðardóttir J, Knudsen Ó, editors. *Iceland – Modern Processes and Past Environments*. London: Elsevier. p 319–34.

Kenward HK, Hall AR, Jones AKG. 1980. A tested set of techniques for the extraction of plant and animal macrofossils from waterlogged archaeological deposits. *Science and Archaeology* 22:3–15.

Kristinsson H. 1998. *A Guide to the Flowering Plants and Ferns of Iceland*. Reykjavík: Mál og Menning. 311 p.

Larsen G. 1996. Gjóskutímatal and gjóskulög frá tíma norræns landnáms á Íslandi [Tephrochronology and tephra layers from the period of Norse settlement in Iceland]. In: Grimsdóttir GA, editor. *Um Landnám á Íslandi, Radstefnurit V.* Reykjavík: Societas Scientarum Islandica. p 81–106. In Icelandic with English summary.

Lawson IT, Gathorne Hardy FJ, Church MJ, Einarsson Á, Edwards KJ, Perdikaris S, McGovern TH, Amundsen C, Sveinbjarnardóttir G. 2006. Human impact on freshwater environments in Norse and early medieval Iceland. In: Arneborg J, Grønnow B, editors. *The Dynamics of Northern Societies*. Copenhagen: National Museum of Denmark. p 375–82.

Lawson IT, Gathorne-Hardy FJ, Church MJ, Newton AJ, Edwards KJ, Dugmore AJ, Einarsson Á. 2007. Environmental impacts of the Norse settlement: palaeoenvironmental data from Mývatnssveit, northern Iceland. *Boreas* 36(1):1–19.

Long HC. 1929. *Weeds of Arable Land*. London: Ministry of Agriculture. Publication 61. 122 p.

Mairs K-A. 2003. Farm settlement and abandonment in Iceland: an analysis of human-environment interactions [MSc thesis]. Edinburgh: University of Edinburgh.

Mairs K-A, Church MJ, Dugmore AJ, Sveinbjarnardóttir G. 2006. Degrees of success: evaluating the environmental impacts of long-term settlement in south Iceland. In: Arneborg J, Grønnow B, editors. *The Dynamics of Northern Societies*. Copenhagen: National Museum of Denmark. p 365–74.

McGovern TH, Vésteinsson O, Friðriksson A, Church M, Lawson I, Simpson IA, Einarsson Á, Dugmore A, Cook G, Perdikaris S, Edwards KJ, Thomson AM, Adderley WP, Newton A, Lucas G, Edvardsson R, Aldred O, Dunbar E. 2007. Landscapes of settlement in northern Iceland: historical ecology of human impact and climate fluctuation on the millennial scale. *American Anthropologist* 109(1):27–51.

Ólafsdóttir R, Schlyter P, Haraldsson HV. 2001. Simulating Icelandic vegetation cover during the Holocene: implications for long-term land degradation. *Geografiska Annuler* 83A(4):203–15.

Pearsall DM. 2000. *Palaeoethnobotany: A Handbook of Procedures*. 2nd edition. San Diego: Academic Press. 700 p.

Schweingruber FH. 1990. *Microscopic Wood Anatomy*; *Structural Variability of Stems and Twigs in Recent and Subfossil Woods from Central Europe*. 3rd edition. Geneva: Swiss Federal Institute for Forest, Snow and Landscape Research.

Simpson IA, Vésteinsson O, Adderley WP, McGovern TH. 2003. Fuel resources in landscapes of settlement. *Journal of Archaeological Science* 30(11):1401–20.

Stace C. 1994. *New Flora of the British Isles*. 2nd edition. Cambridge: Cambridge University Press. 1165 p.

Sveinbjarnardóttir G. 1992. *Farm Abandonment in Medieval and Post-Medieval Iceland: An Interdisciplinary Study*. Oxford: Oxbow Monographs in Archaeology 17, 192 p.

Sveinbjarnardóttir G, Mairs K-A, Church MJ, Dugmore AJ. 2006. Settlement history, land holdings and landscape change, Eyjafjallahreppur, Iceland. In: Arneborg J, Grønnow B, editors. *The Dynamics of Northern Societies*. Copenhagen: National Museum of Denmark. p 323–33.

Sveinbjörnsdóttir ÁE, Heinemeier J, Gudmundsson G. 2004. ^{14}C dating of the settlement of Iceland. *Radiocarbon* 46(1):387–94.

van der Veen M, Fieller N. 1982. Sampling seeds. *Journal of Archaeological Science* 9(3):287–98.

Vinther BM, Clausen HB, Johnsen SJ, Rasmussen SO, Andersen KK, Buchardt SL, Dahl-Jensen D, Seierstad IK, Siggaard-Andersen M-L, Steffensen JP, Svensson A, Olsen J, Heinemeier J. 2006. A synchronized dating of three Greenland ice cores throughout the Holocene. *Journal of Geophysical Research* 111: D13102; doi:10.1029/2005JD006921.

Ward GK, Wilson SR. 1978. Procedures for comparing and combining radiocarbon age determinations: a critique. *Archaeometry* 20:19–31.

Wastl M, Stötter J, Caseldine C. 2001. Reconstruction of Holocene variations of the upper limit of tree or shrub birch growth in northern Iceland based on evidence from Vesturárdalur-Skíðadalur, Tröllaskagi. *Arctic, Antarctic, and Alpine Research* 33(2):191–203.

Zutter C. 1997. The cultural landscape of Iceland: a millennium of human transformation and environmental change [unpublished PhD dissertation]. Edmonton: University of Alberta. 239 p.