



Perspective of landscape change following early settlement (landnám) in Svalbarðstunga, northeastern Iceland

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A series of peat monoliths was collected from Hjálmarvík, Kúðá and Bægistaðir, three abandoned farm sites located on a transect extending from the coast to 18 km inland in the Svalbarðstunga region (northeastern Iceland) in order to document the impact of human occupation and patterns of land use on landscape change and vegetation. Svalbarðstunga is of considerable interest because of the geographical and ecological features that distinguish it from other regions of Iceland, in particular by the more direct influence of the cold East Greenland Current (EGC). Plant and insect macrofossils and diatoms identified in peat monoliths provided proxy indicators of human settlement and land use that in some cases corroborate, and in others expand upon, existing archaeological and historical dates. Based on the presence of ecofacts (calcined bones, fish bones and charcoal), synanthropic insects and some anthropogenic plant-indicators (e.g. weeds), we showed that there was a consistent occupation and use of the coastal site of Hjálmarvík since AD 970. At Kúðá, the scenario is quite different. Two periods of occupation or land use were identified: from prior to c. AD 960 to 1190 and from c. AD 1650 to 1870. In the 15th and into the 16th centuries, the decrease in the deposition of traces of fuel wastes around the inland farm sites (Kúðá and Bægistaðir) suggests that they were used much less frequently. The decline of such proxies for human occupation occurred shortly before the occurrence of the coldest conditions from the 16th to the 17th centuries as well as prior to the V1477 eruption, suggesting that these natural factors may not have been the primary or unique driver of changing modes of tenancy. A scenario of famine-related depopulation would have played a significant role in this decrease in the human impact on vegetation.

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The ecosystems of Iceland, like those of other islands in the North Atlantic (e.g. Greenland and the Faroes), have experienced major transformations over the last millennium. While the 'prime suspects' researched to date include climate change phenomena such as the Medieval Warm Period (MWP, AD 800 to 1250) and the Little Ice Age (LIA, AD 1300 to 1850, see Ogilvie 1992), the real impact of these climate changes at the local and regional scales remains an open question due to the parallel impact of Norse settlement beginning in the late 9th century. Environmental changes coinciding with Iceland's settlement appear to have been complex with respect to spatial scale and timing. Iceland's colonization itself was a rapid process; recent research suggests that essentially all of the territory suitable for settlement was settled in a matter of generations between c. AD 874 and 1000, prior to the end of the MWP (Vésteinsson & McGovern 2012). The first wave of Norse settlers selectively occupied sheltered areas near Iceland's coast and in major fluvial basins in order to gain access to grazing areas in coastal lowlands and to exploit significant marine and freshwater resources (fish, marine mammals, birds and certain plant communities) (Vésteinsson 2000). The warmer and drier climate conditions during the MWP favoured the production of grass and hay, which, as fodder, were essential foundations of the Norse

subsistence economy built around animal husbandry and dairying. The need for fodder steered the efforts of the first settlers to manage the environment in order to promote the growth of grasses, sedges and weed species.

From the 14th century until the 19th century, the scale and density of settlement in Iceland varied significantly, as did the manner and intensity of land use. These changes were related to the influence of the most challenging weather conditions of the historical period (Ogilvie & Jonsson 2001), as well as a series of catastrophic events with severe demographic, social and economic consequences (Karlsson 2000; Vésteinsson *et al.* 2002) and a subsequent demographic expansion. Perhaps the most significant of these factors were two devastating plague epidemics in AD 1402–1404 and 1494–95, each of which killed approximately half the island's population and left many regions depopulated over generations (Streeter *et al.* 2011).

The effects of climate change and natural events (e.g. volcanic activity) on the landscape have been studied in several research projects (e.g. Dugmore *et al.* 2006; McGovern *et al.* 2007). However, these studies have focused on regions of Iceland that are relatively sheltered from northern climatic influences (such as Þórsmörk, on the south coast) or that are defined by distinctive geographical and ecological features that are difficult to

apply to all of Iceland (such as at Lake Mývatn). Svalbarðstunga, located in the Þistilfjörður region (northeastern Iceland), is of considerable interest because its geographical characteristics differ from those of previously investigated areas. The Þistilfjörður region is highly vulnerable to northern climatic influences due to its direct exposure to the Greenland Sea and to its susceptibility to cold water and sea ice carried by the East Greenland current (EGC) that flows along Iceland's northern coast (Ólafsdóttir *et al.* 2010). This region is also unique because of its distinct geography. Heath and peatland have been prevalent for the past 3000 years, primarily at the base of a set of glacial valleys in the western portion (Karlsdóttir *et al.* 2014; Roy 2017).

Recent archaeological research indicates that the Þistilfjörður region was also inhabited by the first wave of Norse settlers. In western Þistilfjörður, Svalbarð has been occupied continuously since at least the middle of the 10th century (Gísladóttir *et al.* 2013). Svalbarð was the principal farm of a sprawling, eponymous beneficium estate, whose settled territory extended approximately 20 km inland from the coast and included a dozen satellite client farms. Given that it represents almost 1000 years of land use and management practices, the region is an excellent location for conducting palaeo-environmental studies into human–environment interrelationships in a region with a distinctive set of vulnerabilities (namely, the proximity to cold currents on the northern side of the Island) and advantages (such as wet soils and marine resources).

This study investigates the environmental changes that occurred at three abandoned farms that were attached to the Svalbarð estate as client farms. Taken together, the three study sites (Hjálmarvík, Kúðá and Bægistaðir) comprise a transect that crosses environmental and ecological gradients extending from the coast to the more continental interior. This transect strategy provides a unique vantage point on the human–environment relationship underpinning a long history of settlement and land use in a distinctive and remote region of Iceland. By using a multidisciplinary methodology that combines the analysis of plant and insect macrofossils and diatoms with existing archaeological and palynological data, the present study aims: (i) to establish the chronology of human occupation based on the study of low-scale contributions of detritus to sediments and soils in inhabited areas; (ii) to measure the extent of floristic changes contemporaneous with those occupations; and (iii) to determine the extent and significance of human impact.

Study region

Environmental context of the Svalbarð farm study region

Svalbarðstunga is the local name for the drainage area between the Svalbarðsá and Sanðá Rivers (Fig. 1). The upstream portion of the Svalbarðstunga region is dom-

inated by glacial landforms such as drumlins and eskers, while debrisflows, debris avalanches, grassland and peatland characterize the downstream portions. Þistilfjörður is notably colder than southern and western Iceland. For example, the average annual temperature and precipitation in Reykjavík and vicinity are 5.2 °C and 830 mm, while in Raufarhöfn (which is located approximately 25 km north of Svalbarð) they are 2.6 °C and 780 mm for the period from 1931 to 2008 (Veðurstofa Íslands 2015).

Plant communities are dominated by sedges along the coast and diverse shrubs such as dwarf birch, dwarf willow and arctic willow in the inland region. Based on recent palynological data from Karlsdóttir *et al.* (2014) and Roy (2017), the local landscape was shaped by peatland and heathland long before the arrival of humans in the region. This region contrasts strongly with other areas in which birch was a key component of the vegetation (Dugmore *et al.* 2006; Lawson *et al.* 2007; McGovern *et al.* 2007). However, Svalbarðstunga is comparable to Ketilsstaðir, an exposed coastal location in southern Iceland, where the high-resolution pollen profiles of this exposed coastal location indicate a largely unwooded pre-settlement environment (Erlendsson *et al.* 2009). In this regard, the Svalbarðstunga study complements previous studies by adding a different environmental context and provides a better understanding of the richness and variety of the Icelandic landscape.

Settlement history of the study sites

As the region's early settlement is essentially undocumented in historical textual sources, most of what is known about the timing and process of settlement from the Viking to Medieval periods is provided by Gísladóttir *et al.* (2013, 2014); see also Amorosi 1992). Archaeological midden deposits at the sites of Svalbarð and Hjálmarvík that underlie the V1477 tephra layer provide evidence of an initial settlement of the region shortly prior to AD 930–940 (Gísladóttir *et al.* 2013, 2014; Sigurgeirsson *et al.* 2013). By c. AD 1300, all of the Svalbarðstunga region and substantial portions of neighbouring lands had been amalgamated into the estate of Svalbarð, the region's central farm, which was itself a beneficium of the Church (Gísladóttir *et al.* 2013). Historical records from the 14th to the 18th centuries identify seven smaller satellite farms that shared the outlying parts of the Svalbarðstunga territory and were tied to the Svalbarð estate through various property and clientage relationships, which persisted until the dissolution of the estate in the 19th century (Þormóðsson 1970). All of these small farms have been abandoned periodically in the past and only two remained in use into the late 20th century. Archaeological surveys have identified as many as five more ephemeral sites in Svalbarðstunga that served as very small farms or seasonal shielings used for pasturing herds and dairying

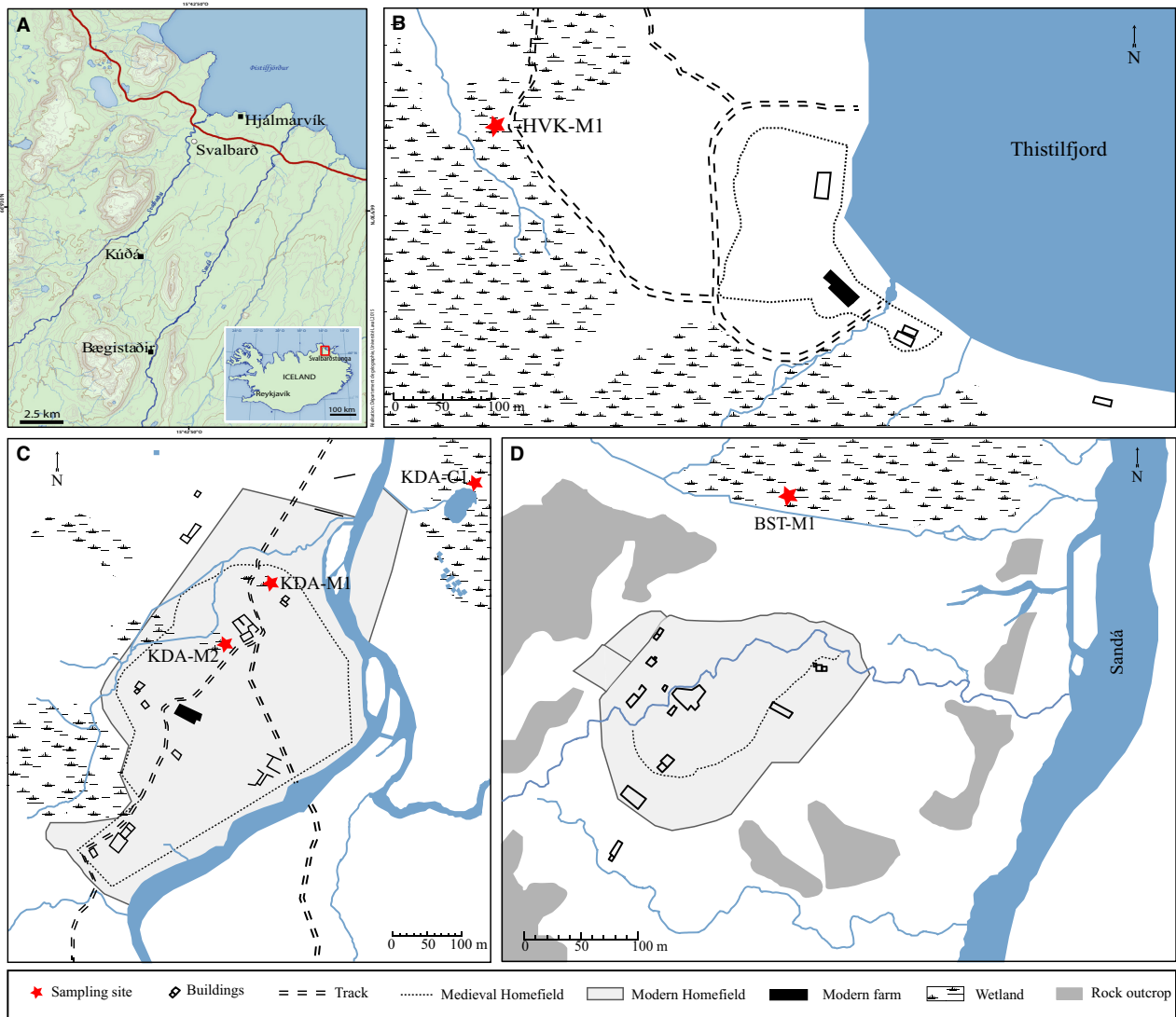


Fig. 1. Location of the Svalbarðstunga (A) and study sites of Hjalmarvík (B), Kúða (C) and Bægistaðir (D).

in summer (Gísladóttir *et al.* 2013, 2014). The Svalbarð central farm is currently the largest farm in the locality and one of the largest in Þistilfjörður. It appears to have been in constant use since the mid-10th century.

The present study focuses on the three satellite farms of Svalbarðstunga with the most substantial archaeological traces of occupation: Hjalmarvík, Kúða and Bægistaðir. Together, these sites form a transect stretching from the coast to 18 km inland and from 2 to 225 m a.s.l. The transect strategy offers an original perspective on land settlement and management on a regional scale from the beginning of occupation until the present day. These three sites all include notable farm mounds (tell-like accumulations of occupation debris in the built-up areas of farms) as well as well-preserved, fertilized and enclosed hayfields essential to the production of winter fodder. Kúða was chosen as the principal study site for

four reasons: the diversity of its immediate locale, which provided many promising sampling sites for various types of palaeoenvironmental records, the diversity of floral communities capable of serving as hayfield and pasture, the site's long settlement history and the fact that it was well preserved.

The Hjalmarvík site is located on the coast about 2 km north of Svalbarð and consists of a substantial farm mound over 20 m long, an enclosed hayfield and the ruins of historical and recent sheep houses (Fig. 1). It is situated close to the shore on a flat and wide terrace dominated by dry heathland and bog. The results of archaeological investigations demonstrated that the site was occupied prior to AD 940; the size of its farm mound and midden deposits indicate that while it was a significant farm site well into the Middle Ages, it dwindled in scale thereafter and had phases of abandonment in the

18th and 19th centuries. It is, presently, simply a pasture (Þormóðsson 1970; Gísladóttir *et al.* 2013, 2014; Ólafsson 2013). The farm mound itself was partially bulldozed in the 20th century, although portions of the farm mound dating to the 17th century and earlier remained intact, in addition to midden deposits dated to between the 10th and 19th centuries. The homefield and its walls also still exist. The middens and architectural ruins associated with the farm mound were the subject of archaeological investigations as reported in Gísladóttir *et al.* (2013, 2014) and Ólafsson (2013).

Kúðá is located approximately 12 km inland from the coast at an elevation of 120 m a.s.l. and about 10 km southwest of the Svalbarð farm (Fig. 1). The Kúðá farm site is situated on a hilltop in the middle of a glacial valley overlooking the Kúðá River. The archaeological ruins of the farmstead include a substantial farm mound, two farm houses, a number of outbuildings and an enclosed hayfield. Archaeological excavations of the farm mound revealed a pair of outbuildings that had been constructed one on top of the other, and overlying older midden deposits. The first was built sometime between the V-Sv 930 to 940 and H1300 volcanic ashfalls, and the second was built prior to the V1477 ashfall (Ólafsson 2013). These buildings were in use (probably with periodic rebuilding) until the 18th century. The building was subsequently abandoned and partially filled with 18th century midden deposits (Gísladóttir *et al.* 2013). Historical sources from 1712 note that Kúðá had been abandoned since AD 1672 except for 1694–1696, and that the farm's occupation remained episodic until AD 1814 (Þormóðsson 1970). The farm saw ongoing expansion and rebuilding during a phase of constant use between AD 1814 and 1966 (Þormóðsson 1970: p. 65; Gísladóttir *et al.* 2013, 2014). Ólafsson (2013) speculatively linked the 18th century abandonment phases to several volcanic events (notably the Laki 1783–84 eruptions) that depopulated other parts of Iceland and preceded the drastic depopulation of the Svalbarð region (Þormóðsson 1970).

The Bægistaðir site is located further inland, approximately 18 km from the coast and 15 km from Svalbarð, at an elevation of 225 m a.s.l. The site is located upstream of the glacial Sandá Valley and the surrounding area is characterized by glacial forms such as eskers, drumlins and kettles and periglacial forms such as hummocks, circles and polygons. It is built on a boggy alluvial fan deposited by a fast-flowing stream that drains an adjacent mountain in the Sandá River. The Bægistaðir site consists of a long farm mound approximately 40 m long with numerous turf-built ruins, well-preserved turf boundary walls, ditches, and several turf outbuildings (Gísladóttir *et al.* 2013). While the site has only seen exploratory excavations, it is clear that the site was occupied by AD 1300 and that a substantial amount of the farm mound was constructed at around that date. Construction appears to have ceased by the mid-15th

century, as the V1477 tephra is present in aeolian sediment covering these older structures (Gísladóttir *et al.* 2013, 2014). This suggests that the site was less intensively used if not abandoned in the 15th century, although charcoal fragments were observed in soil core tests immediately above the V1477 tephra. Most of the currently visible turf ruins relate to a relatively recent occupation and reconstruction of the site in the 19th and 20th centuries. Historical sources report it as having been abandoned for a considerable time prior to the mid-18th century, but it was reoccupied from AD 1830 to 1928 (Gísladóttir *et al.* 2013, 2014).

Material and methods

Soil sampling

Four peat monoliths (KDA-M1, KDA-M2, BST-M1 and HVK-M1) were extracted by hand and sampled for stratigraphical, macrofossil (plants and insects) and diatom analyses as well as radiocarbon dating.

Monoliths KDA-M1 and KDA-M2 were extracted approximately 10 m north and 15 m west of the homefield close to the Kúðá ruins (Table 1, Fig. 1). Both monoliths are 50 cm long and were examined for macrofossil content and insect remains. Diatom analysis was also performed on the KDA-M1 monolith in order to complete the profile of macro-remains and to test whether diatoms may provide additional information about human land use. Their location south of the ruins of the old turf house served as a trap for ecofacts. This choice of sampling location near the ruins of the house increased the likelihood of obtaining the first anthropogenic signals in the landscape immediately surrounding the Kúðá farm (Gísladóttir *et al.* 2014).

The BST-M1 monolith is 30 cm long and was extracted from a paludified zone in the hayfield close to the homefield at Bægistaðir farm (i.e. 300 m away; Fig. 1). Bægistaðir is intersected by several small streams, ensuring that the site is relatively well drained, thus limiting the development of peat. The HVK-M1 monolith is about 27 cm long and was sampled from a peatland located in the hayfield about 350 m west of Hjálmarvík (Fig. 1). The Hjálmarvík homefield is vast and was carefully managed, which led to a disturbed accumulation of natural and anthropic materials in the immediate environment of the site. Monoliths BST-M1 and HVK-M1 were studied for their plant macrofossil content.

Macrofossil analysis

Macrofossil analysis was performed at 2-cm intervals following the protocol outlined by Bhiry & Filion (2001). Each sample consisted of 50 cm³ of sediment. Sediments were treated with a weak 5% aqueous KOH solution and boiled for a few minutes to deflocculate. The material was then wet-screened through a series of sieves (850, 425 and

Table 1. Detailed information about peat monoliths (name, location, altitude, distance from the sea, depth and type of analyses conducted on them).

Sites	Monolith code	Monolith coordinates	Altitude (m a.s.l.)	Distance from the sea (km)	Monolith depth (cm)	Type of analyses
Hjálmarvík	HVK-M1	66°13'24"N, 15°39'11.45"W	5	0.3	27	Plant macrofossils
Kúðá	KDA-M1	66°07'32"N 15°46'39.8"W	120	12	50	Plant macrofossils Insect macrofossils Diatoms
	KDA-M2	66°07'29"N 15°46'30"W	120	12	50	Plant macrofossils Insect macrofossils
Bægistaðir	BST-M1	66°04'19"N 15°45'50"W	225	18	30	Plant macrofossils

180 µm mesh). Macrofossils were identified under binocular and light microscopy. References used to identify the plant remains included Montgomery (1977), Porsild & Cody (1980), Crum & Anderson (1979, 1980), Ireland (1982) and the collection at the Centre d'études nordiques (CEN), Université Laval. The macrofossils of vascular plants are expressed as number of macrofossils per 50 cm³ of sediments. For mosses, the percentage of each species was determined based on a subsample of 100 leaves. Insect remains were recovered from the KDA-M1 and KDA-M2 monoliths while sorting for plant macrofossils. Insects were identified through comparison with modern reference specimens of Icelandic insects and with the aid of entomological publications (Séguy 1944; Lindroth 1969; Bousquet 1990). Macrofossil (plant and insect) diagrams were constructed using Paleo Data Plotter software (Juggins 2002).

Diatom analysis

Diatom analysis was performed at 2-cm intervals on peat monolith KDA-M1 extracted from the Kúðá site. For each level, between 0.035 and 0.05 g of lyophilized sediment was processed following the procedures outlined by Pienitz (2001) (i.e. chemical treatment with HCl 10%, and H₂O₂ 30%). Microspheres of known volume and concentration were added to each sample before preparation to calculate diatom concentration. A minimum of 300 diatoms were counted in each sample. The identification of diatoms was completed with reference

guides from the Aquatic Paleoecology Laboratory at CEN (e.g. Antoniadis 2008; Bathurst *et al.* 2010). Diatom diagrams were drawn using Paleo Data Plotter software (Juggins 2002).

Dating: radiocarbon and tephra deposits

Seven samples consisting of decomposed plant remains, leaves of brown mosses or charcoal were dated using accelerator mass spectrometry (AMS) at CEN's radiocarbon laboratory and the Keck Laboratory at the University of California, Irvine (UL-KIU) (Table 2). Dates were calibrated using the Calib 6.0 program (Stuiver *et al.* 2011) and midpoints were obtained using the weighted median method (Telford *et al.* 2004; Stuiver *et al.* 2011). Results are presented in calibrated years as well as in AD/BC notation. In addition, tephra deposits were used as stratigraphical and chronological marker levels to correlate peat sequences across Svalbarðstunga (Lane *et al.* 2014). Tephra H4, H3, V-Sv 940, H1300 and V1477 were identified and compared with tephra identified in the laboratory by Magnús Á. Sigurgeirsson (Gísladóttir *et al.* 2014). The prefix 'c.' before a date (such as 'c. AD 1840') indicates that the date has been extrapolated using the depth-age relationship. We acknowledge that, these extrapolated dates are approximate, but they provided a useful time frame for the occupation or abandonment of the study sites. We also used these dates to compare our data with the data in the historical and archaeological archives.

Table 2. Radiocarbon and calibrated ages of the samples from the archaeological sites.

Sites	Samples	Lab. number	Age (a BP)	Age (cal. a BP) (2σ)	Age (AD/BC) (2σ)	Midpoint calibrated age (AD/BC)	Dated material
Kúðá	K-M1 (12–13 cm)	ULA-4435	20±20	–	–	Modern	Brown mosses
	K-M1 (24–25 cm)	ULA-4438	950±20	796–875	AD 1080–1150	1100	Charcoal
	K-M1 (36–37 cm)	ULA-4050	995±30	900–960	AD 990–1050	1030	Charcoal
	K-M2 (18–19 cm)	ULA-4440	235±20	280–310	AD 1640–1670	1660	Charcoal
	K-M2 (30–31 cm)	ULA-4439	930±20	790–910	AD 1040–1160	1100	Charcoal
	K-M2 (46–47 cm)	ULA-4452	1340±20	1260–1300	AD 650–690	670	Plant pieces
Hjálmarvík	HVK-C1 (15–16 cm)	ULA-4453	190±20	140–220	AD 1740–1810	1770	Plant pieces
Bægistaðir	B-M1 (29–30 cm)	ULA-4454	475±20	500–530	AD 1420–1450	1430	Plant pieces

Results and interpretation

Macrofossil (plants and insects) and microfossil (diatoms) data from Kúðá plant and insect remains from monolith KDA-M1

Based on the macrofossil (plant and insect) assemblages from the K-M1 monolith, three macrofossil zones were distinguished: M-I, M-II and M-III (Fig. 2).

Zone M-I: 50–39 cm (before AD 1030). – Zone M-I accumulated before AD 1030 and consists of a silt layer that is rich in organic matter. This zone is characterized by highly decomposed organic material and the presence of wood fragments. No identifiable plant or insect remains were found. Such characteristics are indicative of well-drained local conditions and the humification of plants by means of natural oxidation.

Zone M-II: 39–7 cm (AD 1030–c. 1760). – At first sight, zone M-II appears to be dominated by macrofossils related to human land use as it contains many ecofacts. It is composed of highly decomposed orange peat and was subdivided into three subzones: M-IIa, M-IIb and M-IIc.

Subzone M-IIa accumulated at a depth of 39–23 cm between c. AD 1030 and 1160. This subzone is discernible by the abundance of ecofacts and the presence of outdoor insect fauna. Ecofacts found in this subzone included charcoal, burnt bones and fish bones, indicating human occupation of the site at this time. Some of the insect remains were identified as beetles, specifically *Patrobus* sp. and *Otiorhynchus nodosus* (O.F. Müller). The genus *Patrobus* is typically found in open environments on moist soils (Lindroth 1969). Two species are present in Iceland: *Patrobus atrorufus* (Ström) and *Patrobus septentrionis* (Ólafsson 1991). *P. atrorufus* is today only found in the southernmost parts of the island (Larsson & Gíjga

1959), while *P. septentrionis* is very common in Iceland and is found in wet meadows and homefields. *Otiorhynchus nodosus* is commonly found in Iceland in dry biotopes such as grasslands and heaths (Larsson & Gíjga 1959).

Only a few plant macrofossils were identified. *Stellaria media* seeds were found, which is a species that is frequently found on fertilized soils and is usually associated with animal faeces (commonly found along sheep paths; Kristinnsson 2010). Spores of *Selaginella selaginoides* were also found, which is commonly found in pastures and heaths in Iceland (Erlendsson et al. 2009).

Subzone MII-b is approximately 8 cm thick (23–15 cm) and consists of highly decomposed organic peat and the 2-cm-thick V1477 tephra. It contains very few identifiable macrofossils and no ecofacts were found.

Subzone M-IIc accumulated at a depth of 15–7 cm. This subzone is composed of moderately decomposed brown peat and is characterized by a greater number of ecofacts such as charcoal fragments, burnt bones, and animal and fish bones. Moreover, there are seeds from *Montia fontana*, a plant species that usually colonizes habitats disturbed by humans (Blondeau & Roy 2004) in addition to wet areas in natural settings (Payette 2015). Some remains of synanthropic insects such as *Aphodius lapponum* Gyllenhal, *Atomaria* sp. and *Latridius minutus* (gr.) (L.) were also identified. These insects are all connected to human activities. According to Larsson & Gíjga (1959), Buckland et al. (1991) and Forbes (2013), *Atomaria* sp. and *L. minutus* are associated with mould on plant matter and are common in decaying hay in farm buildings (Buckland et al. 1991; Forbes et al. 2016). *Aphodius lapponum* lives in open environments and is dependent on livestock, as it breeds on the dung of large herbivores such as sheep, horses and cattle (Larsson & Gíjga 1959).

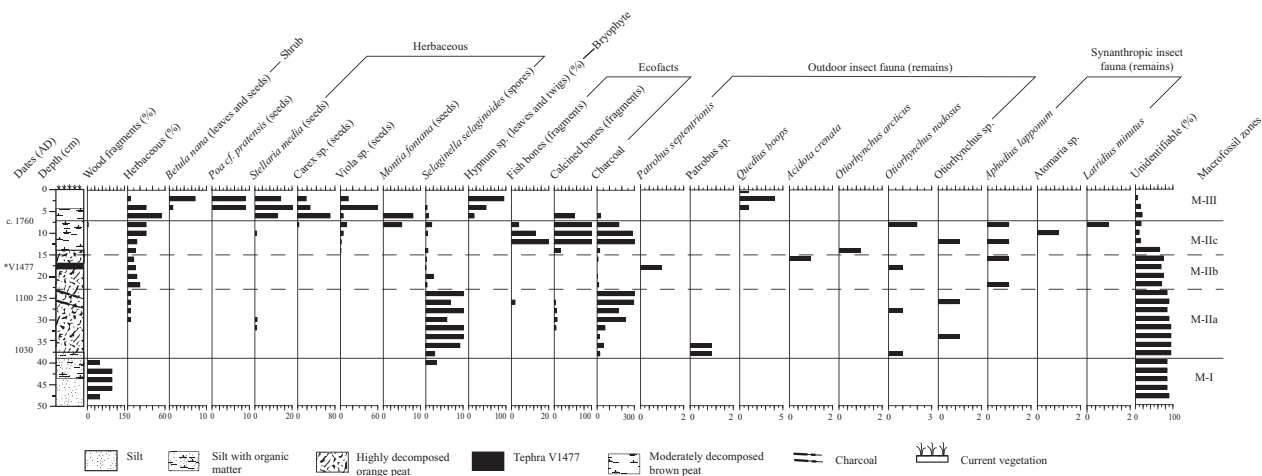


Fig. 2. Macrofossil (plants and insects) diagram of the KDA-M1 monolith sampled at Kúðá (number of macrofossils per 50 cm³).

Zone M-III: 7–0 cm (c. AD 1760–present). – Zone M-III consists of a moderately decomposed brown peat and the current vegetation. This zone is notable for having a greater diversity of species. The remains of *Betula nana*, *Viola* sp. and *Carex* sp. were found. In addition, seeds of *Stellaria media* and *Poa* cf. *pratensis* were identified, which suggests that the soil had been disturbed. In Iceland, both of these plants are known to grow on fertilized soil such as that found at the homefield (Kristinsson 2010). The outdoor rove beetle *Quedius boops*, which lives in a variety of outdoor habitats in Iceland, was also identified (Larsson & Gíjja 1959).

Diatoms from Kúðá: Monolith KDA-M1

Four zones were identified based on changes in the composition of the diatom assemblages: D-1, D-2, D-3 and D-4 (Fig. 3). Zones D-2 and D-4 were further divided into subzones using cluster analysis in Rioja package within R (R Development Core Team 2008; Juggins 2016).

Diatom species appear in the diagram according to the degree to which they require a wet environment (Fig. 3). Five groups were differentiated: Group 1 includes species that rarely live outside of water (aquatic species); Group 2 includes species that primarily live in water, but which may also be found in humid zones (subaquatic species); Group 3 includes species that primarily live in water, but which are often found in humid zones (hygrophilous species); Group 4 includes species that primarily live in humid zones, but which are also found in well-drained conditions; and Group 5 includes aerophilous species that live on temporarily wet substrates.

Zone D-1: 48–39 cm (before AD 1030). – Zone D-1 is mainly characterized by acidophilic taxa, such as *Pinnularia notabilis* Krammer, *Chamaepinnularia krookii* Grunow and *Chamaepinnularia mediocris* Krasske. These taxa are regularly found in wet areas as well as in temporarily dry areas (Group 4). The first two species are often associated with brown mosses and oligotrophic environments (Lange-Bertalot & Genkal 1999). However, no brown moss remains were found, which could be explained by the high degree of decomposition of the organic matter. Some species belonging to Group 3 (e.g. *Nitzschia acidoclinata* Lange-Bertalot, *Brachysira brebissonii* Ross and *Pinnularia microstauron* Ehrenberg) were also present. The presence of *Encyonema lunatum* (W. Smith) Van Heurck and *Eunotia praeurupta* Ehrenberg at the base of this zone (both of which belong to Group 3) is indicative of a favourable ecological context that was well oxygenated, low in organic matter and low in nutrients (Van Dam *et al.* 1994). Their disappearance in the second half of the zone could indicate a deterioration of the environment, as these species are sensitive to pollution (Bey & Ector 2013b). Such deterioration could be caused by the addition of organic matter, such as household waste, which would have been extrinsic to the original environment.

Zone D-2: 39–23 cm (AD 1030–c. 1160). – Zone D-2 includes an abundance of species that live at different moisture levels. Using Coniss software, the zone was divided into subzones D-2a, D-2b and D-2c.

Subzone D-2a is characterized by the establishment of taxa that proliferate in circumneutral water such as

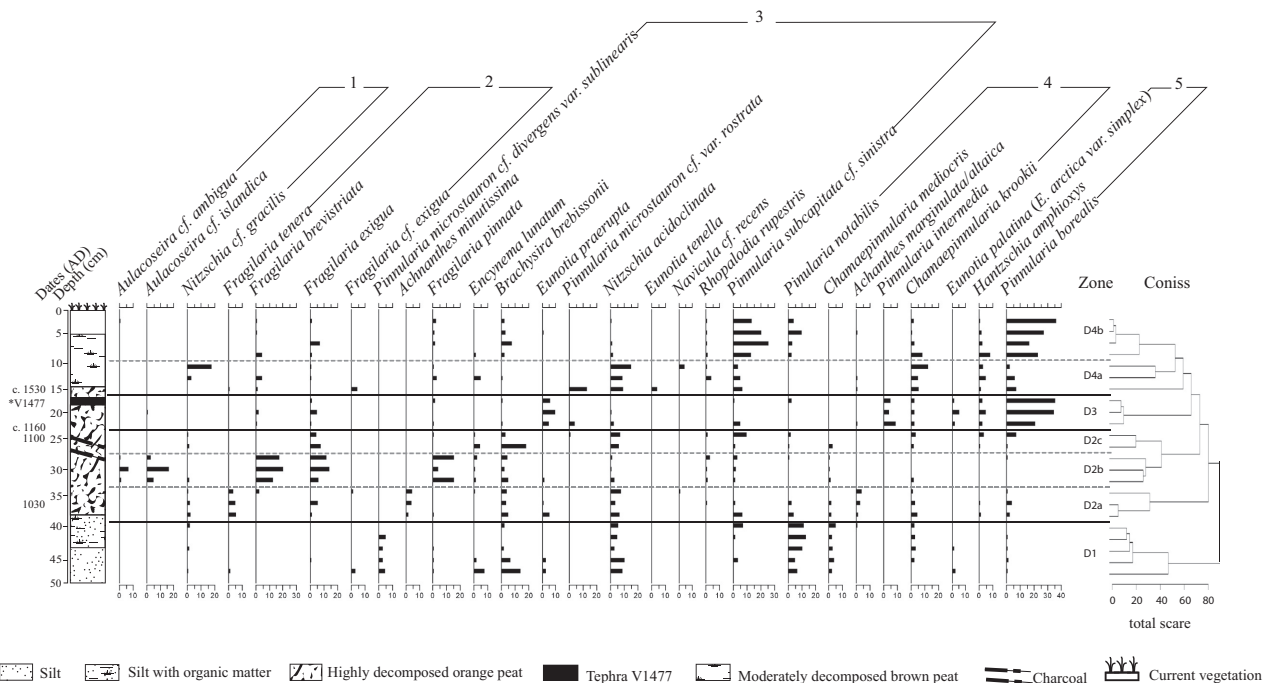


Fig. 3. Diatom diagram of the KDA-M1 monolith sampled at Kúðá.

Fragilaria tenera (W. Smith) Lange-Bertalot and *Fragilaria exigua* Grunow (from Group 2) and by the decline of taxa that are linked to drier conditions. These Group 4 taxa include *P. notabilis*, *C. krookii* and *C. mediocris*. *Achanthes minutissima* Kützing (from Group 3) was identified in this zone (and only here), which indicates a decrease in water quality and/or increased acidity.

Subzone D-2b is characterized by a higher proportion of planktonic diatoms, such as *Aulacoseira* cf. *ambigua* (Grunow) Simonsen (Bey & Ector 2013a) and *Aulacoseira* cf. *islandica* (O. Müller) Simonsen. According to Van Dam *et al.* (1994), both taxa are rarely (if ever) found outside of a body of water (Group 1) and their presence indicates an increase in the water level. The presence of *Meridion circulare* (Greville) C.A. Agardh, which is usually found in riverine (lotic) ecosystems, supports this interpretation and could reflect the warmer and wetter conditions of the MWP (Fukumoto *et al.* 2012).

In subzone D-2c, the reappearance of *Pinnularia* sp. and *Chamaepinnularia* sp., combined with the reduction (or absence) of *Aulacoseira* sp. and *Fragilaria* sp., suggests a gradual return to an acidic environment rich in macrophytes but low in minerals (Rühland *et al.* 2000). In addition, the presence of *B. brebissonii* and *E. lunatum* supports this interpretation. These are both acidophilic species belonging to Group 3 that are usually found in oligotrophic environments (Van Dam *et al.* 1994; Bey & Ector 2013c, e). At the edge of this subzone, freshwater taxa such as *Aulacoseira* sp. and *Fragilaria* sp. decreased or disappeared in favour of aerophilic species from Group 5 such as *Pinnularia borealis* Ehrenberg and *Hantzschia amphioxys* (Ehrenberg) Grunow.

Zone D-3: 23–15 cm (c. AD 1160–1530). – Zone D3 is composed of highly decomposed and orange peat and contains the V1477 tephra layer between 18 and 16 cm. This zone is characterized by a decrease in species diversity and abundance. The majority of identified species (such as *E. praerupta*, *Pinnularia intermedia* (Lagerstedt) Cleve & Grunow and *C. krookii*) normally live in wet or temporarily dry environments (Group 4). However, the most abundant species are aerophilic (*P. borealis*, *H. amphioxys* and *Eunotia palatina* Lange-Bertalot & W. Krüger), which could be an indication of the volcanic activity that triggered the deposition of the V1477 tephra. A diverse range of conditions must have existed: aerobic (*P. borealis*), semi-aquatic habitats or fens (*E. palatina*) and temporarily dry habitats (*H. amphioxys*) (Bey & Ector 2013c). Krammer & Lange-Bertalot (1986–1991) noted that *H. amphioxys* colonizes dry environments that have transitory wet conditions. There was also a sharp increase in *P. borealis*, which suggests a decrease in the availability of water at the site (Pienitz 2001). The disappearance of *N. acidoclinata* also supports this interpretation.

Zone D4: 15–0 cm (c. AD 1530–present). – Zone D-4 was subdivided into two subzones: D-4a and D-4b. Subzone D-4a differs from the previous zone due to the disappearance of *E. palatina* (Group 5), *P. intermedia* (Group 4) and *Eunotia praerupta* (Group 3) and the reestablishment of many taxa such as *C. krookii* that are associated with temporarily submerged moss habitats (Lange-Bertalot & Genkal 1999). This zone is also marked by an increase in β -mesosaprobic taxa, which suggests that aquatic environmental conditions were moderately productive and slightly oxygenated (*Nitzschia* sp.). The presence of alpha-mesosaprobic taxa, which live in water polluted by organic matter (such as ash or household waste) and that is low in dissolved oxygen (*H. amphioxys* and *Navicula* cf. *recens*), indicates a degradation of the environment due to human disturbance. According to Bey & Ector (2013d), *Navicula* cf. *recens* can tolerate conditions with high nutrient concentrations and moderate organic matter loads. Subzone D-4b is dominated by taxa that primarily belong to Group 5, such as *P. borealis* and *H. amphioxys*. Frustules from *Pinnularia subcapitata* cf. *sinistra* Gregory were also found in high percentages (up to 20%) in addition to frustules from *F. exigua* and *B. brebissonii*. At the same time, many of the taxa identified in subzone D-4a had disappeared or significantly declined. These results suggest a change in the hydrological state of the site toward drier conditions. This interpretation is also supported by the dominance of the aerophilic species *P. borealis* (Pienitz 2001).

Macrofossil remains (plants and insects) from monolith KDA-M2

Three macrofossil zones were identified based on changes in the macrofossil assemblages: M-I, M-II and M-III. M-II was further subdivided into three subzones: M-IIa, M-IIb and M-IIc (Fig. 4).

Zone M-I: 50–43 cm (AD 670–c. 780). – Zone M-I is composed of brownish highly decomposed peat. Consequently, identifiable plant remains are very scarce, but some brown moss leaves and herbaceous fragments were detected. In addition, seeds from herbaceous species such as *Carex* sp., *Stellaria media* and *Poa* cf. *pratensis* were found, which suggests that the environment was open and moist (Porsild & Cody 1980).

Zone M-II: 43–7 cm (c. AD 780–1840). – This zone is composed of highly decomposed and oxidized brownish peat overlain by moderately decomposed brownish peat. The abundance of ecofacts at different levels in this zone provides striking evidence of human occupation of the site and/or land use activities.

Subzone M-IIa is characterized by the abundance of charcoal as well as by seeds of *Selaginella selaginoides*, a species that is usually found in pastures and dry

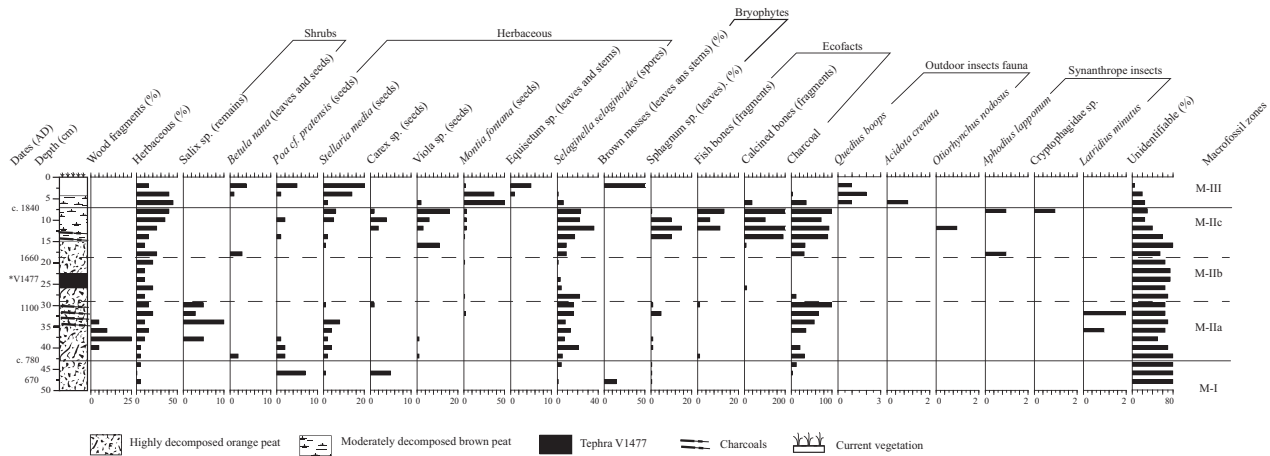


Fig. 4. Macrofossil (plants and insects) diagram of the KDA-M2 monolith sampled at Kúðá (number of macrofossils per 50 cm³).

heathlands in Iceland (Kristinsson 2010), but which can also be found in wet environments (Porsild & Cody 1980). The presence of *Sphagnum* sp. is another sign of wet conditions. Seeds from weeds such as *S. media* and *Poa* cf. *pratensis* were also identified. *Poa* cf. *pratensis* is an early colonizer of disturbed habitats (Aiken *et al.* 2007). While it is typically found in well-drained and fertilized areas, it can also be found in moist soils and peatlands (Kristinsson 2010). *Stellaria media* grows on cultivated fields and pasture soil (Porsild & Cody 1980). Remains of *L. minutus*, a synanthrope indicative of decaying plant matter (Forbes *et al.* 2016), were also identified.

Subzone M-IIb accumulated between *c.* AD 1380 and 1660 and contains the V1477 tephra layer. This zone is almost devoid of identifiable plant and insect remains. It contains only a few fragments of herbaceous roots and a few spores of *S. selaginoides*.

Subzone M-IIc (*c.* AD 1660–1840) is marked by greater species diversity and a greater number of ecofacts and taxa that correspond to human land use. In fact, fragments of charcoal are abundant alongside calcined bones and fish bones. The area surrounding the study site was probably used as pasture, as is shown by the presence of *S. media*, *Poa* cf. *pratensis* and *M. fontana*. Small quantities of beetle specimens were also identified. *Acidota crenata* (F.) and *O. nodosus* are both outdoor species inhabiting grasslands, pastures and heaths. The presence of *A. lapponum*, Cryptophagidae sp. and *L. minutus* is notable as these taxa are synanthropic in Iceland and therefore connected to human activity (Larsson & Gíjja 1959).

Zone M-III: 7–0 cm (*c.* AD 1840–present). – This zone is formed by a moderately decomposed brown peat and contains no ecofacts. However, the abundance of seeds from some herbaceous species suggests that the site (and its surroundings) may have been used for pasture. In

addition, the disappearance of *Sphagnum* sp. indicates a change to a less humid environment.

Macrofossils from Hjálmarvík (HVK-M1)

Monolith HVK-M1 is 27 cm thick and consists of a highly to moderately decomposed fibrous light brown peat that is inserted into the V1477 tephra layer (at 20–22 cm). Three macrofossil zones were identified based on the assemblages of plant remains: M-I, M-II and M-III (Fig. 5).

Zone M-I: 27–22 cm (*c.* AD 970–1477). – Zone M-I contains mostly unidentifiable herbaceous remains and wood fragments. It is dominated by brown moss leaves (*Hypnum* sp.), which indicates that the area was open and wet. This interpretation is supported by the few identifiable plant remains that were found, such as shrubs (*Juniperus* sp. and *Empetrum nigrum*) (which may explain the scarcity of wood fragments) and *Poa* cf. *pratensis* (Kristinsson 2010). These taxa are also found in homefields and fertilized areas along with *Viola* sp. (Porsild & Cody 1980; Kristinsson 2010).

Zone M-II: 22–15 cm (from AD 1477 to 1770). – The base of this zone includes the V1477 tephra layer. Almost no identifiable plant remains were found except for a few wood fragments, some herbaceous remains and a few brown moss leaves.

Zone M-III: 15–0 cm (AD 1770–present). – This zone is marked by a greater diversity of plant species, although herbaceous species (30–50%) and brown mosses (10–30%) continued to dominate. *Carex* sp. and *S. selaginoides* were also found in zone M-III, both of which are usually encountered in heathland and pasture (Kristinsson 2010). However, they may also be found in bogs, along the shores of streams and ponds,

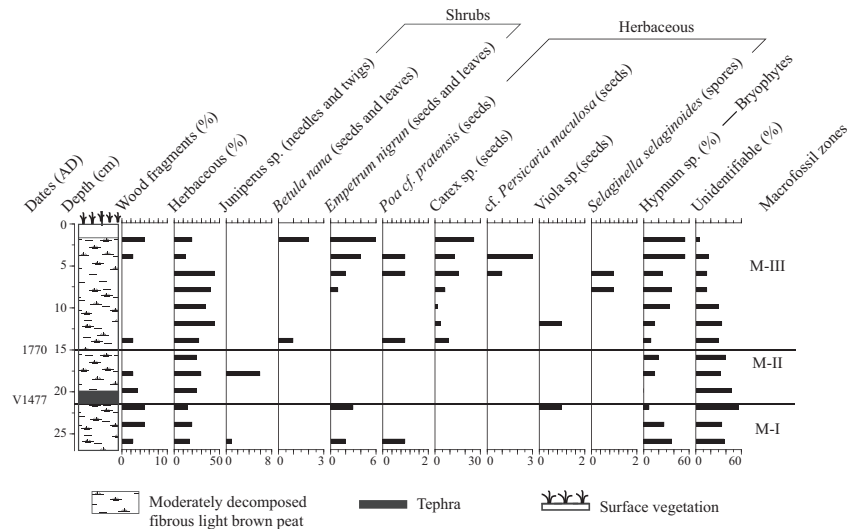


Fig. 5. Macrofossil diagram of the HVK-M1 monolith sampled at Hjalmarvík (number of macrofossils per 50 cm³).

and in grasslands (Porsild & Cody 1980). At the end of this zone, brown mosses (55%) continued to dominate the plant assemblage at the expense of herbaceous species (10–20%).

Macrofossils from Bægistaðir (BST-M1)

The BST-M1 monolith is 30 cm long. We were not able to reach the mineral–peat transition during sampling because of the highly compact character of the peat. As a result, the onset of peat accumulation was not documented. Three macrofossil zones were identified based on the assemblages of plant remains: M-I, M-II and M-III (Fig. 6).

Zone M-I: 30–15 cm (c. AD 1430–1470). – Zone M-I consists of a highly decomposed brown peat that accumulated between c. AD 1430 and 1470. Herbaceous remains (roots, rootlets and stems) dominate the assemblage and only a few identifiable pieces of *Poa cf. pratensis*, *Viola sp.*, *S. selaginoides* and *Carex sp.* were found. As noted above, the first three taxa typically grow in wet conditions, as does *Sphagnum sp.*, which was also found here. *Poa cf. pratensis* and *S. selaginoides* are also found in grassland and pasture. The recovery of many calcined bone fragments and charcoal fragments suggests that the site was inhabited during this period. The relatively rapid peat accumulation (an increase in thickness of 15 cm over

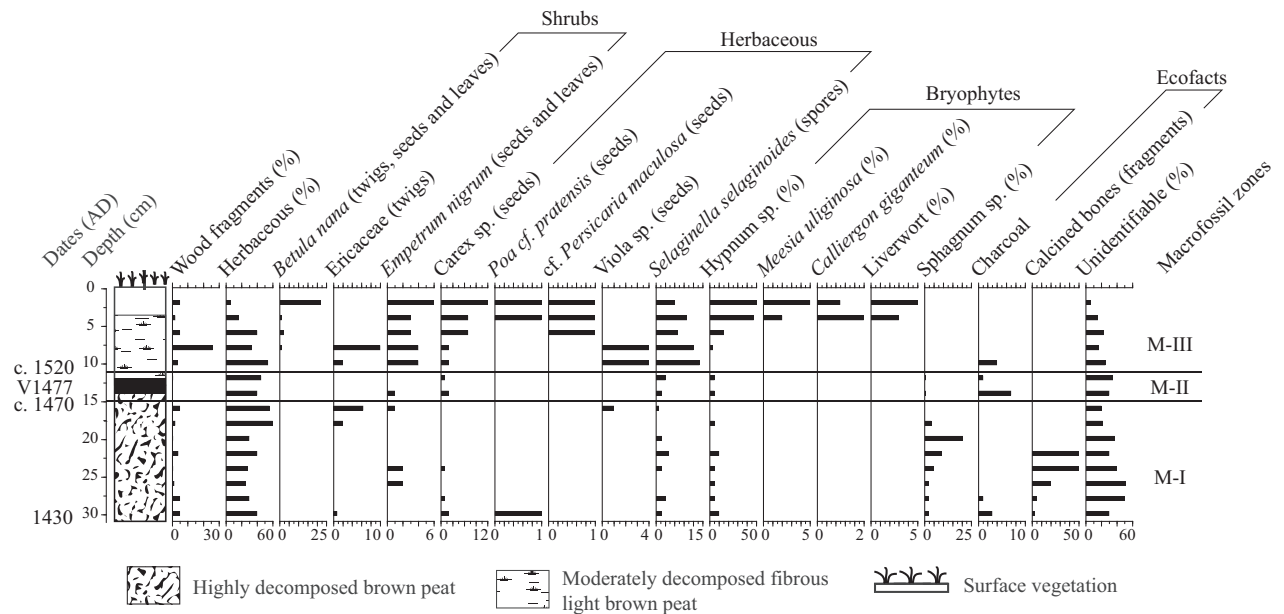


Fig. 6. Macrofossil diagram of the BST-M1 monolith sampled at Bægistaðir (number of macrofossils per 50 cm³).

40 years) could be explained by the frequency of ecofacts.

Zone M-II: 15–11 cm (c. AD 1470–1520). – Zone M-II consists of a highly decomposed brown peat and includes the V1477 tephra deposit (12–14 cm). As was true for all of the monoliths, recognizable macrofossils were uncommon: only few remains from *E. nigrum*, *Viola* sp., *Hypnum* sp. and some charcoal fragments were identified.

Zone M-III: 11–0 cm (c. AD 1520–present). – Zone M-III consists of recent, moderately decomposed fibrous light brown peat. There is a great diversity of shrub species (*B. nana*, Ericaceae and *E. nigrum*) and herbaceous species (*Carex* sp., *P. cf. pratensis*, *Viola* sp., and *S. selaginoides*), but the numbers are low. The sharp increase in *Hypnum* sp. and the establishment of *Meesia uliginosa*, *Calliergon giganteum* and liverwort bryophytes indicate wetter conditions. At the end of this zone, a new species, cf. *Persicaria maculosa*, appeared in the assemblage. In the United Kingdom, this taxon is regarded as a weed that lacks a natural habitat and is always associated with human activity (Simmonds 1945).

Discussion

Human settlement and land use activities and climate change

After examining the ecofacts, specific taxa and synanthropic insects, it was possible to identify four main

periods during which there were significant variations in the intensity of occupation and land use at Hjálmarvík, Kúðá and Bægistaðir (Fig. 7).

First period: AD 940–1400. – The macrofossil data indicate that the coastal site of Hjálmarvík has been an open and wet area, such as a wet meadow or peatland, since AD 970. There are some indications that the area surrounding Hjálmarvík was also altered by human activities during this period. Of particular interest is the presence of *Poa cf. pratensis* and *S. selaginoides*, which are known to grow in homefields, fertilized areas or pasture land in Iceland. *Selaginella selaginoides* is also known to grow on disturbed areas, such as pasture, rather than boggy environments (Erlendsson *et al.* 2009). A palynological study conducted by Roy (2017) showed that the vicinity of Hjálmarvík was composed of peatland and heartland since about 3000 cal. a BP. Furthermore, it revealed that at around AD 970 there was a sharp increase in Poaceae pollen and the establishment of anthropogenic plant-indicators such as *Polygonum cf. aviculare* and *Calluna vulgaris* (Zutter 1997). Ongoing archaeological surveys have also found that the site has been settled since AD 940 (Gísladóttir *et al.* 2014). Thus, taken together, the data highlight the beginning of consistent occupation and land use activities since AD 970.

During this same period at Kúðá, the vegetation included herbaceous species that are frequently found in grasslands, heaths and pastures. In particular, there was a sharp increase in *S. media* seeds in the macrofossil assemblages beginning at approximately AD 960. Accord-

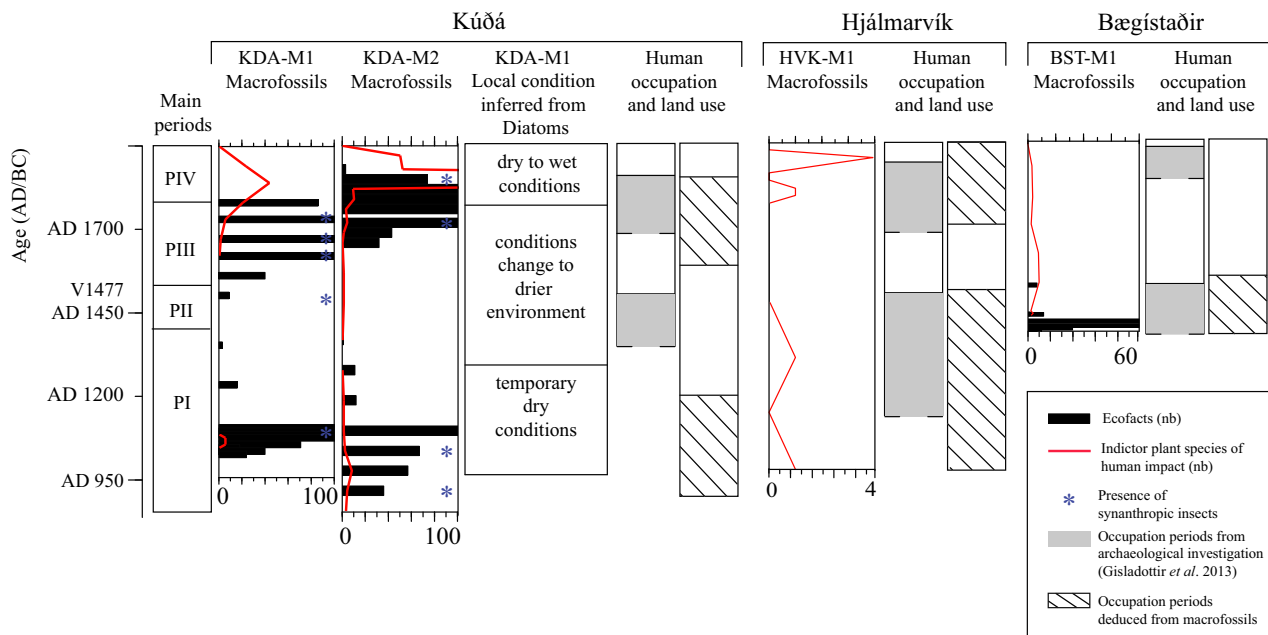


Fig. 7. Correlation diagram for the last 1000 years – summary of macrofossil (plants and insects) and diatom data from Hjálmarvík, Kúðá and Bægistaðir and archaeological data used to reconstruct human occupation and land use activities across Svalbarðstunga.

ing to Edward *et al.* (2005), the presence of the weed *S. media* is consistent with deliberate attempts to improve the fertility and drainage of the soil by means of manuring and plaggening. At approximately AD 1030, the diatom data also indicate hydric change to a slightly wetter environment, which is supported by the presence of *P. septentrionis*, a ground beetle associated with humid meadow-like biotopes (Larsson & Gíjgia 1959; Gudleifsson 2005).

Strongly synanthropic insects such as the mould-feeder *L. minutus* and the dung beetle *A. lapponum* were introduced by the Norse, with the latter being commonly found inside buildings in Iceland (Larsson & Gíjgia 1959; Forbes *et al.* 2016). Their presence serves as additional evidence that Kúðá was occupied during this period.

In Iceland, the Norse are known to have used wet meadows and environments rich in sedges and grasses to produce an adequate fodder (Vésteinsson *et al.* 2002). The increase in herbaceous macrofossils (as found in this study) and herbaceous pollens (as found in Roy 2017) suggests that there was deliberate human intervention to encourage sedge growth for pasture development at Kúðá. Synanthropic beetles recovered from Kúðá would probably have been introduced to the site by the Norse, as was suggested by findings elsewhere in the North Atlantic islands (Larsson 1959; Buckland *et al.* 1991; Sadler 1991; Sadler & Skidmore 1995; Buckland 2000). The same species were also identified in Svalbarð and Hjalmarvík by Forbes (2013). When viewed together, the insects found in this study can be used as chronological indicators for the initiation of human settlement at Svalbarð. However, it would be necessary to carry out a more extensive collection of insect data in a separate palaeo-entomological study at locations external to the archaeological sites in order to track insect fauna changes before and after the arrival of humans. Such a study would provide valuable data that would complement the present study.

Given our findings, it appears that human settlement at Kúðá began *c.* AD 960, which is almost as early as at Hjalmarvík (AD 940). This initial occupation period ended at *c.* AD 1190. This early date for the settlement of the interior may be explained by the easier access to the land due to the absence of birch forest and the availability of pastures. The natural landscape was already dominated by peatland and heath, both of which are good resources for grazing. Accordingly, this natural context probably attracted settlers towards the interior. Several signs of hay production and/or grazing also suggest that the site was used as a farm, a shieling or a summer farm house, although there is no archaeological or historical evidence of human settlement and activity at Kúðá as early as the 10th century.

Second period: AD 1400–1500. – In the monoliths extracted from the Kúðá and Hjalmarvík sites, no identifiable macrofossils (plants or insects) or ecofacts

were found for this period (which also includes the eruption of V1477). This suggests that the farm may have been uninhabited (see below). Nevertheless, a different pattern was observed at Bægistaðir further inland. Our findings indicate that the monolith included waste such as charcoal from the archaeological site between AD 1430–1460 and AD 1480–1560. On the other hand, archaeological data indicate that Bægistaðir was inhabited between AD 1300 and 1477 (Gísladóttir *et al.* 2013).

Third period: c. AD 1500–1800. – At Kúðá, the abundance of ecofacts (calcined bones, fish bones and charcoal) indicates that the land was used by humans. This interpretation contrasts with existing historical records and archaeological findings, which indicate that the site was only occupied between the 13th and the late 15th centuries and from the 18th century until 1960 (Þormóðsson 1970; Gísladóttir *et al.* 2013).

The lack of evidence of anthropogenic features such as artefacts and historical records between AD 1650 and 1870 suggests that Kúðá could have been used as a summer house or a shieling for the main farmhouse at Svalbarð instead of a farm in its own right. This interpretation could explain the fact that the occupation of Kúðá was not mentioned in the land register of 1712 (Þormóðsson 1970). The occupation and land use at Kúðá during this period may have been limited by the cold and dry conditions of the LIA (Massé *et al.* 2008; Sicre *et al.* 2008; Wanner *et al.* 2008). Cryoturbation features have been identified in the upper part of the Svalbarð midden (above the V1477 tephra; Zutter 1997). These features occurred mostly in unconsolidated sediment that was transformed by the deep seasonal frost (French 2007). The harsh climate conditions after AD 1477 would have presumably limited the growing season and negatively affected the capacity for fodder production, as the ground would have been frozen for a much longer period.

Farms such as Kúðá and Bægistaðir were characterized in the historical literature as marginal highland settlement areas because of their high elevation (120 and 200 m a.s.l., respectively) and their poor sustainability. According to Rafnsson (1990), Sveinbjarnardóttir (1992), Vésteinsson & McGovern (2012) and Vésteinsson *et al.* (2014), these high-altitude farms had been abandoned as early as the 13th century and early 14th century in Iceland. Farm abandonment was possibly linked to climate fluctuations, especially as highland settlements are more vulnerable to changes in climate that affect the length of the growing season and the number of days of snow cover, which may prevent grazing. On the other hand, Mairs *et al.* (2006) have demonstrated that in areas where woodland cover was already sparse (or absent) at the time of settlement (as was true of the sites in this study), resilience to grazing by domestic animals may have been greater despite the less favourable ecological conditions. Given that the landscape of Svalbarðstunga was devoid of

birch forest before the arrival of the Norse, the study by Mairs *et al.* (2006) provides an explanation for the continuity of land use at the beginning of the LIA (13th and 14th century) at Bægistaðir and Kúðá, even though marginal highland farms were typically abandoned elsewhere in Iceland. However, the data collected in the present study indicate that there was an abandonment of the farms (or at least some significant changes in land use) in the late 16th century. Weather conditions seem to have been colder at that time, as shown by the pollen data from Kúðá and Hjalmarvík (Roy 2017). At Bægistaðir, the expansion of *E. nigrum* and Ericales, taxa that are commonly found in Icelandic pollen diagrams post-settlement (Erlendsson *et al.* 2009), could reflect the abandonment of the farm in the mid-16th century.

Fourth period: AD 1800–today. – Our macrofossil and microfossil data suggest that the Kúðá site was impacted in significant ways during this period, while the other sites were abandoned.

Changes in vegetation linked to anthropogenic activities and volcanic eruption

Many studies have shown that palaeoenvironmental studies can supplement or offer a new dimension to the chronology constructed by archaeological data (Gauthier *et al.* 2010; Lemieux *et al.* 2011; Massa *et al.* 2012; Roy *et al.* 2012, 2015). In our study, palaeoenvironmental records from archaeological sites (and their immediate vicinity) helped us to identify changes in the landscape and land use by identifying traces left by humans since the occupation of Svalbarðstunga.

Anthropogenic impact. – The palaeoecological data revealed that wood fragments (mostly from shrubs) were a significant component of the macrofossil remains before human occupation and declined afterwards, while herbaceous species increased. This change reflects the development of pasture land at the sites. The diatom data revealed that during this time (AD 800–1200), there was a general trend toward the warm and wet climate conditions typical of the MWP (Massé *et al.* 2008; Wanner *et al.* 2008). Furthermore, the occurrence of taxa such as *Pinnularia* sp. and *Chamaepinnularia* sp. indicates a gradual increase in nutrient concentration and acidity resulting from the addition of organic matter to the ecosystem. The Norse practice of spreading domestic ashes for use as a fertilizer is another example of an environmental pollutant that is reflected in the diatom data from the Kúðá homefield.

The impact of the Veidavötn 1477 volcanic eruption. – The tephra of Veidavötn 1477 (V1477) is evident across Svalbarðstunga. Its distribution and thickness require us to assess the major impact of the tephra on the landscape, especially with regard to vegetation growth. Eruptions

are common in Iceland: there have been approximately 205 since the settlement of Iceland (Thordarson & Larsen 2007). Occasionally, these eruptions have caused human and animal deaths as well as changes to the environment. For example, out-gassing from the Laki eruption in AD 1783 created a toxic haze that killed thousands of Icelanders as well as livestock, which contributed to an ensuing famine. The major eruptions at Hekla in AD 1300 and Örfajökull in AD 1362 may also have caused fatalities, but there is no direct evidence for this (Gudmundsson *et al.* 2008).

Despite its destructive effects, Dugmore *et al.* (2013) found that vegetation re-established itself only a few months following the eruption of Eyjafjallajökull in 2010. In addition, the impact of volcanic hazards would have been modulated and exacerbated by other factors, such as severe weather or economic constraints.

At Kúðá, no identifiable macrofossils (plants or insects) or ecofacts indicative of human activities were found for the period between *c.* AD 1190 and 1530, which suggests that the farm may have been abandoned. This could be explained by the combined impact of the eruption of V1477 and the severe climate conditions of the LIA. The diatom data from K-M1 also show a sharp increase in aerophilic species (*P. borealis*, *H. amphioxys* and *E. palatina*) at the beginning of the LIA. At Bægistaðir, the abandonment of the site seems to have occurred long after the V1477 at approximately AD 1560. Along the coast, the deposition of the V1477 tephra at the Svalbarð and Hjalmarvík sites seems not to have disturbed the use and occupation of the land. Thus, the deposition of the ash layer from the eruption of V1477 appears to have had very little impact on land use in Svalbarðstunga, except at the Kúðá site. Nevertheless, two plagues were identified in the documentary evidence between AD 1402–1404 and in AD 1494 in Iceland. These plagues had a severe impact on the northern region of the country (Karlsson 2000). In turn, the reduction in population size would have freed up lands in another regions.

While more traditional excavation-orientated archaeological research conducted to date indicates that the inland farms of Kúðá and Bægistaðir may have been in a period of contraction or dormancy (due to the apparent cessation of building activities), data collected in this study suggest that these farms had phases of episodic and/or ephemeral use, as indicated by the continued deposition of traces of fuel wastes around the farm sites in the 15th and into the 16th centuries. Notably, the decline of such proxies for human occupation occurred prior to the arrival of the coldest conditions of the 16th and 17th centuries, suggesting that climate may not have been the prime or unique driver of changing modes of tenancy. A scenario of famine-related depopulation could have entailed the use of Bægistaðir as an alternative to Kúðá or as part of sporadic re-colonization initiatives,

although this seems unlikely due to the isolation of the site and because of the more modest productivity of the latter farm in a colder environmental regime. Alternatively, evidence of the ephemeral use of farms in Svalbarðstunga's deep interior is perhaps linked to the availability of late season hay resources that could have been used in support of coastal farms that did remain in use. Summer shielings, autumn round-up camps, hay-cutting facilities and stations located along interior travel routes are all potential roles for cadres of temporary labour derived from coastal farms that could explain the consistent low level of activity seen at Kúðá and Bægistaðir.

Conclusions

Multiproxy records of peat monoliths sampled from the vicinity of the Hjálmarvík, Kúðá and Bægistaðir farms in northeastern Iceland supplied clear evidence of early human settlement and land use.

At Kúðá, the first signs of human settlement occurred at approximately AD 960, as revealed by the presence of charcoal, ecofacts and synanthropic insects. The vegetation changed in favour of pasture species such as *Stellaria media*, which would have been linked to human efforts to create grazing land and/or hayfields as early as c. AD 960. All of these indicators helped us to reconstruct the early settlement of the inland region of Svalbarðstunga, which appears to have occurred over a short period of time (perhaps only one generation). By contrast, Hjálmarvík and Svalbarð were settled earlier at around AD 940. At Hjálmarvík and Bægistaðir, the macrofossil data also allowed us to document the occupation period and land use activities that had been identified in the archaeological and historical records.

The combination of palaeoecological data with archaeological and historical data made it possible to document the history of human occupation in Svalbarðstunga. The present study also showed that changes in land use, volcanic eruptions and climate variations triggered significant changes in the vegetation and landscape. This was particularly evident in the period spanning 1477 and 1850, which included both a volcanic eruption (during the LIA) and a significant period of land occupation illustrated by changes in vegetation and the increase in ecofacts and synanthropic insects.

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