ScARF Scottish Archaeological Research Framework

Regional Archaeological Research Framework for Argyll

Chapter 4. Towards an Environmental History of Argyll and Bute



Prehistoric carvings at Evanachan, Cowal in an area with multiple cupmarked rocks © ScRAP and HES

Scottish Archaeological Research Framework

4. Towards an Environmental History of Argyll and Bute: A Review of Current Data, Their Strengths and Weaknesses and Suggestions for Future Work

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SCARF Scottish Archaeological Research Framework

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4.1 Introduction

For the purposes of the framework, Inland Waters include freshwater environments such as lochs, major rivers, and canals and navigations. By their very nature, inland waters are an integral part, and an extension of the maritime networks around our coasts and estuaries. In many cases aspects of the cultural fabric of Scotland's maritime identity emanates from contact between communities located along our coasts to those situated along these inland 'arteries'. While it could be argued that these 'arteries' may be regarded more as terrestrial entities or classified within other areas of the archaeological discipline (such as industrial archaeology in the case of canals), the very nature of the resource, physically and culturally, displays very real synergy with the 'maritime' sphere; and in the case of lochs and rivers, the very medium that is under exploitation. Clear examples include the fact that many of the major bodies of inland water and canals are connected with the sea, such as Loch Tay and the Forth and Clyde and the Caledonian Canals; and in the case of the latter, are often incorporated into existing rivers and lochs.

Partially submerged sites comprise organic and inorganic structural remains, artefacts and ecofacts that can range in age from prehistoric to Medieval and later occupation sites. The large number of crannogs, island duns and other occupied islets across Scotland provides a huge potential for research over three millennia. Recent advances in dating techniques, theoretical approaches and fieldwork have demonstrated the importance of wetland archaeological remains.

In addition, these waterways were often developed for maritime purposes; the dock complexes developed at the coastal interfaces and the furnishing of local coastal trade through boat and shipbuilding on the Forth and Clyde Canal are but two examples. With this in mind, it is hoped that by including Inland Waters within this framework, the maritime sphere can begin a process of greater integration with other elements of the archaeological discipline.



Crannog in Loch Leathan, Argyll and Bute. © HES.

4.2 The Devensian Lateglacial period in Argyll and Bute

The last British–Irish Ice Sheet covered all of Argyll and Bute (Bradwell et al 2008a; Hubbard et al 2009). Current climatic models provided by high-resolution analyses of annual layers of ice in Greenland's ice-sheet (Lowe et al 2008; Rasmussen et al 2008) describe initial warming of the North Atlantic region at *c* 12700 cal BC. Much deglaciation occurred before this in a cold but dry climate. Chironomid assemblages suggest that mean July temperatures were lower than *c* 7.5°C before the Windermere Interstadial, before *c* 12350 cal BC and reached *c* 12°C after this (Turney, Harkness and Lowe 1997): coleopteran data (Coope et al 1998) suggest temperatures of *c* 18°C in Windermere Interstadial summers.

With warming, soils began to support vegetation and to store organic matter. Biological productivity increased in lake basins. Devensian Lateglacial pollen records in Argyll and Bute are depicted in Figure 17. They uniformly record the colonisation of, first, grasses, sedges and herbs of bare- and disturbed-ground character. A closed vegetation cover may have formed but comparative aridity maintained populations of plants we think of as coastal like sea plantain. Heathland developed rich in crowberry, a heather adapted to dry conditions. Juniper and birch migrated but a closed woodland cover probably did not form.

The earliest shorelines to be formed during deglaciation are found at altitudes of around 40m OD (Ordnance Datum) (Sutherland 1997) because the weight of the last British–Irish Ice Sheet forced the British Isles below contemporary



Figure 17: Map of Devensian Lateglacial and earliest Holocene pollen records © Richard Tipping: Barachander (Tipping 1989b); Drimnagall (Rymer 1977); Ford (Tipping 1989b); Inverliever (Tipping 1989b); Loch a' Bhogaidh (Edwards and Berridge 1994); Loch an' t–Suidhe (Lowe and Walker 1986); Loch Barnluasgan (Tipping 1989a); Loch Cill an Aonghais (Peglar in Birks 1980); Lon Glas (Tipping 1989b); Mishnish (Lowe and Walker 1986); Na Lona Min (Tipping 1986); Pulpit Hill (Tipping 1991).

global sea level, which itself reached 120m below present. With deglaciation, the land rose faster than the sea itself rose, leaving elevated shorelines. A calibrated 14C assay on the abandonment by the sea of one coastal basin in Knapdale at 31.3m OD of 15860–14820 cal BC is, if correct, the earliest for deglaciation in the region (Shennan et al 2006). At other localities in western Scotland, however, shorelines this high and higher are younger, *c* 13000 cal BC (Shennan et al 2006).

Temperatures declined throughout the Windermere Interstadial to around 11°C. Evidence from chironomids suggests three falls in mean July temperature of between 0.5 and 3 °C. Around 11950 cal BC mean July temperatures plummeted to below c. 7.5°C. Plant communities were destroyed. Periglacial conditions promoted heavy soil erosion and on steep slopes, talus or scree accumulated (Ballantyne and Kirkbride 1987; Dawson, Lowe and Walker 1987).

Sea level fell within the Windermere Interstadial. Some areas show the sequential fall over time, as on Oronsay (Jardine 1977), in Kilmartin (Gray and Sutherland 1977) and in the Mhoine Mhor (Peacock et al 1977). Shorelines eroded by the sea become more coherent and continuous. Contemporary shorelines are seen to fall in altitude from north east to south west (see Figure 2.1: Sutherland 1997) because the land around Rannoch Moor rose faster than land on Kintyre. A prominent shoreline, the Main Rock Platform, was mapped by Gray (1974, 1975, 1978) and Dawson (1984) falling from around 12m OD in inner Loch Etive to 0m OD around Campbeltown. This shoreline is thought to have formed in the periglacial climate of the Loch Lomond Stadial (Gray 1978).

Marine sediments relating to the higher sea-levels of the Windermere Interstadial have been recorded in a number of places, including the central valley of Bute, beneath Campbeltown and from the head of the tidal Loch Gilp at Lochgilphead to the entrance to the lower Add valley and under the Crinan Canal, and at South Shian (Peacock 1983, 1989; Peacock et al 1977). These are the Clyde Beds. They contain marine faunas that can define sea surface and deep water marine temperatures in the Devensian Lateglacial. Peacock (1983) estimated from modern analogues that in the early part of the Windermere Interstadial summer sea surface temperatures (SST) were close to present but some 3° C at 25m depth: winter SST was near freezing. Later, perhaps around 10800 cal BC, summer SST may have exceeded 13° C.

An ice sheet centred on Rannoch Moor re-formed towards the end of the Windermere Interstadial (Golledge 2006, 2010) or if like ice sheets further north, began to readvance (Bradwell et al 2008b). Valley glaciers advanced along Loch Etive to the confluence with Loch Linnhe (Gray 1995), down Loch Awe as far as Ford (Gray and Sutherland 1977; Tipping 1989b) and to the head of Loch Fyne (Sutherland 1984). A separate ice sheet formed on Mull (Ballantyne 2002) and a rock glacier emerged on Jura (Dawson 1977). Loch Lomond Stadial ice rucked up marine shells with an age around 9700 cal BC at the west end of Loch Creran (Peacock et al 1989) and incorporated organic mud just east of Loch Lomond at c. 10500 cal BC (Rose, Lowe and Switsur 1988). The climatic change to the Holocene epoch at around 9750 cal BC occurred in a matter of decades or a few years (Taylor et al 1993; Alley 2000).

4.3 Holocene climate change

Tipping et al (2013) have recently summarised the evidence for climate changes that are likely to have affected Scotland and the people living in it. The current paradigm is that climate in the past changed rapidly or even abruptly, as in the switch from the cold of the Loch Lomond Stadial to the warmth of the earliest Holocene, though infrequently (Mayewski et al 2004). Current reconstructions stress short 'moments of crisis' separated by long periods of stability or smaller climatic excursions. The rapidity of the crises gave little time for people to adapt, and prolonged stability meant that coping strategies will have been forgotten (Tipping 2005).

Mechanisms of change at slow temporal scales are the precisely rhythmic very long-term variations of the Earth round the sun, called Milankovitch cycles. At shorter temporal scales variations in solar activity are probably a key driver but feedback processes with many properties of the Earth's surface are complex. Periods of rapid climate change are re-organisations of the atmospheric circulation system, not simply changes in temperature or precipitation. The North American or Laurentide ice sheet, for instance, collapsed abruptly at *c* 6200 cal BC and altered global atmospheric circulation through its effect on North Atlantic Ocean circulation, probably shutting down the 'gulf stream'. Stager and Mayewski (1997) and Debret et al (2009) suggested that the present atmospheric circulation system only emerged with the collapse of this huge ice sheet. Before *c* 6200 cal BC weather charts, could people have plotted them, would have looked very different to today.

The west coast of Scotland experiences alternating cold-dry-still 'continental' weather when a blocking high pressure zone settles over the North Sea and the near-continent, and warm-wet-stormy weather from the Atlantic. Today, these alternate frequently, determined in large part by semi-periodic changes in the North Atlantic Oscillation (NAO), a term which describes the oscillating system of quasi-stable low pressure zones over Iceland and high pressure zones over the Azores. The NAO varies in strength, and our weather also varies because of this, but Trouet et al (2009) have suggested that the climate can get locked into one or other of these phases for very long periods. So the warm Middle Ages in north-west Europe, for example, have been seen as one 200-year or so period when westerly winds prevailed on a strong jetstream, with the subsequent 'little ice age' characterised by cold easterlies.

Tipping et al (2013) tried to summarise for archaeologists and historians the types of data being assembled to construct a new chronology of climate change relevant to Scotland. Charman (2010) summarised data for the British Isles and Swindles et al (2013) have assembled data for Ireland. Many data-sets are being generated from ocean and sea-loch sediment to the west of the Argyll coast because the North Atlantic Ocean is fundamental to understanding these patterns (below). No modern-standard terrestrial climate proxy records exist for the region. Undisturbed parts of the raised moss of the Moine Mhor are suitable for generating a proxy record of hydrological change in late prehistory and history (cf. Charman et al 2006), which could become important in linking the quite different records between Ireland and Scotland in the later Neolithic and Bronze Age (Swindles et al 2013). The invasion and demise of Scot's pine populations on blanket peat in prehistory on Rannoch Moor (Bridge et al 1990) are best interpreted as responses of these trees to hydrological change but detail is lacking. Scots pine trees preserved in peat bogs are, however, a critical data source for annually resolved palaeo-climatic records (Bridge et al 1990; Moir et al 2010).

Schematically, we might recognise the following periods of climatic deterioration as critical:

- Early Holocene climatic events include short-lived deteriorations in climate before *c* 9300 cal BC, at *c* 8350 cal BC and *c* 7550 cal BC (Bos et al 2007; Whittington et al 2015)
- The major early Holocene climatic reversal, the 8.2 ka event (Alley et al 1997; Alley and Ágústdóttir 2005) at *c* 6200 cal BC, had widespread, hemispheric impacts, felt intensely at the latitude of Argyll (Seppa et al 2007) and involved a temperature depression in parts of the North Atlantic of 2–3°C. North-west Europe was markedly more arid.
- From *c* 4400 cal BC until *c* 3800 cal BC a series of complex changes occurred at the Mesolithic-Neolithic transition (Bonsall et al 2002; Tipping 2010 but see Schulting 2012).
- Recent work has emphasised an event centred at *c* 3200 cal BC (Roland et al 2015).
- Many diverse analyses identify the period

2200–1800 cal BC as one of abrupt global climate change (Mayewski et al 2004) though Swindles et al (2013) argue for its weak expression in the eastern North Atlantic region.

- The early Iron Age *c* 800–500 cal BC, long seen as a period of marked climatic deterioration (Burgess 1985; Barber 1998; van Geel et al 1998; Charman 2010; Swindles et al 2013). Armit et al (2015) have recently questioned the impact of this event on societal change in Ireland.
- A 'Dark Age' climatic deterioration is recognised in some reconstructions centred on cal AD 500 (Swindles et al 2013)
- The 'little ice age' commenced at *c* cal AD 1400 and ceased by *c* cal AD 1850 and can be resolved as a series of short-lived climatic extremes: see Section 10.2 for a detailed analysis of the climate change from the Medieval Warm Anomaly to the 'Little Ice Age'.

4.4 Holocene coastal change

4.4.1 Holocene sea level change

This topic can appear remote to archaeologists but in Argyll and Bute it is critical, not just to early prehistorians but to later prehistorians and early historians. Shennan et al (2006) published the first detailed reconstruction for the region, in Knapdale (Figure 18). Their approach was to identify enclosed coastal basins at different altitudes and recognise the time they received estuarine and marine sediment from diatom and pollen analyses, and the time this sediment was replaced by terrestrial sediment (peat) as sea level fell.

Devensian Lateglacial sea level has been described above. Early Holocene shorelines will also have sloped because of differential uplift but we have few data points to reconstruct this gradient. Sea level is modelled to have fallen to -5m below present on Skye, to around 0m on Arisaig but to have remained above present tidal limits, around 2m above present in Knapdale (Shennan et al 2006) but empirical evidence for this at the sites analysed by Shennan et al (2006) is currently lacking. On Islay, Dawson, Dawson and Edwards (1998) date the lowest early Holocene RSL at around 0m OD to *c* 9350 cal BC, as Dawson et al (2001) do on northern Coll.

Dawson et al (1998) then describe a rapid Relative Sea Level (RSL) rise on Islay to 3m OD by *c* 7960 cal BC, slowing to c. 5m OD by the Neolithic period. On Oronsay, Jardine (1977) thought sea level reached *c* 7m OD before this time. Sequences on the Scottish west coast currently lack the chronological precision to test the suggestion (Clarke et al 2003) that the collapse of the Laurentide ice sheet caused a nearly instantaneous global RSL rise of around 1.4m.

In Knapdale this shoreline, the Main Postglacial Shoreline, reached *c* 11m OD (Shennan et al 2006) and *c* 10m OD on Arran (Gemmell 1973). Bonsall and Sutherland (1992) suggested that coast-facing caves in the Oban area occupied prior to the Main Postglacial Shoreline would have been eroded during RSL rise, thus seeming to shorten the duration of the 'Obanian' flint industry.

Dawson et al (1998) suggested that RSL levels remained high on Islay, above 4m OD until the late Iron Age, and a similar suggestion can be made for Coll (Dawson et al 2001) and, outside the region, for Skye (Selby 2004). This differs from the interpretation of Jardine (1977) on Oronsay for a 3m fall in the late prehistoric period and by Shennan et al (2006) in Knapdale who see RSL fall steadily *c* 11m OD at *c* 3500 cal BC to 3–4m OD by *c* cal AD 200. Smith et al (2007) construct a 14C-dated RSL curve for south west Scotland in which RSL continues to remain high (above 8m OD) until after *c* 2000 cal BC. They try to resolve the different interpretations by identifying a narrow zone in south west Scotland where the Main Postglacial Shoreline converges with a later shoreline, the Blairdrummond

Shoreline (Smith, Cullingford and Firth 2000), to maintain relatively high RSL, perhaps into the early historic period. This narrow zone crosses southern Kintyre and separates Islay from northern Kintyre, explaining the contrasts apparent in these two places (above), and straddles Mull (Smith et al 2007, Figure 8).

Reconstructing later prehistoric and early historic RSL change is thus a complex issue in Argyll and Bute, in which site-specific patterns override regional trends. Researchers should be aware of these subtleties in the use of RSL models, and the influence of local topographic settings on the expression of RSL. Radiocarbon dates anywhere in the British Isles on RSL change post-2000 cal BC are rare (Shennan and Horton 2002) but a site like Barr na Criche in Knapdale demonstrates that detailed reconstructions in this period are possible. Sutherland (1997) drew attention to the rare large coastal sediment stores of mid- and later Holocene age where 'unpicking' post-Neolithic RSL change would be feasible. These include the Machrihanish and Moine Mhor embayments. No work at Machrihanish is known to this author. Analyses of RSL change in the Moine Mhor (Haggart and Sutherland 1992) remain skeletal but the potential is enormous because the base of the peat falls from *c* 10m OD to *c* 2m OD, implying that basal peat formed at progressively later times as RSL fell. We do not know if it was possible to sail to the foot of Dunadd in the early Historic period.

There have been very few attempts in the region to depict in map form how coastal areas will have altered with RSL change, although this could greatly aid archaeological understanding of site distributions in the way exemplified in the Forth valley by Smith et al (2010). Dawson et al (1998) described the physical isolation of the Rhinns of Islay from the east of the island as RSL rose in the early Holocene. In the Moine Mhor, Winterbottom and O'Shea (2002) looked at the effect of a 10.0m OD RSL on Neolithic and early Bronze Age archaeological site distributions to great effect.



Figure 18: Map of sediment records of Holocene sea level change© Richard Tipping: Arran (Gemmell 1973); Coll (Dawson et al 2001); Gruinart, Islay (Dawson et al 1998); Knapdale (Shennan et al 2006); Moine Mhor (Haggart and Sutherland 1992); Oban (Bonsall and Sutherland 1992); Oronsay (Jardine 1977, 1987).

4.4.2 Coastline and marine changes

By this is meant change to our coastlines other than directly by sea level change. It embraces evidence for past coastal erosion and deposition and evidence for the abundances in the past of marine and littoral resources. Such evidence is fundamental to understanding the archaeology of Argyll and Bute in several ways.

Perhaps the least important aspect to this is in measuring the rate at which current coastal erosion and storm damage impact on coastal sites (Dawson 2003). The 'soft' dune and machair coasts of the islands are most vulnerable. There are coastal zone archaeological surveys for Coll, Tiree and Islay and Shorewatch programmes on Coll and Islay (ScAPE Trust). There are no surveys, to the authors' knowledge, of the exposed western Kintyre coastline and the dune system around Machrihanish, or of sensitive salt marsh environments at the heads of the Kintyre fjords and the Moine Mhor.

We know very little from the region about the environmental changes at the coast or offshore. The evidence and potential are there, however. Gerard Bond pioneered such research in identifying transport from the Arctic Ocean of 'armadas' of icebergs as far south as the Irish west coast periodically in the Holocene at *c* 9200, 8300, 7400, 6200, 3900, 2200 cal BC and *c* 600 cal AD (Bond et al 1997). Thornalley, Elderfield and McCave (2009) analysed fluctuating surface and deep-water temperature and salinity south of Iceland. Changes in either will have affected the abundance and locations of spawning and feeding grounds for fish populations. They recognise falling salinity from the start of the Holocene to *c* 6000 cal BC: the 6200 cal BC event freshened by 0.4psu the North Atlantic. Sea water was well mixed and fresh after this event for *c* 1000 cal years until *c* 5000 calBC. Salinity then increased to present values at c. 3000 cal BC. Rapid freshening set in after *c*2000 cal BC until this trend was reversed at *c* 1400 cal BC. Particularly warm and saline conditions occurred at *c* 3000 and 700 cal BC and at *c* cal AD1000, probably representing persistent westerly winds at these times. Marret, Scourse and Austin (2004) have described major changes to thermal stratification in the Celtic Sea between Ireland and Wales, with strong contrasts in seasonality inferred for the period *c* 4700 to *c* 1650 cal BC. In the sediments of Loch Sunart, Cage and Austin (2010) define with clarity the switch from the medieval 'warm' period to the 'little ice age' at *c* AD 1400. Annually and seasonally resolved climate signals from marine molluscs are being explored (Stott et al 2010; Wang, Surge and Mithen 2012).

Sand dune accumulation is a major information source. This is no longer seen to be a product of sea level change but as a product of abrupt climate change, and increased storminess in particular (Bjorck and Clemmensen 2004; Clarke and Rendell 2006; De Jong et al 2006; Orme, Davies and Duller 2015), so here we have a measure of sea conditions that were perhaps unpredictable enough to deter crossings. Dunes on the Outer Isles (Gilbertson et al 1999; Dawson et al 2004), in Wester Ross (Wilson 2002) and along the north Irish coast (Wilson, McGourty and Bateman 2004) have been analysed. There is periodicity rather than continuity in dune and machair accumulation, with phases of dune building *c* 4300–3800, 3200, 280–2400, 1400–1200 and 800–300 cal BC, and cal AD 850 and 1400–1800. But dating by 14C is restricted to periods of climatic stability and by optically stimulated luminescence untried on the west coast compared to their deployment on the north Scottish coast (Sommerville et al 2003, 2007; Tisdall et al 2013).

Winterbottom and Dawson (2005) attempted to locate archaeological structures buried by drifting sand on Coll by remote sensing and ground penetrating radar, as Astin has with Mithen (Mithen pers. comm.) but the recovery of archaeological remains from dune systems will always lead to partial chronologies of dune formation. Systematic dating programmes are badly needed.

Sediment-stratigraphic and biological RSL indicators tend to describe mean sea levels, not tidal or wave extremes. Jardine (1987) mapped a series of storm-beach gravel ridges on Oronsay, thought to be of mid-Holocene age, one at least perhaps 10m above contemporary mean sea level. Smith et al (2007) surveyed storm beach ridges probably dating to the mid-Holocene on the west and east coasts of Bute which reached up to 3m higher than contemporary mean sea level. The probable Mesolithic site of Croig (Canmore ID 233381) on Mull is protected by a large storm beach (Mithen pers. comm.) as is the Mesolithic site of Kilmore near Oban (Macklin et al 2000). Early Holocene storm beaches are deposited from a significantly lower sea level, of course. These kinds of observation are rare: there need to be more. Systematic mapping and dating of storm beaches would provide data, though biased to Devensian Lateglacial and post-4000 cal BC events, to infer past periods of increased storminess, the degree of exposure of particular parts of the coast and the modelling of wave extremes that may have been critical to travel by sea. Innovative approaches such as Andrews et al's (1987a) estimation of later Mesolithic storminess from dogwhelks is to be encouraged. These authors suggest the later Mesolithic to have been less stormy than today.

There is no substantiated method other than from archaeological analysis (Barrett, Nicholson and Ceron-Cerrasco 1999) for defining the presence or size of fish populations in near-shore or deep waters (Pickard and Bonsall 2004) but such analyses are bound to reveal more about food selection than availability and abundance. The same is true of analysis of marine shells (Connock, Finlayson and Mills 1993). Sediment-stratigraphic methods need to be developed, perhaps biochemically or from quantification of fish scales (Davidson et al 2003) to define the natural abundance of marine resources and their availability.

4.5 Holocene Terrestrial Change

4.5.1 Geomorphological change

Figure 19 shows the localities where something is known of physical changes in the Holocene to the landscape of Argyll and Bute: the number is distressingly small. We can divide this collection into analyses of colluviation (slope and soil erosion and subsequent re-deposition) and alluviation (fluvial erosion and deposition). The two can be closely linked.

4.5.1.1 Colluvial activity

Tipping et al (2011) obtained perhaps the most securely dated record of slope and soil erosion in Scotland at Torbhlaren in the lower Add valley. Peat forming on the valley-side above the floodplain received varying amounts of soil eroded from sandy glacio-marine terraces above. An alluvial fan on the slope began to form from *c* 7500 cal BC and in one colluvial record, colluviation also commenced within the Mesolithic period, at *c* 5110 cal BC. Despite being only a couple of hundred metres apart, the three dated sediment cores suggest that the phases of most intense soil erosion were diachronous. Sediment delivered at high energies to one borehole between *c* 4800 and *c* 4250 cal BC has no counterpart in an adjacent borehole, though comparable high-energy events might be recorded in both at *c* 3800–*c* 3200 cal BC and *c* 3550 and *c* 3400 cal BC. Further high-energy mineral sediment movement occurred between *c* 200 cal BC and *c* cal AD 50 and after *c* cal AD 700.

In the Oban region, Rhodes, Rumsby and Macklin (1992) and Macklin et al (2000) analysed soil erosion from geochemical signals. Rhodes et al (1992) report analyses for a range of elements at Gallanech Beg but with no discussion of the data while Macklin et al (2000) report only potassium (K) in three additional peat sequences at Lon Mor, Bhuilgh bhith and Cnoc Philip. They argue that soil erosion was greatest in the transition to



Figure 19: Map of records of Holocene geomorphological change © Richard Tipping: Carradale, Kintyre (Tipping et al 1994); Dalness Chasm, Glen Etive (Brazier et al 1988); Dunadd (Miller and Ramsay 2001; Housley et al 2004; Housley et al 2010); Islay (Cressey unpublished); Loch Etive (Howe et al 2002); Oban region (Rhodes et al 1992; Macklin et al 2000); Torbhlaren (Tipping et al 2011).

farming between *c* 3500 and *c* 2000 BC, but also in the same paragraph argue for soil stability between *c* 3600 and *c* 2000 cal BC. Finally, Cressey (unpublished) used geochemical signatures to trace the development of a medieval landscape at Lochs Finlaggan and Ballygrant on Islay.

In upper Glen Etive, the Dalness Chasm debris cone, a large fan-shaped sediment pile formed from eroded material high above, formed between earliest Holocene deglaciation and *c* 2200 cal BC. Around cal AD 1600 the clearance of hazel scrub by people, including by fire, is thought to have re-activated the lower slope of the fan by fluvial erosion (Brazier, Ballantyne and Whittington 1988) though the date of this reworking is coincident at least with the 'little ice age' (Ballantyne 1991). Innes (1983) argued that over-grazing of upland slopes since the late 18th century greatly increased talus and debris cone formation.

4.5.1.2 Fluvial activity

In Loch Etive itself, Howe et al (2002) described how terrestrial sediment sources have dominated sedimentation in this sea loch throughout the Holocene, with accelerating sediment accumulation rates in the last *c* 200 years originating, probably, from changing land use from, for instance, woodland management for the iron-smelting industry.

In and near Kilmartin Glen, Tipping et al (2011) described Neolithic and Bronze Age river development and channel change in the lower River Add at Torbhlaren. There was increased flood frequency/magnitude at around 2400

cal BC and major changes in river behaviour at *c* 1240 cal BC but unchanging channel dimensions through the Holocene suggest that discharge did not significantly vary.

To the west, Housley and co-authors 14C dated one of many peat-filled abandoned channels of the lower Add near Dunadd to the BC–AD boundary. No significance can be attached to this age estimate, though, without also dating other channels. The peat filling this channel was terrestrial (Miller and Ramsay 2001; Housley et al 2004; Housley et al 2010). It would be interesting to know the altitude of this channel in light of the discussion on early historic Relative Sea Level change (above) but this is not given.

Carter and Tipping (1991–2) and Tipping, Carter and Haggart (1994) mapped the terrace surfaces along the lower Carra Water on Kintyre. Most are related to glacial or relative sea level stages but the extensive Rhonadale Wood Terrace is fluvial. It began to accumulate between 4500 and 3500 cal BC when sufficient sediment from earlier-formed terrace fills or soils on slopes filled the river enough to promote frequent flooding and the creation of a floodplain. Its surface was abandoned by the river as it incised at some time in the last few hundred years.

These isolated reports are not nearly enough to write an informed history of landscape change. There is, perhaps, the suggestion that Neolithic colluviation and alluviation were significant, and this would be different to other regions of the British Isles but the evidence is limited. The region needs such a history because changes in human settlement and land uses are implied in the interpretations of some of these physical changes although abrupt climate change provides an additional strong hypothesis. It is very likely that geomorphic changes in the highlands and on steep slopes such as debris cone formation were climatic in origin (Ballantyne 2004) because pastoralism is likely to have made few impacts, but colluviation in lowland valleys as at Torbhlaren need not have been. Yet here Mesolithic and Neolithic colluviation occurred in the absence of evidence for major human activities in the pollen record (Tipping et al 2011). The prevailing paradigm in Holocene alluviation in the British Isles is also for a climatic causation (Macklin, Johnstone and Lewin 2005) but many case studies do not explore the timing or scale of human activities, biasing somewhat the conclusions. Where both hypotheses are equally appraised, human activity emerges as important. Argyll and Bute should provide an important testing ground for this debate.

4.5.2 Pedological change

There were three archaeological sites known to Donald Davidson and Stephen Carter in 1997 that allowed some assessment of soil type and land use quality in the past: An Sithean on Islay (Barber and Brown 1984), Cul a' Bhaile on Jura (Stevenson 1984; Whittington 1988) and at Achnacree (Soulsby 1976; Carter and Dalland 2005). At all three, soils had become acid podsols by the Bronze Age. Impoverished soils were probably the norm in Argyll and Bute in later prehistory. Nevertheless, An Sithean (Canmore ID 37374) and Achnacree contain two of the best-explored later prehistoric field systems in Scotland, though at An Sithean the system is less coherent than first appears (Barber and Brown 1984; Halliday 2015, 284). Beneath the Caisteal nan Gillean II shell midden on Oronsay, the soil was also acid and leached (Paul 1987). Barber (1981) argued that soils at the monastery of Iona were anthropic plaggen soils, a deliberate introduction as agricultural improvement: it would be good to test this idea further.

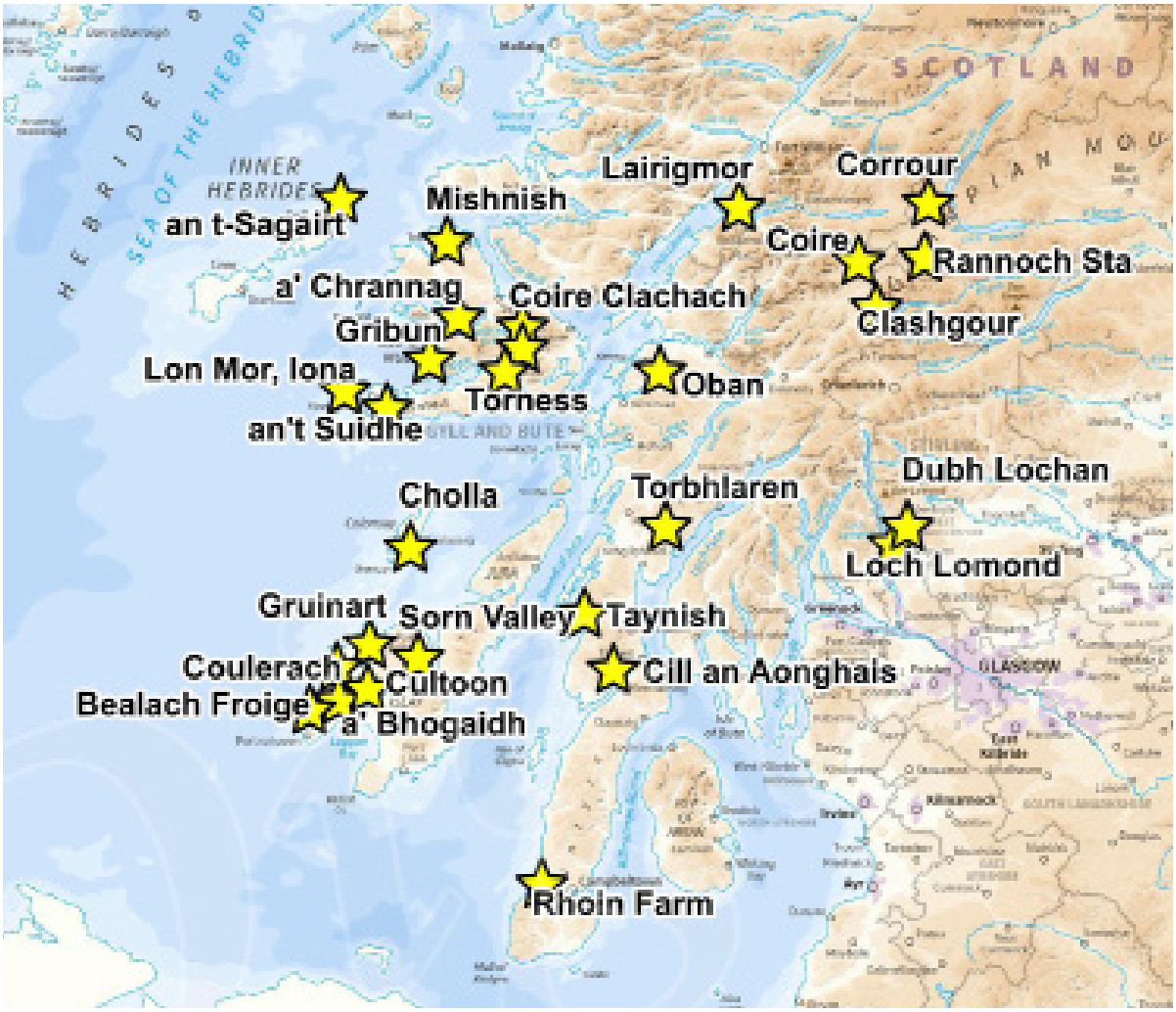
The Moine Mhor is a raised moss, formed on an impermeable substrate of marine clay following mid-Holocene sea level fall, probably over a very long time (above). Such mosses spread laterally: the Moine Mhor at its fullest might have covered 1800 ha compared to 1200 ha today. The archaeological potential beneath the moss remains undiscovered despite ground penetrating radar survey (Housley, Clarke and Campbell 2007).



Figure 20: Map of records of Holocene pedological change © Richard Tipping: Achnacree (Soulsby 1976; Carter and Dalland 2005); An Sithean (Barber and Brown 1984); Cul a' Bhaile (Stevenson 1984; Whittington 1988); Iona (Canmore ID 21649) (Barber 1981); Moine Mhor (Housley, Clarke and Campbell 2007); Oronsay (Canmore ID 37804) (Paul Paul 1987).

The blanket peat cover at Achnacree has been 14C dated, though poorly (Carter and Dalland 2005), to between *c* 1550 cal BC and *c* cal AD 250. The moss has formed on well drained glaciofluvial sands and gravel, so that a palaeo-hydrological signal for peat inception must be suspected, somewhat obfuscated by the great range of the available calibrated 14C assays. The Moss of Achnacree remains one of the most significant later prehistoric archaeological landscapes in the British Isles: its paleo-environmental potential has only inadequately been explored despite the attentions over several decades of many leading archaeologists (see Carter and Dalland 2005). The glaciofluvial sand and gravels are studded with kettle holes, some large but many small, basins containing complete Holocene sediment records which are key. Carter and Dalland (2005) rightly indicate that we would now have less confidence in the stratigraphic integrity of pollen within soils. The small-diameter kettle holes must record, free of disturbance, pollen-analytical data on later prehistoric agricultural activities. Attention has focused on the Bronze Age field system/s at Achnacree, but the kettle holes must also contain a record of the earliest agriculture on substrates known elsewhere to have attracted early Neolithic agriculture (Fairweather and Ralston 1993; Murray et al 2009), very close to the chambered cairn at Achnacreebeag (Ritchie 1970) which plays such a significant role in Alison Sheridan's (2007, 2010) chronology of earliest Neolithic introductions.

Blanket peat is not common in Argyll and Bute, but the region has peaty gleys in abundance because of a clay-rich till (boulder clay), extensive poorly



drained plateaux and a wet climate. Nothing is known of their development but they represent a major impediment to agricultural potential. It is important to understand the timing of this critical pedological change in the region and its relation to climate change and human activities.

4.6 Vegetation change in the Mesolithic period

Figure 21 shows the distribution of pollen sites known to the author that describe Mesolithic-age plant communities in the region: in the absence at a number of sites of detailed 14C-derived chronologies this estimate is based on the rise of Alnus (alder) pollen but the absence of an Ulmus (elm) decline. They are abundant: this is probably the densest array of such sites in Scotland. Those by Durno with Mercer on Jura

Figure 21: Map of Mesolithic–age pollen records © Richard Tipping: Bealach Froige, Islay (Edwards 2000); Clashgour (Bridge et al 1990); Coire Clachach, Mull (Walker and Lowe 1985); Coire Seilich (Bridge et al 1990); Corrour (Walker and Lowe 1979); Coulererach, Islay (Bunting et al 2000); Cultoon, Islay (Edwards 2000); Dubh Lochan (Stewart et al 1984); Fhuaran, Mull (Walker and Lowe 1985); Gribun, Mull (Walker and Lowe 1987); Iona (Scaife and Dimbleby 1990); Loch a' Bhogaidh, Islay (Edwards and Berridge 1994); Loch a' Chrannag, Mull (Sugden 1999); Fyfe et al 2013); Loch an–t Sagairt, Coll (Wicks and Mithen 2013); Loch an t' Suidhe, Mull (Lowe and Walker 1986); Edwards et al 2007); Loch Cholla, Colonsay (Andrews et al 1987); Loch Cill an Aonghais (Peglar in Birks 1980); Loch Gorm, Islay (Bunting et al 2000); Loch Lomond (Dickson et al 1976); Lochan Mor, Iona (Bohncke in Barber 1981); Lochan Taynish (Rymer 1974); Mishnish, Mull (Lowe and Walker 1986); Oban (Davies 1997; Macklin et al 2000); Rannoch Station (Walker and Lowe 1979); Rhoin Farm, Kintyre (Edwards and McIntosh 1988); Sorn Valley, Islay (Edwards 2000); Torbhlaren (Tipping et al 2011); Torness, Mull (Walker and Lowe 1985).

and are of historical interest only (Edwards 2000) but many analyses are cutting-edge. Most of these are uniformly of high quality with regard to pollen taxonomy and temporal resolution, though in many there was no recording of microscopic charcoal. Most are 'sensitive' sites, describing plant communities and their changes at spatial scales small enough to identify and be supportive of archaeological evidence for similarly small-scale human activities.

The majority have not been analysed to explore anthropogenic activities, however. Some sites extend analyses of Devensian Lateglacial sediment into the early Holocene (Map 1: above). Others were constructed to understand the dynamics of deglaciation of ice sheets and valley glaciers of Loch Lomond Stadial age. Those along Loch Awe at Ford, Inverliever and Barachander (Tipping 1988, 1989a) and in Cowal at Na Lona Min (Tipping 1986) do not extend to sediments younger than *c* 9000 cal BC. However, those on Rannoch Moor at Clashgour, Corrour, Kingshouse and Rannoch Station (Walker and Lowe 1977, 1979, 1981, 1985, 1987), on Loch Linnhe at Lairigmor (Walker and Lowe 1981) and on Mull at Coire Clachach, Fhuaran, Gribun and Torness (Lowe and Walker 1986) describe plant communities for the bulk of the Mesolithic period. None of these sites have records of microscopic charcoal.

Holocene vegetation histories at Lochan Taynish (Rymer 1974) and Cill an' Aonghais, both in Kintyre (Peglar 1980), in Loch Lomond (Dickson, Jardine and Price 1976) and on the east bank of Loch Lomond at Dubh Lochan (Stewart, Walker and Dickson 1984) are constructed by applying a uniform sampling interval, not specifically looking for or exploring in detail human activities but noting them when recorded. Their locations may in turn not be optimal for the archaeological record. Peglar's record has not been published: it is available only in a field guide which has almost no interpretation. The Loch Lomond record lacks detail.

A cluster of pollen sites on Islay were analysed to understand Mesolithic vegetation history and human disturbance to plant communities (Mithen 2000) including Coulerach (Bunting et al 2000), Bealach Froige, Cultoon, Gruinart, Loch Gorm and Sorn Valley (Edwards 2000) and Loch a'Bhogaidh (Edwards and Berridge 1994; Edwards and Mithen 1995). Analyses at Loch Cholla, Colonsay were intended to understand the Oronsay shell middens excavated by Mellars (Andrews et al 1987b). On Coll, the site of Loch an-t Sagairt is as yet unpublished (Wicks and Mithen 2013). Edwards, Langdon and Sugden (2007) tried to disentangle anthropogenic from climatic effects on the vegetation at Loch an't Suidhe on Mull around *c* 6200 cal BC. The site of Rhoin Farm, west of Campbeltown, was analysed by Edwards and Mackintosh (1988; Edwards 1990) to explore pre-elm decline agricultural activity.

Four pollen sites are included in Macklin et al's (2000) paper on the Oban region. These are very problematic. The full data-set is found in Fay Davies's (1997) PhD thesis. The pollen sum (the basis for all percentage calculations) is unconventional in that it includes spores and pollen of aquatic plants. This renders the pollen diagrams hard to compare with others and difficult to interpret. Interpretation requires the full data-set but Macklin et al (2000) present summaries only, of all trees and shrubs, Gramineae, cereal-type pollen and Plantago major, together with concentrations of microscopic charcoal (their Figure 3). Grouping all trees and shrubs together is too simplistic an approach to describing woodland loss. Choosing P. major to describe pastoral activities is odd: P. lanceolata is the accepted indicator. These choices make these pollen records far less than the cornerstone of future work they should be. No details of how the chronologies for the pollen diagrams were constructed is given by Macklin et al (2000): construction appears not to have been straightforward (Davies 1997). The discussion by Macklin et al (2000) is synthetic from the start, lacks detail as a result and is too concise.

The difficulties of defining an unambiguous hunter-gatherer signal in pollen records are many, not least because new data on the intensity of abrupt climate change introduce mechanisms by which vegetation can be naturally disturbed. Tipping (1996) argued, for instance, that relative drought increased the likelihood of wildfires in northern Scotland, contested by Bishop, Church and Rowley-Conwy (2015) though true at the global scale (Carcaillet et al 2002). Random events like lightning-strike fires and tree-felling in storms (eg Tipping (2008) at Clashgour on Rannoch Moor) are feasible sources of woodland change. Edwards et al (2007) elegantly evaluated human-climate agencies at Loch an't Suidhe on Mull across the major early Holocene abrupt climate change event at *c* 6200 cal BC. Losses of deciduous woodland around 6300 cal BC are accompanied by increases in microscopic charcoal, which were argued to have been anthropogenic in origin because climatic deterioration was recorded from chironomid analyses after, not during woodland loss. Errors in 14C dating may explain why the climatic deterioration appears not to be that at *c* 6200 cal BC (though see Edwards et al 2007 for other interpretations) but do not detract from their more general conclusions.

On Islay, Mesolithic anthropogenic activity has been suggested from closely spaced pollen analyses seeming to describe short-lived vegetation disturbance, accompanied by burning (Edwards 2000). Events are diachronous across the island, which Edwards (2000) uses to dismiss climatic causation. Disturbance was particularly widespread in the 6th millennium BC. The astonishing find of burnt hazel nuts – the product of perhaps some 15000 trees – at Staosnaig on Colonsay (Mithen and Finlayson 1991) excited much interest, with the suggestion that the pollen record might be able to detect this event (Edwards 2000) but the key factor for the human community on Colonsay would have been the sustainability of the resource through management. We cannot currently demonstrate woodland management from pollen data with conviction (Waller, Grant and Bunting 2012), but tree-ring data from hazel stems can suggest coppicing cycles. Such evidence needs to be sought. Andrews (in McCullagh 1989) also identified possible anthropogenic woodland disturbance on Islay, around the Sorn Valley, around 5900 cal BC. In the Oban area significant woodland loss, associated with burning, is also recorded for short time intervals throughout the Mesolithic.

Anthropogenic signals in the Mesolithic were not recorded at any of their fourteen sites by Lowe and Walker (1986: Walker and Lowe 1977, 1979, 1981, 1985, 1987). This may in part be because microscopic charcoal was not recorded by them, or because the time interval between pollen samples was too coarse, but this is an intriguing if negative result. Andrews et al (1987b) also did not report Mesolithic-age anthropogenic impacts on Colonsay though the sampling interval is comparatively coarse and microscopic charcoal not recorded. Tree pollen rarely exceeds 20% total pollen and spores in the diagram, though, and the landscape must have been quite open, maintained by a high degree of exposure to winds. Walker and Lowe (1985) also infer a high degree of exposure to wind from the low representation of trees at sites on Mull, and around Iona Loch the dominant vegetation in the Mesolithic is a grass-heath with few trees (Scaife and Dimbleby 1990). It is difficult to see in these open settings why people would have needed to disturb woodland: models for anthropogenic interference derived from the closed deciduous woodlands of eastern England (Simmons 1996) need not have applied to the Scottish west coast. Other landscapes appear more wooded, but nevertheless the precise 'ecology' of these disturbances in western Scotland, and if purposeful what they achieved, needs to be explored much more fully. This is now a pressing need because if anthropogenic signals in Mesolithic-age pollen records along the Scottish west coast can be demonstrated, the technique is one of the few that could test Wicks and Mithen's (2013) suggestion of population collapse in and after the 6200 cal BC abrupt climate change.

The possibility that Mesolithic people might have precociously planted cereal crops was for a time an intriguing idea (Edwards 1989; Edwards and Hirons 1984). Macklin et al (2000) report cereal-type pollen as early as *c* 9250 cal BC at Gallanach Beg but interpret them as deriving from wild grasses. The site at Rhoin Farm was analysed (Edwards and Mackintosh 1988) to test this by scanning for cereal type pollen for much longer than normal in pollen counts. Cereal type pollen in pre-elm decline contexts was found, but was not shown unambiguously to be from cereal grasses: almost all the pollen grains are of Hordeum type (barley type), which includes many wild grasses known to produce cereal-size pollen it habitats such as the sand dunes that surround the site today and probably also in prehistory.

4.7 Vegetation change and land uses in later prehistory and the historic period.

Figure 22 shows the locations of pollen sites in Argyll and Bute that cover all or some of the period from *c* 4000 cal BC to the present or close to it. The current data-set for this long period fragments when the times the pollen records span and their purposes are described. The sites on Mull at Gribun (Walker and Lowe 1987), Fhuaran and Torness (Walker and Lowe 1985), Loch Cill an Aonghais (Peglar 1980), Loch Lomond (Dickson et al 1976), and Clashgour and Coire Seilich on Rannoch Moor (Bridge et al 1990) are vegetation histories (see Section 4) rather than land use histories but the long records at Loch Cholla (Andrews et al 1987b), Loch a'Bhogaidh (Edwards and Berridge 1994), Dubh Lochan (Stewart et al 1984) and the four sites in and around Oban presented by Macklin et al (2000) were intended to have human activities as their investigative focus.

Hale's pollen analyses at Glengorm on Mull (in Martlew and Ruggles 1996) were designed to throw light on inter-visibility from standing stones and rows, but the data were not dated or presented, only discussed, and the pollen record itself (Hale pers. comm.) is considered by this author not to relate in time to the monuments. The sites of Cairnbaan and Glasvaar in and near Kilmartin (Long 2002; Winterbottom and Long 2006) and at Torbhlaren (Tipping et al 2011) were analysed to understand the landscape contexts of later prehistoric rock art sites. The first two are undated. Analyses at Dunadd (Miller and Ramsay 2001; Housley et al 2010) commence in the later Iron Age and explore land use change around the fort in the early historic and medieval periods. Iona in the early historic period has unsurprisingly attracted much palynological interest (Bohncke in Barber 1981; Balaam in Reece 1981; Scaife and Dimbleby 1990; Tipping in McCormick 1993) but has generally disappointed. Small 'snapshots' in time were generated by Balaam, Bohncke and Tipping and although Scaife and Dimbleby (1990) argued that the sediments in Iona Loch are a complete Holocene record, this is very unlikely, and peat cutting is suggested here to have truncated the stratigraphy above the later prehistoric period. At the head of Loch Awe is a concentration of analyses that have recently specifically explored medieval and later land uses (Sansum 2004; Davies and Watson 2007).

Macklin et al (2000, 113) described 'substantial deforestation' from *c* 4300 cal BC at some sites, but in detail (Davies 1997) the losses are often seen to be of wetland trees and need not have been anthropogenic. 'Clearance' around Cnoc Philip at *c* 2000 cal BC is from the expansion of ling heather (*Calluna*) and, probably, blanket peat (Davies 1997) and again need not have been anthropogenic, which perhaps challenges the suggestion of widespread synchroneity around Oban of 'more settled farming practices' in the early Bronze Age (Macklin et al 2000). The suggested correspondence between later prehistoric phases of farming with climatic change is exciting but rests on absences of cereal type pollen, which is always under-represented in pollen records.



Figure 22: Map of later prehistoric and historic period pollen records © Richard Tipping: Cairnbaan (Long 2002; Winterbottom and Long 2006); Clashgour (Bridge et al 1990); Coire Seilich (Bridge et al 1990); Corries, Loch Awe (Davies and Watson 2007); Dalness Chasm (Brazier et al 1988); Dubh Lochan (Stewart et al 1984); Dunadd (Miller and Ramsay 2001; Housley et al 2010); Fhuaran, Mull (Walker and Lowe 1985); Glasvaar (Long 2002; Winterbottom and Long 2006); Glengorm (Hale in Martlew and Ruggles 1996); Gribun, Mull (Walker and Lowe 1987); Iona (Bohncke in Barber 1981; Balaam in Reece 1981; Scaife and Dimbleby 1990; Tipping in McCormick 1993); Loch a' Bhogaidh, Islay (Edwards and Berridge 1994); Loch a' Chrannag, Mull (Sugden 1999; Fyfe et al 2013); Loch Cholla (Andrews et al 1987a); Loch Cill an Aonghais (Peglar in Birks 1980); Loch Lomond (Dickson et al 1976); Lochan Taynish (Rymer 1974); Oban Davies 1997; Macklin et al 2000); Sansum (2004): sites along Loch Awe at Cladich, Fernoch and Glen Nant; Torbhlaren (Tipping et al 2011); Torness (Walker and Lowe 1985).

4.7.1 Neolithic activity

Whitehouse et al (2013) have recently argued for the beginning of the Irish Neolithic at *c* 3750 cal BC. Around Coire Clachach in central Mull (Walker and Lowe 1985), *Plantago lanceolata* appears in the early Neolithic at c. 3850 cal BC, and some dryland trees like hazel and oak began to be lost. This pattern is described from Loch a'Bhogaidh on Islay from this date (Edwards and Berridge 1994) and from the Sorn Valley (Andrews in McCullagh 1989) from *c* 3750 cal BC, though at the latter site by a single pollen grain only. At Gribun on the exposed west coast of Mull a plant community with wild grasses was established before the elm decline, further increasing from *c* 2850 cal BC as the birch population fell (Walker and Lowe 1987). Losses in hazel and an expansion of grassland with *P. lanceolata* occurred prior to the elm decline around Iona Loch, and cereal type pollen is recorded from the elm decline (Scaife

and Dimbleby 1990). Also on Iona, Bohncke (in Barber 1981) suggested Neolithic farming included cereal crops. Near Kilmartin, valley-floor woods at Torbhlaren were partly cleared from as early as *c* 4300 cal BC (Tipping et al 2011), with regeneration between *c* 3200 and *c* 2900 cal BC. Cereal cultivation was introduced at *c* 3300 cal BC. Tipping et al (2011) suggested that at *c* 2900 cal BC oak woodland began to be conserved, or perhaps planted, and grown on for some 800 cal years until the woodland was abruptly felled at *c* 2100 cal BC. This activity may have coincided with the creation of rock art on the valley floor. At Lochan Taynish, Rymer (1974) reported only limited woodland disturbance in the Neolithic, after c. 3400 cal BC. Close by at Loch Cill an Aonghais (Peglar 1980), whilst *P. lanceolata* appeared at the elm decline, grassland expanded only from *c* 3400 cal BC. In the Sorn Valley, grassland with *P. lanceolata* was established around 3100 cal BC (Andrews in McCullagh 1991).

Long's (2002; Winterbottom and Long 2006) reconstructions of the local landscapes around the rock art panels at Cairnbaan and Galsvaar (Map 5) suffer from the absence of dating controls. Elm declines are recognised at both pollen sites but at the boundary between mineral soil and overlying peat, so that it is unclear whether the decline is real or is a taphonomic effect: these sites need to be re-visited and ^{14}C dated.

4.7.2 Bronze Age activity

On Mull at Torness, *P. lanceolata* appears from *c* 2500 cal BC and a large expansion of grasses is recorded from *c* 2000 cal BC with falls in hazel. At Fhuaran a sharp fall in oak pollen proportions at *c* 2000 cal BC coincides with a rise in those of wild grasses, with *P. lanceolata* consistently recorded after *c* 1500 cal BC with a sustained decline of birch, oak and alder. At Gribun *P. lanceolata* was established from *c* 2000 cal BC in a landscape of grass and heath (Walker and Lowe 1987). Andrews et al (1987b) described a grazed grassland with *P. lanceolata* established around Loch Cholla on Colonsay from *c* 2650 cal BC and around An t-Aoradh on Oronsay after *c* 1700 cal BC. It is possible that arable activity is recorded from *c* 1900 cal BC around Loch Cholla. Cereal type pollen is also found from *c* 2000 cal BC on Islay, around Loch a'Bhogaidh (Edwards and Berridge 1994) with an expansion in grazed grassland. The Dubh Lochan record (Stewart et al 1984) differs from those in the west of the region in showing negligible woodland clearance until the later Bronze Age at around 1100 cal BC, and little further change.

4.7.3 Iron Age activity

Andrews et al (1987b) saw birch wood regeneration from *c* 800 cal BC to *c* 570 cal BC on Colonsay as indicating reduced human activities. After *c* 500 cal BC, however, came further woodland clearance and the emergence of a treeless landscape. On Kintyre a loss of hazel woodland in the region is recorded from Taynish Fen by Rymer (1974) after *c* 500 cal BC, more sustained after the BC–AD boundary. Losses of oak and alder woodland occurred around Loch Cill an Aonghais at this time (Peglar 1980). Around Gribun on Mull the alder and hazel woodlands collapsed at *c* cal AD 150 (Walker and Lowe 1987).

4.7.4 The historic period

Grassland around Dunadd was common at the BC–AD boundary. Locally, proportions of wet woodland declined at *c* cal AD 400 and those of dry woodland declined *c* cal AD 650. Heathland was established locally *c* cal AD 450 but in the region only after *c* cal AD 1100. A peak in the proportions of birch is seen immediately following abandonment of Dunadd c. cal AD 900, though later medieval woodland clearance removed it (Miller and Ramsay 2001). The Dunadd record has its interpretative problems in that the pollen signal seems somehow muted, not what you expect around such a site, and maybe the abandoned channel lay at the time

within a larger Moine Mhor, distant from fields. There are other major, perhaps more significant citadel forts than Dunadd in the region such as Dunagoil on Bute (Harding 2004, 141–4) with peat close by which would reward investigation.

Bohncke (in Barber 1981) presented pollen data from Iona Fosse, ^{14}C dated to around cal AD600. These have always perplexed in their interpretation of ash and oak woodland around the monastery when the ditch began to infill, not found by either Balaam (in Reece 1981) and Tipping (in McCormick 1993), who both sampled for pollen analyses a peat buried beneath the bank of the inner vallum of the monastery, pre-dating monastic colonisation by 300–500 years. It is simplest to assume that the tree pollen in Bohncke's record pre-dated any early historic period. Even so, ash-oak woodland would be unusual on the west coast and Bohncke's pollen spectra might be distorted by taphonomic processes. Balaam's and Tipping's samples came from different parts of the same bank, it is thought, and in detail they do not correlate (Tipping in McCormick 1993) but broadly it can be suggested that an open woodland of, probably, hazel was lost as Calluna heath expanded, and this was then succeeded by grazed grassland, but no record of other agricultural activities could be recognised. Ditch I stood next to a hedge of elder (Bohncke in Barber 1981). It is doubtful if new sediment stratigraphies will be found on Iona. Kingarth on Bute (Laing, Laing and Longley 1998) is almost surrounded by peat bogs. Lismore in the early historic period is yet to be understood fully. And what human activities might we expect around Eigg's monastic settlement with its links to the ascetic Céli Dé movement, the 'desert isle in the ocean' (Fraser 2009, 370).

The transformation of the diverse landscapes around Oban from wooded to largely treeless was a product of clearance in a couple of hundred years after *c* cal AD 850 (Macklin et al 2000). Though the pollen data for the eastern Loch Lomond oakwoods (Stewart et al 1984) reveal no evidence for intense woodland management in the last several centuries identified by Lindsay (1975) from the documentary record, Sansum (2004) profitably explored both in establishing the history over the last millennium of semi-natural western oakwoods at sites at the head of Loch Awe (Map 6), emphasising 18th and 19th century management of oak and hazel for commercial ventures. In the same area, Davies and Watson (2007) used both data sources to explore over the last *c* 400 years the management of hill pastures and upland woods. Both studies employed what are known as 'small hollows', peat in basins small enough you can almost hop over, which describe the close details of a taskscape.

These brief descriptions of the results of many pollen analyses in the region might be seen as poor reflections of the interpretations but in most instances they are often not: they are what we have. It is not unsurprising in research strategies to see more data demanded but this simple observation is true for Argyll and Bute. The historic period in Argyll and Bute has been poorly served until very recently (see Section 10.2). In part this is because the establishment of organised agrarian landscapes in the last *c* 1500 years has led to an apparent lack of landscape change. There is perhaps little for the pollen analyst to be interested in even though the demonstration of prolonged agricultural stability is often very significant to the archaeologist.

Pollen records like those on Mull and Rannoch Moor are from locations far from population centres. It is difficult, for example, to extract information on human activities from the sites on Rannoch Moor analysed by Bridge et al (1990), partly because only partial pollen diagrams showing only major pollen taxa were presented, but also because the landscape was probably devoid of human occupation for long periods. It is useful to understand land uses at the margins of occupation, although we tend to interpret these as extensions of core activities, like mixed farming, simply expanding onto more intractable soils and climates. We are not good at identifying in the pollen record distinctive

locale-specific activities such as shieling that may explain why people were in such seemingly marginal settings.

We have not investigated critical landscapes like Kilmartin (Sheridan 2012) or, in any depth, Achnacree (Carter and Dalland 2005). There is no clear understanding of the landscape settings of later prehistoric 'ritual' sites like Ruggles' corpus on Mull (Ruggles, Martlew and Hinge 1991; Ruggles and Martlew 1992; Martlew and Ruggles 1996) despite flawed attempts (Hale in Martlew and Ruggles 1996). Proving that trees were not blocking the view between a monument and what was to be looked at will be difficult but is feasible: intervisibility is a fundamental but un-tested assumption in archaeology (Fisher et al 1997; Cummings and Whittle 2003; Gibson 2004). Later prehistoric 'ritual' landscapes, if they existed, must have been managed or monuments would have been lost within regenerating woodland. Perhaps they were inside woodland: we should not think that the dynamic early Bronze Age agrarian landscape at Torbhlaren (Tipping et al 2011) tells us anything about Kilmartin: Torbhlaren is still marginal to this.

Only in recent decades have we come to ask questions of direct archaeological significance, working where the archaeologist is working, as at Glengorm in Mull, on Iona, however frustratingly short of information these data are, and at Dunadd and Torbhlaren. The idea at Dunadd was excellent: what impact did the precisely dated rise to regional dominance of the fort have on local livelihoods? We need many more data in this critical period for Argyll. We can barely put together a coherent narrative for later periods. Did the transfer of power away from Dunadd have significance for the regional economy? What is the meaning of the regeneration of birch trees at Dunadd *c* cal AD 900?

4.8 Recommendations

1. It seems to this author that Argyll and Bute is very well placed to take a lead role in relating its archaeology to the sea. In Argyll 'we can sense the presence of the sea', Whittow said in his *Geology and Scenery in Scotland* (1977, 194). The development of a sophisticated multi-disciplinary research programme in Argyll on the significance of the sea to the archaeology of Scotland and north-west Europe would be a great achievement. The Irish Sea is fundamental to any understanding of Scottish archaeology in any period. More than elsewhere in Scotland, the sea has connected people within Argyll and Bute and in the wider region. From the Mesolithic dispersal across the Inner Hebrides of Rhum bloodstone (Wickham-Jones 2005) and in the earliest Neolithic of Arran pitchstone across Scotland (Ballin and Faithfull 2009) we are accustomed to thinking of coastal travel between mainland and islands and the sea in general as a benign way of facilitating linkages between people.

There is the need to recognise that in the long term the sea and the marine environment have changed in ways we are only coming to realise. Callaghan and Scarre (2009), for example, calculated the journey times by sea from Brittany to Ireland and on to western Scotland in the early Neolithic as if weather, seas and tides were as they are now: they weren't.

The principal driver in such change is the complex interaction of marine currents and gyres in the North Atlantic Ocean that, simplistically, we call the 'gulf stream'. This transports warm water poleward, of course. It is far from stable. Empirical and modelling experiments have shown the fragility of this system to internal and external stresses. It is thought to have stopped functioning during the Loch Lomond Stadial and may have stopped at times in the Holocene (see Tipping et al 2013). A product of these is rapid or abrupt climate change.

Tipping (2010) took the Mesolithic-Neolithic

transition in the British Isles as an example of the types of coastal change we might expect during this and other periods of abrupt climatic change. We can observe between *c* 4000–3000 cal BC major changes in North Atlantic ocean circulation, significant fluctuations in salinity, much lower sea surface and deeper water temperature profiles, the dispersal of 'armadas' of icebergs as far south as western Ireland and increased precipitation which accelerated the input to the Arctic Ocean of fresh water, thus slowing the 'gulf stream' further. Under certain conditions, westerly wind speeds would increase in strength and frequency and wave heights in the eastern North Atlantic would increase. We would expect these changes to have induced very significant changes in the abundance and distribution of coastal sediment, coastal settlement and the abundance, spatial and temporal patterning of marine and littoral resources. At the Mesolithic-Neolithic transition, people that lived by the coast in Argyll appear to have 'slighted' the sea, turning from marine food resources (Schulting 1998; Schulting and Richards 2002). Were these resources lost from our coast through climatic deterioration? Schulting (1998, 214) considered this possibility, but only through proposing falling sea level, which is surely the wrong mechanism when climate change re-arranges ocean currents, slight changes in sea surface temperatures can comprehensively re-structure marine ecosystems and resources and storm-rich periods decimate coastal resources.

Argyll and Bute sits at the centre of a whole web of inter-connecting evidential strands to do with people and the sea. The laboratories of the Scottish Association for Marine Studies (SAMS) outside Oban could be very significant in this. The region has more recognised key coastal and marine heritage sites than elsewhere in Scotland (Baxter et al 2011, 157). And it has Scotland's most extensive Marine Protected Area from Loch Sunart to the Sound of Jura.

2. There is a need in Argyll and Bute as elsewhere for archaeologists and natural scientists to exchange data and swap ideas.

3. Scattered throughout the text above, suggestions for further research have been made. This section brings those together but arranges them in chronological order:

a. We need empirical evidence for modelled low relative sea level stands in the region between the Loch Lomond Stadial and the mid-Holocene
b. There is an urgent need to establish securely dated early Holocene relative sea level rise to establish the 1.4m jump in the surface of the eastern Atlantic at *c* 6200 cal BC
c. The work on Mesolithic-age human disturbance of plant communities in the region has been a sustained and major contribution at an international level. However, such disturbances are far from unambiguously recognised and there are now more alternative hypotheses to explain them by natural means. One advance would be a careful assessment of the ecological processes involved in these small-scale events, and a more critical testing of models of human impact 'imported' from environments unlike the west coast of Scotland. The significance of this work would be enormous because these disturbances, if clearly defined, offer one of the few tests of the post-6200 cal BC population collapse hypothesis of Wicks and Mithen (2013)
d. We need a systematic programme of mapping and dating storm-beach ridges along the Argyll coast (Bute has one: Smith et al 2007). Previous fieldwork has suggested that these appear to have been foci of Mesolithic occupation but further fieldwork and analysis of this link is necessary. They would provide data on past storminess
e. The 'slighting of the sea' is one of the most significant recent interpretations of social and economic change at the Mesolithic-Neolithic transition but it is still relatively unexplored. More research is needed on this and Argyll and Bute is a good place to undertake this. We need fine-grained, highly resolved records of the changing abundances of marine resources

through time from marine sediment archives

f. We know nothing about one of the most important assemblages of later prehistoric monuments in north-west Europe at Kilmartin

g. Renewed archaeological and palaeo-ecological work on the Moss of Achnacree must be pursued because of the significance, first, of early Neolithic activity and, second, because the Bronze Age field walls remain one of the most significant places in Scotland to understand the complexity of later pre-historic agriculture

h. The exploration of novel proxy indicators of storminess should be encouraged, such as sedimentological or geochemical signatures in coastal peat

i. Clarification at a number of localities of the behaviour of the sea surface after the highest Holocene shoreline at *c* 4500 cal BC in later prehistory and early history is needed because some models imply high relative sea level into the early historic period

j. Greater visualisation through Geographic Information Systems (GIS) of changing coastlines through time would greatly aid the archaeologist (Bicket and Tizzard 2015, Bicket et al 2016) in understanding the immediate significance of relative sea level fall

k. A programme of ^{14}C and optically stimulated luminescence (OSL) dating is needed to define even a rudimentary chronology of sand dune formation and episodicity, to understand long-term changes in Atlantic Ocean storminess

l. The peat of the Moine Mhor needs to yield a proxy record of later prehistoric and historic hydrological change (cf Charman et al 2006) to link the existing records between Ireland and Scotland (Swindles et al 2013)

m. There is a need simply for more pollen data for later prehistory and the historic period in addressing testing specific hypotheses generated by the archaeologist and historian

n. The promising work on providing from pollen data local landscape settings for particular rock-art panels should be developed

o. Macklin et al (2000) attempted to relate phases of later prehistoric and historic agricultural activities to periods of climatic amelioration and vice versa. Whilst this study was unconvincing, exploring resilience on sustainable farming practices is increasingly a major concern for archaeologists

p. Pollen analyses to test the archaeological assumption of intervisibility between monuments and from monument to skyline should be welcomed

q. Work on the timing and extent of gleying in soils across the region would lead to a new understanding of agricultural productivity and success

r. New work on understanding the chronology and scale in the region of colluvial and alluvial change is necessary because almost nothing is known of these. They are of direct significance to the archaeologist in that human causation in some events is very likely. The consequence of change has impacts on human communities

s. Careful reconstruction of later Holocene relative sea level fall is needed at Dunadd if we are to fully understand the significance of the coastal setting of this fort. The potential for this is enormous but untapped

t. It would be very good if the pollen analyses of Miller and Ramsay (2001) in the early historic period near Dunadd could be tested at a network of sites

u. We might concede that an environmental history of Iona in the early historic period, though desirable, is unlikely to emerge, and turn to monastic settings where work would be more rewarding

v. It is uncomfortable to think that we know so little about so much of the environmental history of the last c. 1500 years in the region (see also Section 10.2).

4.9 Bibliography

A

Alley, R B 2000. The Younger Dryas cold interval as viewed from central Greenland. *Quaternary Science Reviews* 19, 213–26.

Alley, R and Ágústdóttir, A M 2005. The 8k event: cause and consequences of a major Holocene abrupt climate change. *Quaternary Science Reviews* 24, 1123–49.

Alley, R B, Mayewski, P A, Showers, T, Stuiver, M, Taylor, K C and Clark, P U 1997. Holocene climatic instability: a prominent, widespread event 8200 yr ago. *Geology* 25, 483–86.

Andrews, M V, Beck, R B, Birks, H J B and Gilbertson, D D 1987a. The past and present vegetation of Oronsay and Colonsay. *In*: Mellars, P. (ed) *Excavations on Oronsay*. Edinburgh: Edinburgh University Press, 520–77.

Andrews, M V, Gilbertson, D D and Kent, M 1987b. Storm frequencies along the Mesolithic coastline. *In*: Mellars, P (ed) *Excavations on Oronsay*. Edinburgh: Edinburgh University Press, 108-14.

Armit, I et al 2015. Rapid climate change did not cause population collapse at the end of the European Bronze Age. *Proceedings of the National Academy of Sciences* (doi/10.1073/pnas.1408028111).

B

Ballantyne, C K 1991. Late Holocene erosion in upland Britain: climatic deterioration or human influence? *The Holocene* 1, 81–5.

Ballantyne C K 2002. The Loch Lomond Readvance on the Isle of Mull, Scotland: glacier reconstruction and palaeoclimatic implications. *Journal of Quaternary Science* 17, 759–71.

Ballantyne C K 2004. Geomorphological changes and trends in Scotland: debris-flows. *Scottish Natural Heritage Commissioned Report No. 052* (*ROAME No. F00AC107A*).

Ballantyne, C K and Kirkbride, M P 1987. Rockfall activity in upland Britain during the Loch Lomond Stadial. *Geographical Journal* 153, 86–92.

Ballin, T and Faithfull J 2009. 'Gazetteer of Arran Pitchstone Sources: Presentation of exposed pitchstone dykes and sills across the Isle of Arran, and discussion of the archaeological relevance of these outcrops' *Scottish Archaeology Internet Report* [online] 38. Society of Antiquaries Scotland: Edinburgh Available at http://archaeologydataservice.ac.uk/archives/view/sair/contents.cfm?vol=38 (accessed 30 March 2017).

Ballin, T B, Saville, A, Tipping, R and Ward, T 2010. An Upper Palaeolithic flint and chert assemblage from Howburn Farm, South Lanarkshire, Scotland: First Results. *Oxford Journal of Archaeology* 29 (4), 323–60.

Barber, J W 1981. Excavations on Iona, 1979. Proceedings of the Society of Antiquaries of Scotland 111, 282–380.

Barber, J W and Brown, M M 1984. An Sithean, Islay. *Proceedings of the Society of Antiquaries of Scotland* 114, 161–88.

Barber, J 1998. *The Archaeological Investigation of a Prehistoric Landscape: Excavations on Arran 1978–1981*. Edinburgh: Scottish Trust for Archaeological Research.

Barrett, J H, Nicholson, R and Ceron-Cerrasco, R 1999. Archaeo-ichthyological evidence for long-term socioecononomic trends in northern Scotland: 3500BC to AD1500. *Journal of Archaeo-logical Science* 26, 353–88.

Baxter, J M et al 2011. *Scotland's Marine Atlas: Information for the national marine plan*. Edinburgh: Marine Scotland, 191.

Bicket, A and Tizzard, L 2015. A review of the submerged prehistory and palaeolandscapes of

the British Isles. *Proceedings of the Geologists' Association* 126, 643–63.

Bicket, A R, Mellett, C L, Tizzard, L and Waddington, C 2016. Exploring Holocene palaeogeography in the 'white ribbon': a Mesolithic case study from the Northumberland coast. *Journal of Quaternary Science* (doi /10.1002/jqs.2897/epdf).

Bishop, R R, Church, M J and Rowley-Conwy, P A 2015. Firewood, food and human niche construction: the potential role of Mesolithic hunter-gatherers in actively structuring Scotland's woodlands. *Quaternary Science Reviews* 108, 51–75.

Bjorck, S and Clemmensen, L B 2004. Aeolian sediment in raised bog deposits, Halland, SW Sweden: a new proxy record of Holocene winter storminess variation in southern Scandinavia? *The Holocene* 14, 677–88.

Bond, G et al 1997. A pervasive millennial-scale cycle in North Atlantic Holocene and glacial climates. *Science* 278, 1257–66.

Bonsall, J C 1992. Archaeology. *In*: Walker, M.J.C., Gray, J M and Lowe, J J (eds) *The South-West Scottish Highlands: Field Guide*. Cambridge: Quaternary Research Association, 27–34.

Bonsall, C, Macklin, M G, Anderson, D E and Payton, R. W 2002. Climate change and the adoption of agriculture in north-west Europe. *European Journal of Archaeology* 5, 9–23.

Bonsall, J C and Sutherland, D G 1992. The Oban Caves. *In*: Walker, M J C, Gray, J M and Lowe, J J (eds) *The South-West Scottish Highlands: Field Guide*. Cambridge: Quaternary Research Association, 115–21.

Bos, J A A, van Geel, B, van der Plicht, J and Bohncke, S J P 2007. Preboreal climate oscillations in Europe: wiggle-match dating and synthesis of Dutch high-resolution multi-proxy records. *Quaternary Science Reviews* 26, 1927–50.

Bradwell, T et al 2008a. The northern sector of the last British Ice Sheet: maximum extent and demise. *Earth-Science Review*, 88, 207–26.

Bradwell, T et al 2008b. Ice caps existed throughout the Lateglacial Interstadial in northern Scotland. *Journal of Quaternary Science* 23, 401–8.

Brazier, V, Whittington, G and Ballantyne, C K 1988. Holocene debris cone evolution in Glen Etive, western Grampian Highlands, Scotland. *Earth Surface Processes and Landforms* 13, 525–31.

Bridge, M C, Haggart, B A and Lowe, J J 1990. The history and palaeoclimatic significance of subfossil remains of Pinus sylvestris in blanket peats from Scotland. *Journal of Ecology* 78, 77–99.

Bunting, M J et al 2000. A palaeoecological investigation of the vegetational and environmental history of the Loch Gorm area, NW Islay. *In*: Mithen, S 2000. *Hunter-Gatherer Landscape Archaeology: The Southern Hebrides Mesolithic Project 1988–1998.* Cambridge: MacDonald Institute for Archaeological Research, 137–47.

Burgess, C 1985. Population, climate and upland settlement. *In*: Spratt, D.A. and Burgess, C. (eds) *Upland Settlement in Britain*. Oxford: (BAR British Series 143, 195–230.

C

Cage, A G and Austin, W E N 2010. Marine climate variability during the last millennium: The Loch Sunart record, Scotland, UK. *Quaternary Science Reviews* 29 (13–14), 1633–47.

Callaghan, R and Scarre, C 2009. *Simulating the western seaways*. *Oxford Journal of Archaeology* 28 (4), 357–72.

Carcaillet, C et al 2002. Holocene biomass burning and global dynamics of the carbon cycle. *Chemosphere* 49, 845–63.

Carter, S and Dalland, M 2005. Bronze Age banks at the Black Crofts, North Connel, Argyll, a

synthesis and re-assessment. *Proceedings of the Society of Antiquaries of Scotland* 135, 191–212.

Carter, S and Tipping, R 1991–2. *The prehistoric occupation of Carradale, Kintyre*. Glasgow Archaeological Journal 17, 39–52.

Charman, D J, Blundell, A, Chiverrell, R C, Hendon, D, Langdon, P G 2006. Compilation of non-annually resolved Holocene proxy climate records: stacked Holocene peatland palaeo-water table reconstructions from northern Britain. *Quaternary Science Reviews* 25, 336–50.

Charman, D J 2010. Centennial climate variability in the British Isles during the mid-late Holocene. *Quaternary Science Reviews* 29, 1539–54.

Clarke, G et al 2003. Superlakes, megafloods, and abrupt climate change. *Science* 301, 922–23.

Clarke, M L and Rendell, H M 2006. Effects of storminess, sand supply and the North Atlantic Oscillation on sand invasion and coastal dune accretion in western Portugal. *The Holocene*, 16, 341–55.

Connock, K D, Finlayson, B and Mills, C M 1992. The excavation of a shell midden site at Carding Mill Bay, near Oban, Scotland. *Glasgow Archaeological Journal* 17, 25–38.

Coope, G R, Lemdahl, G, Lowe, J J and Walkling, A 1998. Temperature gradients in northern Europe during the last glacial-Holocene transition (14-9 14C kyr BP) interpreted from coleopteran assemblages. *Journal of Quaternary Science* 13, 419–34.

Cummings, V and Whittle, A W R 2003. Tombs with a view: landscape, monuments and trees. *Antiquity* 77: 255–66.

D

Davidson, T A, Sayer, C D, Perrow, M R et al 2003. Representation of fish communities by scale sub-fossils in shallow lakes: implications for inferring percid–cyprinid shifts. *Journal of Paleolimnology* 30, 441–49.

Davies, A L and Watson, F 2007. Understanding the changing value of natural resources: an integrated palaeoecological – historical investigation into grazing – woodland interactions by Loch Awe, western Highlands of Scotland. *Journal of Biogeography* 34, 1777–91.

Davies, F M 1997. *Holocene Palaeoenviron-mental Studies in the Oban Region, Western Scotland*. Unpublished PhD Thesis, Newcastle upon Tyne.

Dawson, A G 1977. A fossil lobate rock-glacier in Jura. *Scottish Journal of Geology* 13, 37–42.

Dawson, A G 1983. *The Quaternary of Islay and Jura: Field Guide*. QRA: Coventry.

Dawson, A G 1984. Quaternary sea-level changes in western Scotland. *Quaternary Science Reviews* 3, 345–68.

Dawson, A G 2003. Estimating the vulnerability of Scotland's coastline to the effects of future climate change and sea level rise. *In*: Dawson, T. (ed) *Coastal Archaeology and Erosion in Scotland*. Edinburgh: Historic Scotland, 25–35.

Dawson, A G, Dawson, S and Edwards, K J 1998. Rapid Holocene relative sea-level changes in Gruinart, Isle of Islay, Scottish Inner Hebrides. *The Holocene* 8, 183–95.

Dawson, A G, Dawson, S, Mighall, T M, Waldmann, G, Brown, A and MacTaggart, F 2001. Intertidal peat deposits and early Holocene relative sea-level changes, Traigh Eilereag, Isle of Coll, Scottish Hebrides. *Scottish Journal of Geology* 37, 11–18.

Dawson, A G, Lowe, J J and Walker, M J C 1987. The nature and age of the debris accumulation at Gribun, Western Mull, Inner Hebrides. *Scottish Journal of Geology* 23, 149–62.

Dawson, S, Smith, D E, Jordan, J and Dawson, A G 2004. Late Holocene coastal sand movements

in the Outer Hebrides, N.W. Scotland. *Marine Geology*, 210, 281–306.

De Jong, R, Bjorck, S, Bjorkman, L and Clemmensen, L B 2006. Storminess variation during the last 6500 years as reconstructed from an ombrotrophic peat bog in Halland, southwest Sweden. *Journal of Quaternary Science* 21, 905–19.

Debret, M, Sebag, D, Crosta, X, Massei, N, Petit, J-A, Chapron, E and Bout-Roumazeilles, V 2009. Evidence from wavelet analysis for a mid-Holocene transition in global climate forcing. *Quaternary Science Reviews* 28, 2675–88.

Dickson, J H, Jardine, W G and Price, R J 1976. Three late-Devensian sites in west-central Scotland. *Nature*, 262, 43–44.

E

Edwards, K J 1989. Meso-Neolithic vegetation impacts in Scotland and beyond : palynological considerations. *In*: Bonsall, C (ed) *The Mesolithic in Europe*. Edinburgh: John Donald, 143–63.

Edwards, K J 1990. Fire and the Scottish mesolithic: evidence from microscopic charcoal. *In* Vermeesch, P M and Van Peer, P (eds) *Contributions to the Mesolithic in Europe*. Leuven: Leuven University Press, 71–79.

Edwards, K J 2000. Vegetation history of the Southern Inner Hebrides during the Mesolithic Period. *In*: Mithen, S (ed) *Hunter-gatherer Landscape Archaeology: The Southern Hebrides Mesolithic Project 1988–1998.* Volume 1: Project Development, Palaeoenvironments and Archaeological Fieldwork on Islay. Cambridge: MacDonald Institute Monographs, 115–27.

Edwards, K J and Berridge, J M A 1994. The Late-Quaternary vegetational history of Loch a'Bhogaidh, Rinns of Islay SSSI, Scotland. *New Phytologist* 128, 749–69.

Edwards, K J and Hirons, K R 1984. Cereal pollen grains in pre-elm decline deposits: implications for the earliest agriculture in Britain and Ireland. *Journal of Archaeological Science* 11, 71–80.

Edwards, K, Langdon, P and Sugden, H 2007. Separating climatic and possible human impacts in the early Holocene: biotic response around the time of the 8200 cal. yr BP event. *Journal of Quaternary Science* 22 (1), 77–84.

Edwards, K J and McIntosh, C J 1988. Improving the detection rate of cereal-type pollen grains from Ulmus decline and earlier deposits from Scotland. *Pollen et Spores* 30, 179–88.

Edwards, K J and Mithen, S 1995. The colonization of the Hebridean islands of western Scotland: evidence from the palynological and archaeological records. *World Archaeology* 26, 348–65.

Evans, D J A 2003. *The Quaternary of the Western Highland Boundary: Field guide*. London: Quaternary Research Association.

F

Fairweather, A D and Ralston, I B M 1993. The Neolithic timber hall at Balbridie, Grampian Region, Scotland: the building, the date, the plant macrofossils. *Antiquity* 67, 313–23.

Fisher, P et al 1997. Spatial analysis of visible areas from the Bronze Age cairns of Mull. *Journal of Archaeological Science* 24, 581–92.

Fraser, J E 2009. *From Caledonia to Pictland. Scotland to 795*. Edinburgh: University Press.

Fyfe, R M et al 2013. The Holocene vegetation cover of Britain and Ireland: overcoming problems of scale and discerning patterns of openness. *Quaternary Science Reviews* 73, 132–48.

G

Gemmell, A M D 1973. The deglaciation of the island of Arran, Scotland. *Transactions of the Institute of British Geographers* 59, 25–39.

Gibson, A 2004. Visibility and intervisibility: some thoughts on Neolithic and Bronze Age sites. *In*: Shepherd, I A G and Barclay, G (eds) *Scotland in Ancient Europe. The Neolithic and Early Bronze Age of Scotland in their European Context*. Edinburgh: Society of Antiquaries of Scotland, 155–69.

Gilbertson, D D, Shwenninger, J-L, Kemp, R A and Rhodes, E J 1999. Sand-drift and soil formation along an exposed North Atlantic coastline: 14,000 years of diverse geomorphological and human impacts. *Journal of Archaeological Science* 26, 439–69.

Gillen, C 2004. Geology and Landscape. In Omand, D (ed) *The Argyll Book*. Edinburgh: Birlinn, 1–16.

Golledge N R 2006. The Loch Lomond Stadial glaciation south of Rannoch Moor: new evidence and palaeoglaciological insights. *Scottish Geographical Journal* 122: 326–343.

Golledge, N R 2010. Glaciation of Scotland during the Younger Dryas Stadial: a review. *Journal of Quaternary Science* 25, 759–64.

Gray, J M 1974. Lateglacial and postglacial shorelines in western Scotland. *Boreas* 3, 129–38.

Gray, J M 1975. The Loch Lomond Readvance and contemporaneous sea-levels in Loch Etive and neighbouring areas of western Scotland. *Proceedings of the Geologists Association* 86, 227–38.

Gray, J M 1978. Low-level shore platforms in the SW Scottish Highlands: altitude, age and correlation. *Transactions of the Institute of British Geographers New Series* 3, 151–64.

Gray, J M 1995. The kame terraces of lower Loch Etive. *Scottish Geographical Magazine* 111, 113–18.

Gray, J M and Sutherland, D G 1977. The 'Oban-Ford Moraine': a reappraisal. *In*: Gray, J M and Lowe, J J (eds). *Studies in the Scottish Lateglacial Environment*. Oxford: Pergamon Press, 33–44.

H

Haggart, B A and Sutherland, D G 1992. Moine Mhor. In Walker, M J C, Gray, J M and Lowe, J J (eds) *The South-West Scottish Highlands: Field Guide*. Cambridge: Quaternary Research Association, 143–52.

Halliday, S P 2015. Scotland in Europe. In Fraser, H and Ralston, I (eds) *Scotland in Later Prehistoric Europe*. Edinburgh: Society of Antiquaries of Scotland, 281–93.

Harding, D W 2004. *The Iron Age in Northern Britain*. London: Routledge.

Housley R A et al 2004. A high-resolution study of human impact and land use around the first millennium AD royal centre at Dunadd, Argyll. *In*: Housley RA, Coles G (eds.) *Atlantic Connections and Adaptations*. Oxbow: Oxford, 12–28.

Housley, R A et al 2010. Late Holocene vegetation and palaeoenvironmental history of the Dunadd area, Argyll, Scotland: chronology of events. *Journal of Archaeological Science* 37, 577–93.

Housley, R A, Clarke, C and Campbell, E N 2007. Modelling the archaeological potential of a Scottish werland: a case study from the Mhoine Mhor, Argyll. *In*: Barber, J et al (eds) *Archaeology from the Wetlands: Recent persepectives*. Edinburgh: Society of Antiquaries of Scotland, 355–63.

Howe, J A et al 2002. Post-glacial depositional environments in a mid-high latitude glacially-overdeepened sea loch, inner Loch Etive, western Scotland. *Marine Geology* 185, 417–53.

Hubbard, A et al 2009. Dynamic cycles, ice streams and their impact on the extent, chronology and deglaciation of the British-Irish Ice Sheet. *Quaternary Science Reviews* 28, 758–76.

I

Innes, J L 1983. Landuse changes in the Scottish Highlands during the 19th century: the role of pasture degeneration. *Scottish Geographical Magazine* 99, 141–49.

J

Jardine, W G 1977. The Quaternary marine record in southwest Scotland and the Scottish Hebrides. *In*: Kidson, C and Tooley, M J (eds) *The Quaternary History of the Irish Sea*. Liverpool: Seal House Press, 99–118.

Jardine, W G 1987. The Mesolithic coastal setting. *In*: Mellars, P (ed) *Excavations on Oronsay*. Edinburgh: Edinburgh University Press, 25–51.

L

Laing, L, Laing, J and Longley, D 1988. The early Christian and later medieval ecclesiastical site at St. Blane's, Kingerth, Bute. *Proceedings of the Society of Antiquaries of Scotland* 128, 551–65.

Lindsay, J M 1975. Charcoal iron smelting and its fuel supply: the example of Lorn Furnace, Argyllshire, 1753–1786. *Journal of Historical Geography* 1, 283–98.

Long, D 2002. *Rock Art and its Prehistoric Context in the Kilmartin Valley*. Kilmartin: Historic Scotland.

Lowe, J J and Walker, M J C 1986. Lateglacial and early Flandrian environmental history of the Isle of Mull, Inner Hebrides, Scotland. *Transactions of the Royal Society of Edinburgh: Earth Sciences 77, 1–20.*

Lowe, J J, Rasmussen, S O et al 2008. Synchronisation of palaeoenvironmental events in the North Atlantic during the Last Termination: a revised protocol recommended by the INTIMATE Group. *Quaternary Science Reviews* 27, 1175–87.

M

Macklin, M G, Johnstone, E and Lewin, J 2005. Pervasive and long-term forcing of Holocene river instability and flooding in Great Britain by centennial-scale climate change. *The Holocene* 15, 937–43.

Macklin, M G, Bonsall, C, Davies, F M and Robinson, M R 2000. Human-environment inter-actions during the Holocene: new data and interpretations from the Oban area, Argyll, Scotland. *The Holocene* 10, 109–22.

Marret, F, Scourse, J and Austin, W 2004. Holocene shelf-sea seasonal stratification dynamics: a dinoflagellate cyst record from the Celtic Sea, NW European shelf. *The Holocene* 14, 689–96.

Martlew, R D and Ruggles, C 1996. Ritual and landscape on the west coast of Scotland: an investigation of the stone rows of northern Mull. *Proceedings of the Prehistoric Society* 62, 117–31.

Mayewski, P A et al 2004. Holocene climate variability. *Quaternary Research* 62, 243–55.

McCormick, F 1993. Excavations on Iona, 1988. Ulster *Journal of Archaeology* 56, 78–108.

McCullagh, R 1989. Excavation at Newton, Islay. *Glasgow Archaeological Journal* 15, 23–51.

Miller, J and Ramsay, S 2001. *The Vegetation History of Kilmartin Glen over the last two millennia*. Glasgow: School of Archaeology.

Mithen, S 2000. *Hunter-Gatherer Landscape Archaeology: The Southern Hebrides Mesolithic Project 1988–1998*. Cambridge: MacDonald Institute for Archaeological Research. 2 Vols.

Mithen, S and Finlayson, B 1991. Red deer hunters on Colonsay? The implications of Staosnaig for the interpretation of the Oronsay middens. *Proceedings of the Prehistoric Society* 57, 1–8.

Moir, A K, Leroy, S A G, Brown, D and Collins, P E F 2010. Dendrochronological evidence for a lower water-table on peatland around 3200–3000 BC from subfossil pine in northern Scotland. *The Holocene* 20 (6), 917–30.

Murray, H K et al 2009. *A tale of the unknown unknowns: a Mesolithic pit alignment and a Neolithic timber hall at Warren Field, Crathes, Aberdeenshire.* Oxford: Oxbow.

O

Orme, L C, Davies, S J and Duller, G A T 2015. Reconstructed centennial variability of late Holocene storminess from Cors Fochno, Wales. *Journal of Quaternary Science* 30 (5), 478–88.

P

Paul, C R C 1987. Land-snail assemblages from the shell midden sites. *In*: Mellars, P (ed) *Excavations on Oronsay*. Edinburgh: Edinburgh University Press, 91–107.

Peacock, J D 1983. A model for Scottish inter-stadial marine palaeotemperatures 13,000 to 11,000 BP. *Boreas* 12, 73–82.

Peacock, J D 1989. Marine molluscs and Late Quaternary environmental studies with particular reference to the Late-glacial period in Northwest Europe: a review. *Quaternary Science Reviews* 8, 179–92.

Peacock, J D et al 1977. Evolution and chronology of Lateglacial marine environments at Lochgilphead, Scotland. *In*: Gray, J M and Lowe, J J (eds) *Studies in the Scottish Lateglacial Environment*. Oxford: Pergamon, 89–100.

Peacock, J D et al 1989. Radiocarbon ages for a glaciomarine bed associated with the maximum of the Loch Lomond Readvance in west Benderloch, Argyll. *Scottish Journal of Geology* 25, 69–79.

Peglar, S 1980. Loch Cill an Aonghais. In Birks, H.J.B. Quaternary Vegetational History of Western Scotland. Cambridge: unpublished.

Pickard, C and Bonsall, C 2004. Deep-sea fishing in the European Mesolithic: fact or fantasy? *European Journal of Archaeology* 7, 273–90.

R

Rasmussen, S O et al 2008. Synchronisation of the NGRIP, GRIP and GRIP2 ice cores across MIS2 and palaeoclimatic implications. *Quaternary Science Reviews* 27, 18–28.

Reece, R 1981. *Excavations on Iona, 1964 to 1974*. University of London, Institute of Archaeology Occ. Pap. No. 5.

Rhodes, A N, Rumsby, B T and Macklin, M G 1992. Gallanach Beg, Oban. *In*: Walker, M J C, Gray, J M and Lowe, J J (eds) *The South-west Scottish Highlands:Field Guide*. Quaternary Research Association: Cambridge, 121–24.

Ritchie, J N G 1970. Excavation of the chambered cairn at Achnacreebeag. *Proceedings of the Society of Antiquaries of Scotland* 102, 31–55.

Ritchie, G 1997. *The Archaeology of Argyll*. Edinburgh: University Press.

Roland, T P et al 2015. The 5.2 ka climate event: evidence from stable isotopes and multi-proxy palaeoecological peatland records in Ireland. *Quaternary Science Reviews* 124, 209–23.

Ruggles, C, Martlew, D and Hinge, P 1991. The north Mull project: (2) the wider astronomical potential of the sites. *Archaeoastronomy* 16, S51–75.

Ruggles, C and Martlew, R D 1992. The North Mull Project: (3) prominent hill summits and their astronomical potential. *Archaeoastronomy* 17, S1–13.

Rose, J, Lowe, J J and Switsur, R 1988. A radiocarbon date on plant detritus beneath till from the type area of the Loch Lomond Readvance. *Scottish Journal of Geology* 24, 113–24.

Rymer, L 1974. The Palaeoecology and Historical Ecology of the parish of North Knapdale, Argyllshire, Unpublished PhD Thesis, Cambridge.

Rymer, L 1977. A Late-glacial and early post-glacial pollen diagram from Drimnagall, north Knapdale, Argyllshire. *New Phytologist* 79, 211–21.

S

Sansum, P A 2004. Recent Woodland Management Practice in Western Scottish Oak Woods:

A Palynological and Documentary History. Unpublished Ph.D. Thesis, Stirling.

Scaife, R G and Dimbleby, G W 1990. Landscape Change on Iona. *Bulletin of the Institute of Archaeology, University of London* 27, 25–61.

Schulting, R J 1998. Slighting the sea: stable isotope evidence for the transition to farming in northwestern Europe. *Documenta Praehistorica* 15, 203–18.

Schulting, R J 2012. Holocene environmental change and the Mesolithic-Neolithic transition in north-west Europe: revisiting two models. *Environmental Archaeology* 15 (2), 160–72.

Schulting, R J and Richards, M P 2002. The wet, the wild and the domesticated: the Mesolithic-Neolithic transition on the west coast of Scotland. *Journal of European Archaeology* 5, 147–89.

Selby, K A 2004. Lateglacial and Holocene vegetation change on the Isle of Skye: new data from three coastal locations. *Vegetation History and Archaeobotany* 13, 233–47.

Seppa, H et al 2007. Spatial structure of the 8200 cal yr BP event in northern Europe. *Climates of the Past* 2, 225–36.

Shennan, I and Horton, B 2002. Holocene land and sea-level changes in Great Britain. *Journal of Quaternary Science* 17, 511–27.

Shennan, I et al 2006. Relative sea-level observations in western Scotland since the Last Glacial Maximum for testing models of isostatic land movements and ice-sheet reconstructions. *Journal of Quaternary Science* 21, 601–13.

Sheridan, A 2007. From Picardie to Pickering and Pencraig Hill? New information on the 'Carinated Bowl Neolithic' in northern Britain. *In*: Whittle, A.W.R. and Cummings, V. (eds) *Going Over: the Mesolithic-Neolithic Transition in north-west Europe*. Proceedings of the British Academy 144, 439–90.

Sheridan, A 2010. The Neolithization of Britain and Ireland: the 'big picture'. *In*: Finlayson, B and Warren, G (eds) *Landscapes in Transition*. Oxford: Oxbow, 89–105.

Sheridan, A 2012. Contextualising Kilmartin: building a narrative for developments in western Scotland and beyond, from the Early Neolithic to the Late Bronze Age. *In*: Meirion Jones, M, Pollard, J, Allen, M and Gardiner, J (eds) *Image, Memory and Monumentality. Archaeological engagements with the material world*. Prehistoric Society Research Paper 5. Oxbow: Oxford, 163–83.

Simmons, I G 1996. *The Environmental Impact of Later Mesolithic Cultures.* Edinburgh: University Press.

Smith, D E et al 2007. Holocene relative sea level changes in a glacio-isostatic area: new data from south-west Scotland, United Kingdom. *Mar. Geol*., 242, 5–26.

Smith, D E, Davies, M H, Brooks, C L, Mighall, T M, Dawson, S, Rea, B R, Jordan, J T and Holloway, L K 2010. Holocene relative sea levels and related prehistoric activity in the Forth lowland. *Quaternary Science Reviews* 29, 2382–410.

Smith, D E, Cullingford, R A and Firth, C R 2000. Patterns of isostatic land uplift during the Holocene: evidence from mainland Scotland. *The Holocene* 10, 489–501.

Sommerville, A A et al 2003. Optically stimulated luminescence dating of large storm events in Northern Scotland. *Quaternary Science Reviews* 22, 1085–92.

Sommerville, A A et al 2007. Optically stimulated luminescence (OSL) dating of coastal aeolian sand accumulation in Sanday, Orkney Islands, Scotland. *The Holocene* 17, 627–37.

Soulsby, J A 1976. Palaeoenvironmental interpretation of a buried soil at Achnacree, Argyll. *Transactions of the Institute of British Geographers* 1, 279–83.

Stager, J C and Mayewski, P A 1997. Abrupt early to mid-Holocene climatic transitions registered at the Equator and the Poles. *Science* 276, 1834–36.

Stevenson, J B 1984. The excavation of a hut circle at Cul a'Bhaile, Jura. *Proceedings of the Society of Antiquaries of Scotland* 114, 127–60.

Stewart, D E, Walker, A and Dickson, J H 1984. Pollen diagrams from Dubh Lochan, near Loch Lomond. *New Phytologist* 98, 531–49.

Stott, K J et al 2010. The potential of Arctica islandica growth records to reconstruct coastal climate in northwest Scotland. *Quaternary Science Reviews* 29 (13–14), 1602–13.

Sugden, H 1999. High-resolution Palynological, Multiple Profile and Radiocarbon dated Studies of Early Human Impacts and Environmental Change in the Inner Hebrides, Scotland. Unpublished Ph.D. Thesis, University of Sheffield.

Sutherland, D G 1984. The Quaternary deposits and landforms of Scotland and the neighbouring shelves: a review. *Quaternary Science Reviews* 3, 157–254.

Sutherland, D G 1997. The environment of Argyll. In Ritchie, G (ed) The Archaeology of Argyll. Edinburgh: Edinburgh University Press, 10–24.

Swindles. G T et al 2013. Centennial-scale climate change in Ireland during the Holocene. *Earth-Science Reviews* 126, 300–20.

T

Taylor, K C et al 1993. The 'flickering switch' of late Pleistocene climate change. *Nature* 361, 432–36.

Thornalley, D J R, Elderfield, H and McCave, I N 2009. Holocene oscillations in temperature and salinity of the surface subpolar North Atlantic. *Nature* 457, 711–14.

Tipping, R 1986. A late-Devensian pollen site in Cowal, south-west Scotland. *Scottish Journal of Geology* 22, 7–40.

Tipping, R 1988. The recognition of glacial retreat from palynological data: a review of recent work from the British Isles. *Journal of Quaternary Science* 3, 171–82.

Tipping, R 1989a. Devensian Lateglacial vegetation history at Loch Barnluasgan, Argyllshire. *Journal of Biogeography* 16, 435–47.

Tipping, R 1989b. Palynological evidence for the extent of the Loch Lomond Readvance in the Awe Valley and adjacent areas, SW Highlands. *Scottish Journal of Geology* 25, 325–37.

Tipping, R 1996. Microscopic charcoal records, inferred human activity and climate change in the mesolithic of northernmost Scotland. *In*: Pollard, A and Morrison, A (eds) *The Early Prehistory of Scotland*. Edinburgh: Edinburgh University Press, 39–61.

Tipping, R 1999. Kilmartin Valley: landforms and landscape evolution. *In*: *RCAHM(S) Kilmartin: Prehistoric and Early Historic Monuments*. Edinburgh: RCAHM(S), 1–4.

Tipping, R 2005. Coping with climatic stresses: climate change, prehistoric farmers and the transmission of knowledge. *Landscape Archaeology and Ecology* 5, 90–5.

Tipping, R 2008. Storminess as an explanation for the decline of pine woodland ca. 7,400 years ago at Loch Tulla, western Scotland. Vegetation History *and Archaeobotany* 17, 345–50.

Tipping, R 2010. The case for climatic stress forcing choice in the adoption of agriculture in The British Isles. *In*: Finlayson, B and Warren, G (eds) *Landscapes in Transition*. Oxford: Oxbow, 66–77.

Tipping, R et al 2011. Landscape and landscape Dynamics at Torbhlaren. *In*: Jones, A M et al *An Animate Landscape: Rock Art and the Prehistory of Kilmartin, Argyll, Scotland.* Macclesfield: Windgather Press, 122–77.

Tipping, R. et al 2013. Moments of crisis: from coincidence to hypothesis testing in defining the impacts of abrupt climate change in Scottish prehistory. *Proceedings of the Society of Antiquaries of Scotland* 142, 1–17.

Tipping, R, Carter, S and Haggart, B A 1994. Late Quaternary valley floor evolution in the lower reaches of Carradale, Kintyre. *Scottish Journal of Geology* 30, 131–45.

Tisdall, E W, McCulloch, R D, Sanderson, D C W, Simpson, I A and Woodward, N L 2013. Living with sand: A record of landscape change and storminess during the Bronze and Iron Ages, Orkney, Scotland. *Quaternary International* 301, 1–11.

Trouet, V, Esper, J, Graham, N E, Baker, A, Scourse, J D and Frank, D C 2009. Persistent positive North Atlantic Oscillation mode dominated the Medieval Climate Anomaly. Science 324, 78–80.

Turney, C S M, Harkness, D D and Lowe, J J 1997. The use of microtephra horizons to correlate Late -glacial lake sediment successions in Scotland. *Journal of Quaternary Science* 12, 525–33.

V

van Geel, B, van der Plicht, J, Kilian, M R, Klaver, E R, Kouwenberg, J H M, Renssen, H, Reynaud-Ferrara, I, Waterbolk, H T, 1998. The sharp rise of D14C ca. 800 cal BC: possible causes, related climatic teleconnections and the impact on human environments. *Radiocarbon* 40, 535–50.

W

Walker, M J C and Lowe, J J 1977. Postglacial environmental history of Rannoch Moor, Scotland. I. Three pollen diagrams from the Kingshouse area. *Journal of Biogeography* 4, 333–51.

Walker, M J C and Lowe, J J 1979. Postglacial environmental history of Rannoch Moor, Scotland. II. Pollen diagrams and radiocarbon dates from the Rannoch Station and Corrour areas. *Journal of Biogeography* 6, 349–62.

Walker, M J C and Lowe, J J 1981. Postglacial environmental history of Rannoch Moor, Scotland. III. Early- and mid-Flandrian pollen stratigraphic data from sites on western Rannoch Moor and near Fort William. *Journal of Biogeography* 8, 475–91.

Walker, M J C and Lowe, J J 1985. Flandrian environmental history of the Isle of Mull, Scotland: I. Pollen-stratigraphic evidence and radiocarbon dates from Glen More, south-central Mull. *New Phytologist* 99, 587–610.

Walker, M J C and Lowe, J J 1987. Flandrian environmental history of the Isle of Mull. III. A high-resolution pollen profile from Gribun, western Mull. *New Phytologist* 106, 333–47.

Walker, M J C, Gray, J M and Lowe, J J 1985. *Island of Mull: Field Guide*. Cambridge: Quaternary Research Association.

Walker, M J C Gray, J.M. and Lowe, J J 1992. *The South-West Scottish Highlands:Field Guide*. Cambridge: Quaternary Research Association.

Waller, M P, Grant, M J and Bunting, M J 2012. Modern pollen studies from coppiced woodlands and their implications for the detection of woodland management in Holocene pollen records. *Review of Palaeoecology and Palynology* 187, 11–28.

Wang, T, Surge, D, Mithen, S, 2012. Seasonal temperature variability of the Neoglacial (3300–2500 BP) and Roman Warm Period (2500–1600 BP) reconstructed from oxygen isotope ratios of limpet shells (Patella vulgata), Northwest Scotland. *Palaeogeography, Palaeoclimatology, Palaeoecology* 317, 104–113.

Whitehouse, N J et al 2013. Neolithic agriculture on the European western frontier: the boom and bust of early farming in Ireland. *Journal of Archaeological Science* 40 1–25.

Whittington, G 1983. A palynological observation of a second millennium BC bank-system in the Black Moss of Achnacree. *Journal of Archaeological Science* 10, 283–91.

Whittington, G 1988. Environmental reconstruction at Cul a' Bhaille, Isle of Jura. *In*: Bintliff, J, Davidson, D A and Grant, E G (eds) *Conceptual Issues in Environmental Archaeology*. Edinburgh: University Press, 38–48.

Whittington, G et al 2015. Lateglacial and early Holocene climates of the Atlantic margins of Europe: stable isotope, mollusc and pollen records from Orkney, Scotland. *Quaternary Science Reviews* 122, 112–30.

Whittow, J 1977. *Geology and Scenery in Scotland*. London: Pelican

Wickham-Jones, C 2005. Summer walkers?—mobility and the Mesolithic. *In*: Milner, N and Woodman, P (eds) *Mesolithic Studies at the beginning of the 21st Century*. Oxford: Oxbow Books, 30–41.

Wicks, K and Mithen, S 2013. The impact of the abrupt 8.2 ka cold event on the Mesolithic population of western Scotland: a Bayesian chronological analysis using 'activity events' as a population proxy. *Journal of Archaeological Science* 45, 240–69.

Wilson, P 2002. Holocene coastal dune development on the South Erradale peninsula, Wester Ross, Scotland. *Scottish Journal of Geology* 38, 5–12.

Wilson, P, McGourty, J and Bateman, M D 2004. Mid- to late-Holocene coastal dune event stratigraphy for the north coast of Ireland. *The Holocene* 14, 406–16.

Winterbottom, S J and Dawson, T 2005. Airborne multi-spectral prospection for buried archaeology in mobile sand dominated systems. *Archaeological Prospection* 12, 205–19.

Winterbottom, S J and Long, D J 2006. From abstract digital models to rich virtual environments: landscape contexts in Kilmartin Glen, Scotland. *Journal of Archaeological Science* 33, 1356–67.

Winterbottom, S J and O'Shea, C 2002. *Using Geographic Information Systems (GIS) techniques to identify landscape siting criteria for rock art sites in the Kilmartin Valley.* Stirling University: Report to Historic Scotland. pp. 16.