Alternative strategies to agriculture: the evidence for climatic shocks and cereal declines during the British Neolithic and Bronze Age (a reply to Bishop),

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Abstract

Our suggestion that agriculture was temporarily abandoned for several centuries throughout much of mainland Britain after 3600 BC has provoked criticism, notably the claim by Bishop (2015) that we have missed continuity in Scotland. We demonstrate that firm evidence for widespread agriculture within the later Neolithic is still unproven. We trace the disappearance of cereals and the associated population collapse to a probable climatic shift that impacted the abundance of rainfall and lowered temperatures, thus affecting the reliability of cereals. Divergent strategies and patterns are identified on the Scottish Islands versus the mainland, which has more in common with England, Wales and Ireland. We argue that climate shocks disrupt existing subsistence patterns, to which varied responses are represented by divergent island and mainland patterns, both in the Late Neolithic and during the Early and Middle Bronze Age. Favourable climates encouraged population growth and subsistence innovation, such as at the start of the Neolithic and in the Beaker period.

The case for agricultural abandonment in the British Isles

The possibility of dramatic changes from Early Neolithic to Late Neolithic Britain has long been proposed (e.g., Childe 1947; Piggott 1954, 365; Wainwright and Longworth 1971; Whittle 1978). The application of systematic archaeobotanical research to sites undoubtedly did much to rectify this situation, potentially providing a means by which the changing nature of Neolithic and Bronze Age subsistence could be examined. However, careful scrutiny of an existing dataset (Jones and Rowley-Conwy 2007) proved problematic, with several charred cultigens proving to be intrusive when directly dated, and cereal bearing contexts being incorrectly phased. The use of radiocarbon summed probability distributions (SPD) offered a means by which all these issues could be studied and resolved, utilizing a database of over 700 direct dates on crop remains and edible wild plant foods compiled for the British Isles from the Mesolithic through the Bronze Age (Stevens and Fuller 2012). That similar distributions are seen in other studies that included bone and charcoal dates (Collard et al. 2010; Shennan et al. 2013; Timpson et al. 2014) suggests charred remains of edible plants represent not just plant use but are a reasonable proxy for human population. Our findings demonstrated an introduction of cereals to the British Isles around 4000 BC, in line with existing theories (Brown 2007; Whittle, Healey, and Bayliss 2011), followed by a rapid increase in population (as with Collard et al. 2010; Shennan et al. 2013). Further increases in population were associated with decreased reliance on cereals (see Thomas 2015, 1074; Bogaard et al. 2013), and perhaps a greater input of wild foods into the diet from around 3650 BC. After 3350 BC a dramatic downturn of population occurred, with little to no cereal remains present until around 2300 BC.

Stevens and Fuller (2012) recognized that island communities, particularly those in Scotland, showed continued cereal agriculture until around 2850 BC, when a significant decline in population is suggested. Around 2450 BC, at the start of the Beaker period, low levels of cereal agriculture began to reappear across Britain, gradually replacing wild foods, and with rising population levels until 2000 BC. At this point populations on the Islands continued to rise, but total population, rather than just cereals, declined on the mainland. Around 1500 BC, concurrent with the start of the Middle Bronze Age, a rapid rise in population and cereal agriculture was seen with much less evidence for wild foods than in earlier periods. Additional boom and bust cycles are evident through the Bronze Age, with the Scottish Islands often out of phase with the mainland (Fig. 1).

Scales of geography: a case for regional variation (e.g. Scotland)?

The criticism of this paper by Bishop (2015) can be divided into four points: research bias (see also Rowley-Conwy and Legg 2015, 440); too few archaeobotanical assemblages/settlements; actual evidence for Late Neolithic cereals that we missed, and that our dataset is too small to be valid.

The aspect of research bias has been anticipated and answered by Shennan et al. (2013). If dating is substantially biased towards any one period then a full cycle, from boom to bust and back to boom, would not appear. Cereals are present and dated from the Bronze Age, and given the importance of the later Neolithic in terms of monument construction it is arguably implau- sible that this period would not also generate substantial research and ^{14}C dates (both by academics and within the commercial sector). Further, that ^{14}C dates on hazelnut shells continue throughout this period would indicate both the existence of datable material and domestic food waste. However, the relatively very high peaks in Neolithic dates compared to later Bronze Age (Fig. 1) might reflect some bias in data collection but trends of rising and falling population are still evident.

The purpose of using ^{14}C SPDs is to demonstrate past population levels, be it of cereals or people. The proxy is that radiocarbon dates are an indication of levels of archaeological evidence itself – a reflection of past human activity that can then be related to past population density (Gkiasta et al. 2003; Shennan and Edinborough 2007). As such, fewer people equal fewer settlements, fewer archaeobotanical assemblages and fewer radiocarbon dates. Our own ^{14}C SPD, using only plant ^{14}C dates, suggest that population levels for mainland Britain around 2350 BC fell to *c*.25 per cent of previous levels, similar to ^{14}C SPDs using a wider range of material (cf. Collard et al. 2010; Shennan et al. 2013). In response to Bishop's questions concerning why there is not an increase in wild plant dates in the Late Neolithic/Early Bronze Age, the number of dates on wild plant foods only falls to 30 per cent of previous levels, while cereal dates fall to *c*. 13 per cent declining in the next three centuries to only a trace. So relatively dates on wild food remains do increase in comparison to those on cereals.

The next issue raised by Bishop is that there is good evidence for cereals within the Scottish later Neolithic. Bishop (2015) states that at least nine sites on the mainland and six on Scottish Islands with radiocarbon dates 'have sizable assemblages of cereals from stratigraphically and chronologi- cally secure Late Neolithic contexts'. The examples she lists on Orkney support our stated hypoth- esis that cereal cultivation continued on Scottish Islands until populations fell at 2850 BC. The phase 2 midden samples from Tofts Ness have grain but in much lower density (Bond 2007).

Intrusiveness is a very real issue, and in the absence of directly-dated crops and/or high- density archaeobotanical evidence from later Neolithic to Early Bronze Age deposits, we cannot assume unchanging agricultural dependence. In our study we found that 19 per cent of direct dates on crop remains were intrusive, producing calibrated median ages of 500 BC or younger (Stevens and Fuller 2012). The level is even higher if Middle/Late Bronze Age dates on 'Neolithic' cereals are included. Whitehouse et al. (2014) in their analysis of the Irish Neolithic reported 10.7 per cent (20 out of 187) direct AMS dates on crop seeds were similarly intrusive. Several major examples of this problem are presented by Pelling et al. (2015), including direct AMS dates on cereals from Durrington Walls, none of which turned out to be Neolithic, despite careful excavation and systematic archaeobotanical sampling. The funda- mental problem is that for the last 3500 years cereal agriculture has been widespread throughout the British Isles and thus the background noise of cereal processing has increased over time, offering ample scope for intrusive grains.

Therefore we must consider the evidence of Bishop (2015) cautiously (Table 1). Only on four of the 13 proposed sites do cereal remains unquestionably amount to more than 10 grains, and none of these low density deposits provide acceptable trustworthy evidence for cereal cultivation. Indeed these issues were raised in two of the site publications (Fairweather and Smith cited in Barclay and Russell-White 1993, 52; Holden 1997, 54), Of the four richer assemblages, Lairg, site 0870, might potentially be of an earlier date than the charcoal radiocarbon date, judging by the context descriptions (see Table 1; Holden 1998, 169; McCullagh and Tipping 1998, 95, 98). The dates for the remaining three sites, including direct dates on cereal remains, all fall between 3400 and 2900 cal. BC, with a median around 3200 to 3150 cal. BC (Fig. 2). As such they might indicate a slightly longer continuation of arable farming in mainland Scotland, already noted by Stevens and Fuller (2012) for Kinbeachie (Barclay et al. 2001), but this still leaves centuries with no confirmed cereal evidence after this date.

The final issue is the accuracy of ^{14}C SPD models, and the minimal number of dates required. The figure of 500 dates given by Williams (2012) is because the addition of further dates did not greatly alter the observed trends in SPDs required to see broad, long-term demographic changes for all of Australia over 50,000 years. However, recent testing of such models has demonstrated that statistically significant results can be obtained utilizing much smaller datasets, specifically critiquing Williams on statistical grounds (Timpson et al. 2014). Where the signal is strong, as in the contrast we found between cereal boom and bust periods, the sample needed to recover that signal is smaller. Even so, we used 760 dates for a much smaller time period and geographical area than in the Australian study, and drew attention to regional variation in sampling across Britain, stating the need for further work, especially concerning regional variation.

We have therefore considered just Scotland, separated into the mainland and islands. Our original dataset has been augmented by the four dates listed by Bishop, as well as forty-three dates on cereals drawn from the radiocarbon database for Scotland (CANMORE 2015). This expanded sample can be compared to the complete British Isles dataset combining these Scottish dates, the Irish dates of Whitehouse et al. (2014) and the English and Welsh dates of Stevens and Fuller (2012) (Fig. 1). As seen the pattern remains largely unchanged, although the tail of cereal decline stretches from 3350 to 3000 BC. However, the site of Standing Stones, Moreham (East Lothian) yielded two dates on naked and hulled barley (see Hamilton 2011, 236) that hint at the existence of some cereal agriculture settlements from 3000 to 2500 BC. Further data are required to assess whether such sites represent short-lived reintroduc- tions, or a low level but widely practised agriculture. However, given that cereal evidence remains low for some 800 years across much of the British Isles, where one might have expected cereals to increase if they were present, then it seems more likely that either cultural subsistence practices prevented it from re-establishing or such cereal farmers were rare and short-lived. The Scottish Islands still present an interesting contrast, with much more evidence for agricultural settlement in the later Neolithic and Early Bronze Age than elsewhere in Britain (see also Farrell et al. 2014).

Table 1 **An assessment of Late Neolithic sites from mainland Scotland used by Bishop (2015) to argue for cereal cultivation**

Site	*Quantity cereal grains*	*Our comments*
Balfarg	No quantity reported. But appears very small. 150+ barley grains from Cist A dated to Beaker	Fairweather and Smith (cited in Barclay and Russell- White 1993, 52) state 'the tiny number of seeds was the result of a general background of carbonized material finding its way into pits and layers' of the henge. Material from Cist A is likely Beaker but was not felt secure enough to date.
Becton Farm	Five barley grains from two four-post structures undated. One grain from feature F092 dated to 2890–2350 cal. BC.	Material comes from an undated four-post structure. The undated four-post structures could be Bronze Age or later. The other single dated grain, could be Late Neolithic or Early Bronze Age (Pollard 1997)
Carsie Mains	Seventy-six cereal grains, undated. Barley and naked barley	The radiocarbon date is on hazelnut shell, 3350–2930 cal. BC, in line with other Middle Neolithic cereal and nut dates. (Fig. 2) (Brophy and Barclay 2004)
Cowie Road	Four single grains from different pits.	Holden (1997, 54) notes: 'The grains from Area 2 were not in a condition whereby hulled or naked varieties could be separated; it is difficult, therefore, without direct dating, to state with confidence that these are of Neolithic date.'
Eweford Road	Two barley grains listed by Bishop, Church, and Rowley-Conwy (2009)	It is unknown if the two grains are associated with a directly dated feature. It is notable that grains of Beaker date were common on the site (see Stevens and Fuller 2012). The (SUERC-5294) date given by Bishop we believe is on hazel charcoal.
Lairg	3,546 grains in total (1,158 barley 1,980 naked barley 408 emmer wheat)	The secure deposit is within a truncated pit sealed by a cairn & buried soil. The date is on wood charcoal from the pit or buried soil under cairn. But the context of the dated wood charcoal and grain appears uncertain. Compare comments on p. 95 to those on p. 98 (McCullagh and Tipping 1998).
Milton of Leys	No more than three grains of barley and/or three grains of oat	The report states 'Charred cereal grain, naked barley (*Hordeum vulgare* var *nudum*) and oat (*Avena* sp), was present in only three features and in no case did the assemblage from any one feature amount to more than one grain of each' (Hastie 2003, 38). The features are all less than 0.13m deep. It is unclear which of features/C^{14} dates are associated with cereals
Overhailes	Seven grains in total – including two barley and one oat (Bishop, Church, and Rowley-Conwy 2009)	The report is unpublished. Plough truncated pits form part of a Grooveware Settlement (Stuart 2002; Stuart 2003)
Stoneyhill Farm	825+ cereal grains mostly naked barley	Has two direct dates on a rich deposit of naked barley dating to 3370–3110 cal. BC and 3340–3100 cal. BC (Fig. 2). See Suddaby and Ballin (2010)
Tinto Sands	Two cereal grains total – one barley and one indeterminate (Bishop, Church, and Rowley- Conwy 2009)	Unpublished report. Radiocarbon dates on charcoal SUERC-2624; SUERC-2622 and SUERC-2623 all seem to be of intrusive material dating to the Late Bronze Age and later Saxon period in Neolithic features CANMORE; http://canmore.org.uk/c14index/269437
Upper Forth Crossing	No quantity reported	Two radiocarbon dates securely Middle Neolithic, 3490–3100 cal. BC and 3340–2930 cal. BC.

Bellfield	Bishop, Church, and Rowley-Conwy 2009: list naked barley grain = ‘abundant’.	In Timpany (2009): two samples only with ‘rare’ naked barley.
Midmill	Naked barley recorded as ‘abundant’.	While four of fifteen Neolithic features were sampled, only two with abundant hazelnut had pottery, hence are phased; both are recorded as having rare grains of naked barley. Both also have daub which is thought to be intrusive (Timpany 2009). Pits are phased to Late Neolithic/Early Bronze Age (Jones 2009). Primary report not seen by the authors

While the role of cereals can be debated, other analysis using different datasets have yielded ^{14}C SPDs extremely similar to our own, including individual datasets for Ireland, Scotland and Wessex (see Shennan et al. 2013; Woodbridge et al. 2014; Whitehouse et al. 2014). Some minor differences were noted for Scotland (Timpson et al. 2014), but this might be the result of summing mainland and islands together. Presently, we still feel there is no reason to reject or substantially modify our previous conclusions that cereal agriculture remained more important on the Scottish Islands after it declined, or was abandoned, in most other parts of Britain.

Why do populations ‘boom and bust’? The case for climate

This brings us to the issue of explaining these fluctuations in population. At their most basic level ^{14}C SPD curves can be seen to represent periods in which the death rate exceeded the birth rate. Possible reasons include disease, famine, warfare and cultural practices such as infanticide. An overriding factor is one of the general health or nourishment of a population, such that their susceptibility to other factors is diminished. Shennan et al. (2013) speculated that population growth combined with soil depletion or over-reliance on a limited number of species (e.g., cereal crops and domestic animals) might provide one set of reasons, arguing climatic shifts could not explain the inter-regional variation in demography However, experiments indicate that prolonged cultivation does not necessarily lead to long-term soil exhaustion (Catt 1994; Hall 1905, 29–37; Reynolds 1999). The levels of impact that might cause such depletion of soils, e.g., by erosion, are generally only seen from the Bronze Age (Macklin, Lewin, and Jones 2014; Bell 1983). It is also possible that pests and diseases caught up with cereal agriculture (see Dark and Gent 2001). However, explanations for sharp population declines must account for the widespread, relatively rapid curtailing of life expectancy and prolonged lack of recovery. While all of the explanations listed might constrain population, causing disruption in birth and death rates, we argue that climatic events played a key role, exacerbating other trends or even triggering them. A recent review by Whitehouse et al. (2014) also attribute population decline in Ireland during the Neolithic to climatic change.

While climate change may be viewed as environmentally determinist, in any study of population decline during the Little Ice Age, it simply cannot be ignored (Fagan 2000). As Riede (2009, 309) writes: 'much of human material culture functions as a buffer against climatic changes, and the study of prehistoric population dynamics, estimated through changing frequencies of calibrated radiocarbon dates, therefore affords insights into how effectively such buffers operated and when they failed'.

Our view is theoretically akin to *environmental possibilism* (Ellen 1982), in that the environment offers challenges and opportunities that cultural strategies cope with, and adapt to, with varying degrees of long-term success. As such we can view climatic events as shocks to existing socio-economic systems testing their anticipation, resilience and ability to recover from such events (Pfister and Brázdil 2006; Pribyl, Cornes, and Pfister 2012). In response to these climatic shocks not all systems will fail; not all will succeed and many will be transformed. The outcome of climate change is then as much culturally determined as it is determined by the severity or persistence of such events. A key challenge is that if climatic changes impact cereal yields or inter-annual reliability, there may be alternative strategies to meet this challenge, including intensification of the human-cereal relationship or abandonment of it.

We will argue that in the colder north, where the effects were more extreme, increased reliance on barley was the adopted strategy, in both the Late Neolithic and the later Early Bronze Age. The alternative, we argue for England, but also seen in other parts of northern Europe (Rowley-Conwy and Legg 2015), was the abandonment of cereal farming in favour of mobility, and diversity, e.g., foraging, pastoralism, hunting and fishing.

The relationship of climate and cereal productivity

Climate does not affect demography directly, but through the medium of food. To understand the relationship between climate and population we must then understand how climate alters the availability of foods, in particular the productivity and reliability of staple foods. There are a number of key factors to consider, including the constraints on seasonality of cereals, the minimal temperature resistance of cereals, and the effect of climate during flowering.

Most wild wheat and barley are genetically tied to autumn sowing and spring flowering through day-length triggers and vernalization, a low temperature period necessary to promote flowering (Fuller and Allaby 2009). These have been recurrent targets for selection in crops, through new mutations after domestication and via selection from rare genetic variants in the wild (e.g., Cockram, Jones, and O'Sullivan 2011; Chen et al. 2013). Recent work indicates that the earliest barleys of the Near East and Neolithic Europe would have been constrained to autumn sowing and spring flowering, and thus the modern practice in northern latitudes of spring sowing and autumn harvests only became possible secondarily when new barley types became available with eastern (Iranian) ancestry; whether this happened already before the Neolithization of Britain is unclear (Jones et al. 2013). Similarly, emmer wheat is predominantly autumn sown, although rare spring-sown landraces exist in the present day (Zaharieva et al. 2010). The prehistory of these is as yet unknown, but it might be hypothesized that in the Neolithic emmer and barley were still tied to autumn sowing and vernalization. Climatic constraints like this may account for the correlation of the advent of cereal use in Britain with a period of rising winter temperatures around 4000 BC, as reconstructed from pan-European pollen datasets (Mauri et al. 2015). A millennium earlier the northern extension of cereals from the *Linearbandkeramik* zone would have been constrained by winter temperature reconstructed as one degree colder in Southwest England and at least two degrees colder in the west and far north (cf. Bonsall et al. 2002).

Differences in low temperature tolerance and water requirements between wheat and barley varieties may be significant. Periods of high temperature during flowering reduce yields experimentally while temperatures that are too low may be lethal (Porter and Gawith 1999). These are expected to differ between wheat varieties and between wheat and barley.

When the SPDs for Scotland, together with nearby northern England, are broken down into the contribution of direct dates on wheat (mainly emmer) and barley, striking differences between the resilience of these two cereals can be suggested (Fig. 3). Wheat represents many fewer of the Neolithic dates overall, and contributes none of the dates from the Scottish Islands (see also Bishop, Church, and Rowley-Conwy 2009). All of the dates of wheat come from the Early Neolithic, whereas Neolithic cereal dates from mainland Scotland are exclu- sively on barley after 3400 BC until the Bronze Age, a shift noted by Bishop, Church, and Rowley-Conwy (2009). From 3400 BC the contribution of dates on barley increases on the islands while decreasing on the mainland. Hazelnut use continues, but only on the mainland. After 3000 BC population continuity continues on the islands, while barley becomes rarer on the mainland, but hazelnut use increases. This suggests changes in agriculture from 3400 BC are reflected in a preferential persistence of barley and abandonment of emmer wheat. The greater low temperature tolerance and general stress resilience of barley can be suggested to have been important; barley farmers hence may have been 'pre-adapted' to this climatic shock (Bishop 2015).

In historical times the devastating effect of climate on European harvests has been associated with periods of prolonged summer rainfall, during and following harvest, resulting in decreased yields and poor grain storage, as well as with high inter-annual variability, e.g., shifts of 1.5°C between harvests (Pfister and Brázdil 2006). Successive years of drought will also be detri- mental, as shown for emmer and spelt in the Butser Farm experiments (Reynolds 1981). Thus we must consider rainfall as a critical variable.

Correlation of ^{14}C SPDs with climatic changes in Neolithic and Early Bronze Age Britain

Correlating evidence for climate change with population is far from straightforward. In part this occurs because even on the same site different climatic proxies don't always agree (Langdon and Barber 2005), further complicated by different interpretations of the same dataset (Schulting 2010).

For the purpose of this paper we are interested in climate corresponding to four periods of cultural transition representing significant shifts in the importance of cereal agriculture (Fig. 1, Fig. 4: a–d). While there are a large number of different proxies providing Holocene palaeoclimate data for Northern Europe (e.g., Mokeddem et al. 2010; Van Vliet-Lanoë et al. 2014; Roland et al. 2014; Brown, Bailey, and Passmore 2015), we have selected three that represent some of the key variables relevant to cereals, namely tempera- ture, from the Greenland ice-core (Alley 2004), rainfall inferred from studies of palaeohy- drological proxy data from peat deposits in England, Northern Ireland and Scotland (Hughes et al. 2000; Roland et al. 2014; Macklin et al. 2000; Anderson 1998; Anderson, Binney, and Smith 1998), and north Atlantic sediment cores that capture ice rafted debris as haematite stained grains (Fig. 4). The last provides information on changes within ocean circulation systems, and hence periods of climatic fluctuations, instability and storminess (Bond et al. 1997, 2001). The start of the Neolithic, just after 4000 BC, coincides with a thermal maximum with temperatures declining thereafter (Larocque and Hall 2004; Mauri et al. 2015). Winter temperatures were higher than a millennium earlier while rainfall was lower (Mauri et al. 2015; Fig. 4). Indeed, this combination of warmer and drier conditions was suggested by Bonsall and others (2002) to account for the adoption of farming across northwest Europe.

A key transition took place from 3600 BC to around 3350 BC, the transition to the Middle Neolithic (Fig. 4: a). We infer a marked downturn in cereals and population across most of Britain (Fig. 1C), except in the Scottish Isles (Fig. 1A), with evidence for wheat declining in northern England and Scotland while barley persists (Fig. 3). This period correlates with the hypothesized population collapse identified by Shennan et al. (2013) for Britain, but when taken on their own population and cereals increase in the Scottish Isles. Selected proxies indicate a marked drop in temperatures, followed by a shift to wetter conditions from 3500 to 3000 BC across parts of Europe (cf. Magny 2004; Magny and Haas 2004; Caseldine et al. 2005), and along with higher levels of haematite-stained grains associated with increased ice-rafting (Fig. 4). The latter has also been noted to broadly correlate with other proxies for colder wetter climatic conditions (cf. Langdon and Barber 2005; Mauquoy et al. 2008). Other records also demonstrate rhythms of increased wetness at 3750 and 3450 BC (Barber, Chambers, and Maddy 2003; Johnstone, Macklin, and Lewin 2006; Langdon et al. 2012), while alluvial records show extreme flooding events in northern England at this time (Macklin, Johnstone, and Lewin 2005). High resolution geochemical and pollen analyses of sediment cores from Templevanny Lough, Western Ireland provide a closer insight into these changes (Stolze et al. 2013).

A number of climatic events, associated with increased precipitation, punctuated by drier phases were identified. Notably these episodes were often short-lived, from 25 to

100 years, but could be tied directly to changes in human activity. The period from 3360 to 3290 BC was identified as particularly cool and wet, and attributed as the main cause behind human abandonment of the area resulting in total woodland regeneration. Subsequent climatic amelioration around 3110–3050 BC was proceeded by two short periods of high rainfall between 3060–3030 BC and 2940–2900 BC.

Mobility, dietary diversity, storage and exchange have all been highlighted as important strategies for dealing with uncertainties in subsistence (Halstead and O'Shea 1982). The climatic shifts of the mid fourth millennium BC would appear to have been detrimental to cereal farming, but barley, favoured on the Scottish islands and increasingly so in northern Britain (see Fig. 3), was more resilient to these changes than wheat. In the face of uncertainty Scottish Neolithic island communities appear to have invested more in agriculture and cereal storage. In southern Britain we argue that diversity through the exploitation of wild foods like hazelnuts, along with mobility, increasingly became the strategies adopted after poor cereal yields (see Figs. 1 and 3).

Around 3200 BC warmer temperatures returned, potentially stimulating short warm, dry phases; recorded from Scotland, ca. 3100 BC and ca. 3030 BC (Moir et al. 2010) and between 3250 BC and 2810 BC in Ireland (Langdon et al. 2012; Whitehouse et al. 2014; see also Stolze et al. 2013). Such conditions potentially aided cereal farmers in the Scottish Isles, and even if the populations elsewhere in Britain generally continued a trend away from cereals, possibly some short-lived resurgence in their use occurred. 2900 BC (Fig. 4: b) saw temperatures drop rapidly to a low around 2800 BC, while Swindles and others (2007) refer to a cooler wetter phase preceding 2800 BC (Fig. 4). Multi-proxy studies from Scottish Lochs note a rapid cooling event at ca. 2850 BC (Mokeddem et al. 2010), while increased sea-ice is indicated off the Orkney Isles (Lee et al. 2010). Macklin, Johnstone, and Lewin (2005) infer extreme flooding across most of Britain focused on 2890 BC. It is in this period that population even in the Scottish islands declines, along with hazelnut consumption on the mainland (Fig. 3). After this there is almost no evidence for cereals at all for a few centuries, although a few sites on both mainland and island Scotland have produced directly dated barley until as late as perhaps 2600–2500 BC. At this point there is a real possibility of a complete break in farming, even if it had persisted in some corners of Scotland until this time.

The causes are not necessarily the same as those associated with the demise of population in the preceding centuries. From around 2900 to 2800 BC in the Scottish Islands falling tempera- tures, rather than climatic instability, are the more likely cause of low and declining population levels, and colder conditions are clearly visible within the climatic data from the far north (Mauri et al. 2015).

With the transition to the Early Bronze age, 2300–2200 BC (Fig. 4: c), despite being the global '4.2.K event' (Bond et al. 2001), there is little evidence for a period of climatic disruption in Britain (Roland et al. 2014). Indeed dune systems on the north-west coast of Scotland indicate a relatively stable period 2390–2050 BC (McIlvenny, Muller, and Dawson 2013). This stable, warmer and drier period was associated with expansion of the Beaker culture into Britain, but was curtailed around 1900 BC perhaps by a return shift towards colder and wetter conditions (Fig. 4: d). The cereal SPDs suggest to us a response in terms of less cereal agriculture and fewer people. After this time we see apparent fluctuations in human and cereal population with striking comparability to palaeoclimatic proxies, in particular with respect to the mainland Middle Bronze Age boom and Late Bronze Age bust (Fig. 4). While a full exploration of such subsistence-demography-climate linkages through the Bronze Age is beyond the scope of this paper, suffice it to say that boom bust cycles were often out of step in the Scottish Islands and elsewhere, suggesting regional differences in strategy that deserve further investigation and debate (cf. Armit et al. 2014).

The nature of Neolithic subsistence, non-analogue economies and alternative subsistence strategies

The transition to agriculture signifies a pivotal economic change in prehistory, but it has been argued that early cultivators of the Near East represent non-analogue societies often mislead- ingly compared to ethnographic village farmers (Asouti and Fuller 2013) and the same is likely true for Neolithic Britain.

Early Neolithic subsistence relied on a limited range of crops, with a significant degree of wild food use, archaeobotanically unparalleled in later periods. Early Neolithic societies also likely differed in terms of food processing and storage. Querns are rare on British Neolithic sites in contrast to the Bronze Age (Stevens 2007), and the discrepancy between the charred evidence for cereals and the lack of evidence for dental caries (Jones and Legge 2008; McKinley 2008) is perhaps explained through cereals not always being ground. Thus rather than placing Neolithic Britain in a cultural world of bread, grinding and ovens (see Fuller and Rowlands 2011), we should consider alternative processing and consumption patterns, such as compound foods that mixed wild plants with cereals, as identified recently in the Dutch Neolithic (Kubiak-Martens, Brinkkemper, and Oudemans 2015). Furthermore the lack of chaff from Early Neolithic sites has been explained through the dehusking of emmer spikelets prior to storage, perhaps implying their use as a seasonal resource (Stevens 2007). Long-term storage of cereals might also be questioned, in the absence of grain storage pits, four-post structures and suitable house struc- tures in mainland Neolithic Britain just prior to 3350 cal. BC, that might have offered a buffer against failed harvests.

We concur with Bishop (2015) on the need for more archaeobotanical analysis of the British Neolithic, as well as the Bronze Age. We would contend, however, that the use of radiocarbon dates as data (SPDs) is a powerful tool for identifying demographic and subsistence change that can be correlated with climatic events and cultural developments.

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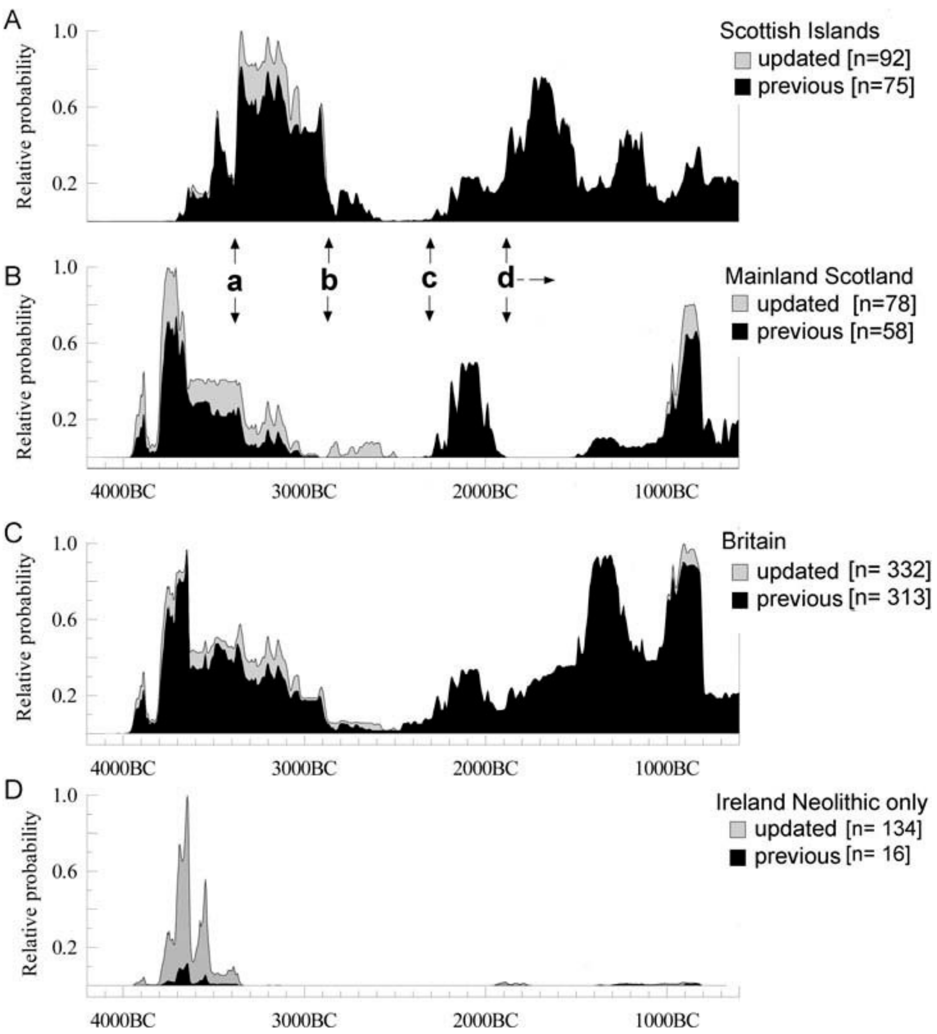

Figure 1 Comparison of calibrated SPDs for crop direct dates, from (A) Scottish Islands and (B) Scottish mainland comparing the results of Stevens and Fuller (2012) [black] with an updated dataset [the larger grey distribution]. (C) An updated all British, including the updated Scottish dataset and English and Welsh the dates from Stevens and Fuller (2012). (D) Irish Neolithic SPD including Irish dates from Whitehouse et al. (2014) and Stevens and Fuller (2012). Indicated on this diagram are the proposed subsistence transitions of Stevens and Fuller (2012): (a) arable farming (and population) decline on the mainland during Middle Neolithic while arable production expands on islands, (b) arable farming collapse every- where in the Late Neolithic, (c) possible reintroduction of crops and farming in the Early Bronze Age with population boom, (d) subsequent Bronze Age boom and bust cycles.

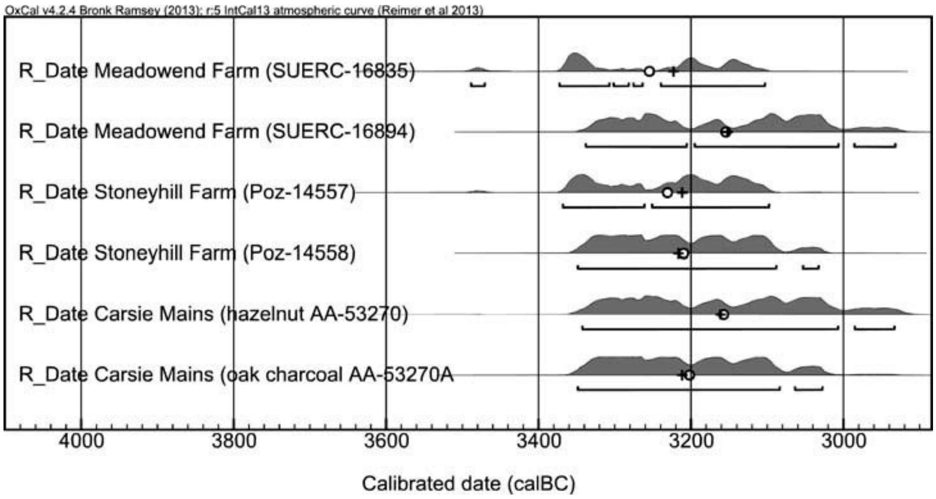

Figure 2 Calibrations of six radiocarbon dates; Meadowend Farm Stoneyhill Farm and Carsie Mains (see Table 1; Bishop 2015; CANMORE 2015) suggested by Bishop (2015) to contradict Stevens and Fuller (2012), but which fit our recognized continuity of cereals up to 2900 BC.

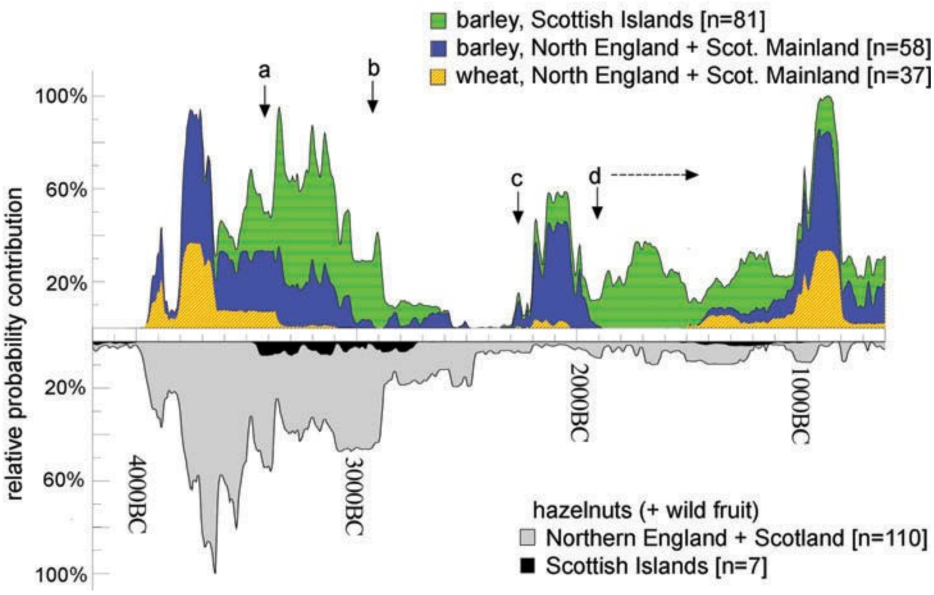

Figure 3 SPD distribution of direct AMS dates on identified crops, indicating the relative contribution of dates on wheat (and flax [n = 2]) from Northern England and Mainland Scotland, barley from No rthern England and Mainland Scotland, and barley from the Scottish Islands; inverted in grey and black is the SPD for direct dates on hazelnut shell and other wild foods (hawthorn & crab-apple [n = 2]), indicating the contrast in wild food use continuity through the Neolithic, but not the Bronze Age. Based on the updated dataset of Fig. 1.

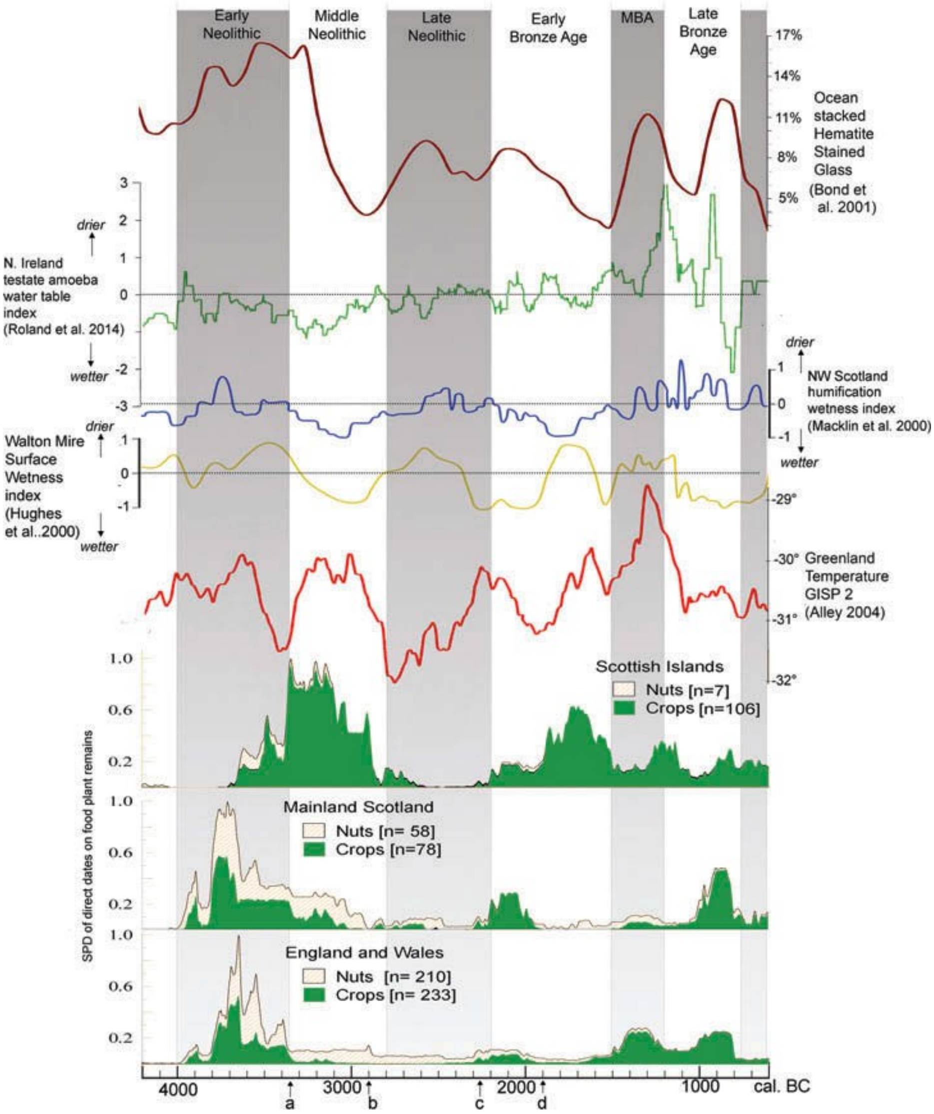

Figure 4 Select proxies for climate change, 4200–600 BC, correlated with the SPD on direct crop and nuts dates from Scottish Islands, Mainland Scotland and England plus Wales. Scottish SPDs based on the updated dataset of Fig. 1. England and Wales is based on Stevens and Fuller (2012). The relative contribution of direct dates on crops versus nuts are indicated. Subsistence/demographic transitions discussed in the text, a-d, indicated along timescale at the bottom. Wetness indices are normalized (after Roland et al. 2014).