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The impact of the Neolithic agricultural transition in Britain: a comparison of pollen-based land-cover and archaeological ^{14}C date-inferred population change

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ABSTRACT

Britain's landscapes were substantially transformed as a result of prehistoric agricultural clearance and deforestation. This process began in the Neolithic and is recorded in multiple different "archives", notably those deriving from archaeological site excavations and from off-site pollen records. This paper assesses the extent to which these two independent sources show common trends and timing in terms of demographic and environmental change across Britain during the millennia prior to and after the appearance of the first farming communities. This period is analysed within the wider context of the 9000–3400 cal. BP time frame. We compare land-cover change aggregated from 42 pollen records employing a pseudo-biomisation approach with radiocarbon (^{14}C) date probability density functions from archaeological sites, which have been inferred to indicate shifts in population density. We also compare these results with selected palaeoclimate records in order to test alternative drivers of landscape change. At a broad geographical scale, pollen and archaeological records reveal very similar phases between 9000 and 3400 cal. BP. Following an initial demographic shift and landscape opening during the Late Mesolithic (~7600 cal. BP) conditions were stable until 6400 cal. BP. Around 6400–6000 cal. BP (Mesolithic–Neolithic transition) a new phase began of forest disturbance and population increase. By 6000–5300 cal. BP early Neolithic population growth is clearly evident in the archaeological record with significant impacts on woodland cover, which is evident in the pollen record, reaching a maximum between 5700 and 5400 cal. BP. Between 5300 and 4400 cal. BP the archaeological record is inferred to indicate reduced mid-late Neolithic landscape impact, and this is matched by evidence of woodland re-establishment in the pollen record. Between 4400 and 3400 cal. BP renewed late Neolithic woodland clearance coincided with further population increase, which continued into the early Bronze Age. A very similar pattern is evident using a smaller-scale dataset from Scotland alone. Thus, rather than being slow and progressive, the initial Neolithic cultural transformation of Britain's landscape was relatively rapid and widespread; however, after several centuries of expansion, this process was halted and even reversed, before recommencing during the later 3rd millennium BC (after ~4500 cal. BP). The impact of Neolithic forest clearance is clearly detectable as a driver of regional-scale mid-Holocene landscape change, alongside variations in climate. The Neolithic agricultural transition began a long process of anthropogenically-driven land-cover change in the British Isles, which has continued up until the present-day.

1. Introduction

Prehistoric agricultural land clearance, burning and deforestation have transformed the landscapes of the British Isles since the Mesolithic–Neolithic agricultural transition around 6000 years ago (~4000 BC). Evidence of cultural landscape transformation has been preserved in numerous different archives, including archaeological sites and fossil pollen records, which provide information

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on past vegetation and land-use change. The expansion of agriculture in Europe was strongly linked to the Neolithic demographic transition (Bocquet-Appel et al., 2012). Both demic diffusion by migration and cultural diffusion of ideas are thought to have been important factors in initiating this agricultural shift (Lemmen et al., 2011). The Mesolithic–Neolithic transition in the British Isles (see e.g. Darvill (2010) for standard definitions of these and other period names in Britain) is characterised by a number of key environmental changes and economic shifts (Cayless and Tipping, 2002). These include anthropogenic vegetation disturbance, fluctuating patterns of burning, and the elm (*Ulmus*) decline (~5650–5600 cal. BP). Cereal cultivation was one of the earliest elements of Neolithic life to be introduced to Northwest Europe, with the arrival of farming occurring over a 200–300 year period around 6000 BP. Whittle et al. (2011) describe the process of spread of the Neolithic in Britain as time-transgressive and regionalised, beginning in southeast England and taking over two centuries to spread to other areas. However, Bocquet-Appel et al. (2012) demonstrate that compared with most other regions of Europe the spread of farming to and then through Britain was extremely rapid and must have involved sea routes, not just overland expansion (cf. Collard et al., 2010). There are numerous factors that are likely to have influenced the nature and spread of the agricultural transition, and these will have had different impacts and consequences in different regions. Among them, Gronenborn (2009) suggests that the emergence and spread of farming resulted from climate-induced crisis periods.

Research that attempts to address whether the Neolithic transition resulted from demic migration or cultural diffusion, and whether this was gradual or more rapid, has been limited by a focus on single sources of spatially-aggregated data, either archaeological or palaeoecological. Whittle et al. (2011), for example, commented that few archaeological studies of Neolithic subsistence incorporate pollen data, partly due to the geographical disjunction between the varying sets of evidence. Each approach on its own has potential biases and limitations. For example, archaeological radiocarbon (^{14}C) dates derive from a combination of different contexts and site types including domestic settlements, burials and monumental sites, and the balance between these varies temporally and spatially within the archaeological record in later prehistory. Similarly, pollen-inferred vegetation changes during the mid-Holocene had multiple drivers, including climate change and long-term ecological dynamics, as well as anthropogenic impact. It has also been argued (e.g. Brown, 1997) and demonstrated in simulation experiments (Tipping et al., 2009) that regional pollen diagrams lack sufficient spatial resolution to detect isolated clearings and the effects of subtle human impacts. In order to overcome these archive-specific biases, in this study we compare two approaches – pollen-inferred land-cover reconstruction and ^{14}C date distributions from archaeological sites – for Britain as a whole. One advantage of this multi-archive approach is that changes in vegetation and land-use can be directly compared with inferred demographic change on a common calibrated radiocarbon timescale. We also compare these datasets with selected palaeoclimate records in order to explore the prospective roles of human activity and climate in influencing Holocene land-cover change in Britain.

2. Methods

2.1. Pollen-inferred land-cover change

Various approaches have been employed to utilise pollen in reconstructing land-cover change (e.g. Behre, 1986; Berglund, 1991; Gaillard et al., 1994; Sugita et al., 1999; Sugita, 2007; Favre et al., 2008). Within the pseudo-biomisation (PBM) approach used here, pollen count data from ^{14}C-dated sediment sequences are transformed into records of natural and culturally-modified land-cover change according to the shifting dominance of different taxa through time (Fyfe et al., 2010). This method uses the indicator species approach (Behre, 1981) to assign pollen taxa to different land-cover classes (LCCs) and is an extension of the transformation of pollen counts to biomes using plant functional type (PFT) scores (Prentice et al., 1996; Peyron et al., 1998; and Gachet et al., 2003). The version of the PBM used here includes three woodland LCCs (coniferous, deciduous, wet/carr) and three open-ground classes (pastoral/meadow, arable, heath) (see Fyfe et al. (2010) for a full list of pollen taxa assigned to each LCC). The PBM transformation allows 'affinity scores' to be calculated for each pollen sample: these values range between −100 (open pasture/heath/meadow/arable classes) and +100 (closed arboreal classes). Semi-open land-cover types are determined using a threshold value of 20 (Fig. 1a) (see Fyfe et al., 2010 for detailed methods). Although this approach is not based on a rigorous understanding of the pollen–vegetation relationship, the technique allows straightforward analysis of broad land-cover change.

The PBM method has previously been applied to pollen sites from two case study regions of the UK (northwest Scotland and southwest England) (Fyfe et al., 2010). In the current study, it has been applied to a larger dataset of 42 well-dated pollen records from Britain. These were obtained from the European Pollen Database along with additional records from southwest England (see Fig. 2 and Appendix 1 for details). Radiocarbon dates were calibrated for all sites using CALIB 5.0.2 (Stuiver et al., 1986–2005) and the mid-points of the calibrated age ranges were used to construct age–depth models using linear interpolation. The LCCs assigned to each pollen sample have been summed in 200-year time slices according to their interpolated date in order to create a spatially-aggregated land-cover record for the whole of Britain over the last 9000 years. These values have then been converted to percentages of total land-cover for comparison with the archaeo-demographic data. In addition, we have analysed a sub-set of the records covering only Scotland, in order to test the extent to which trends are scale-dependent. The pollen records used in this synthesis have been limited by data availability and are only a fraction of the total number of published pollen diagrams for the British Isles. Geographical coverage is uneven, with few sites included from Wales and central England, for example. Inclusion of a larger number of sites in future will allow our results and conclusions to be tested more robustly.

2.2. Inferring demography from dated archaeological sites

Summed ^{14}C date densities from multiple sites have been extensively used as a proxy to estimate demographic change (e.g. Shennan and Edinborough, 2007; Williams, 2012 for a review). Within the British Isles, Collard et al. (2010) found evidence for a rapid increase in population density that coincided with the appearance of cultigens around 6000 cal. BP. Significant further population fluctuations have also been identified throughout the course of the Neolithic in Europe (Shennan and Edinborough, 2007), which are also reflected in records of charred cereals within the UK (Brown, 2007). Greater densities of dated archaeological sites are believed to relate to higher human population densities, and changes in the summed probability distributions of calibrated ^{14}C dates derived from different site phases can therefore provide a proxy for changes in relative population size despite potential taphonomic and visibility issues (Collard et al., 2010). Thus, Collard et al. showed that the summed probabilities for all sites, including visible monuments of types not present in the Mesolithic, and those for non-monument sites alone produced exactly the same pattern for the British earlier Neolithic. As part of the European Research Council-funded EUROEVOL research project, radiocarbon dates from various public and private sources

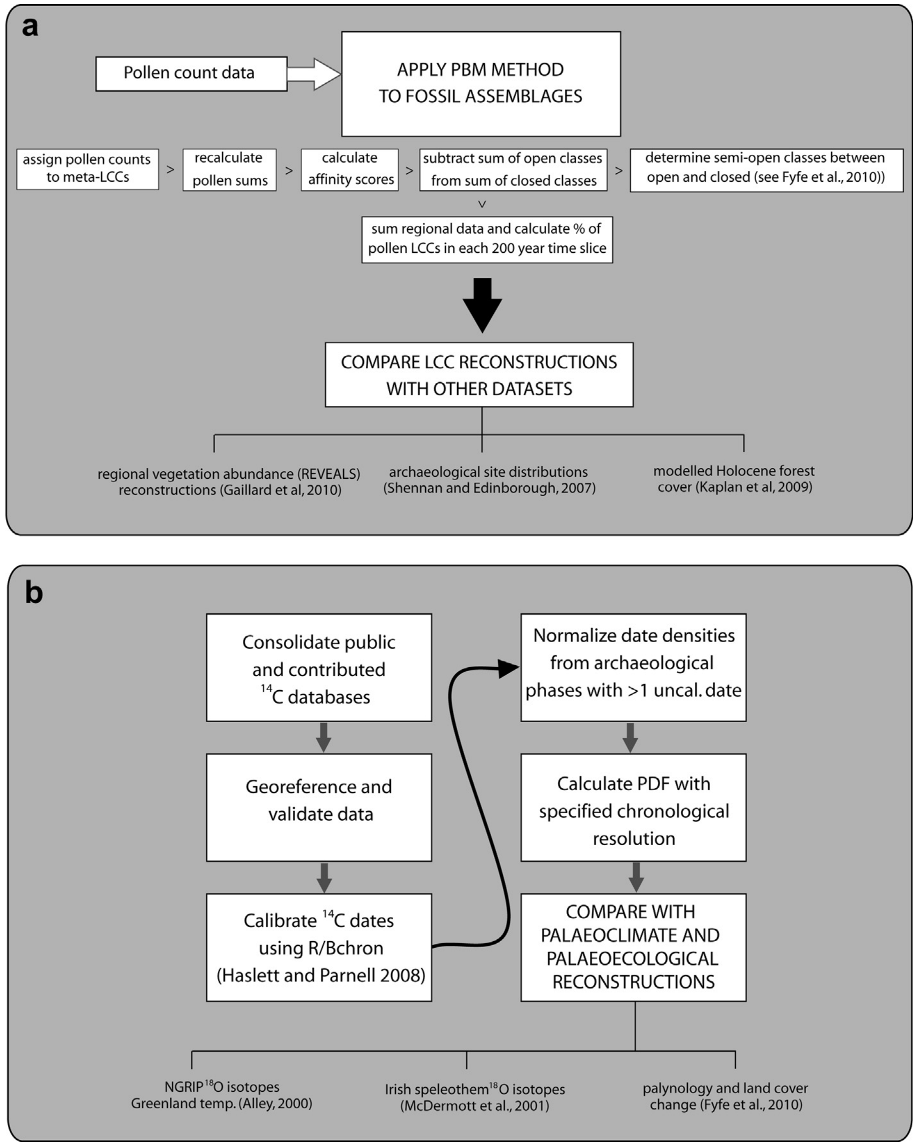

Fig. 1. a) The pseudo-biomisation approach to land-cover reconstruction, b) methodology for inferring demography from archaeological site radiocarbon dates.

covering both Britain and Europe have been collected and consolidated into a common database. Fig. 1b outlines the methodology used to generate the demographic proxy. It should be noted that all available dates that were not obviously incorrect have been included, even those with relatively large standard deviations by modern standards, on the basis that this procedure would be likely to obscure or smear the patterns in which we are interested, rather than the reverse, and would therefore be conservative. A summed date density distribution has been produced through calibrating the archaeological dates using the IntCal09 calibration curve (Reimer et al., 2009) and the R/Bchron package (Haslett and Parnell, 2008, R Development Core Team, 2011). In instances where multiple dates were recorded at a site for a single archaeological phase the calibrated date distributions for all the dates were summed and then normalised to have the weight of a single date. The resulting density distribution has been binned into 200-year intervals matching the temporal resolution of the pollen analysis (Figs. 3 and 4), and 10-year intervals for comparison to palaeoclimate data (Fig. 5). The archaeological data include 2413 dates from 914 sites across the UK covering 9000–3400 cal. BP, which includes the British Neolithic transition (~6000–4500 cal. BP). Archaeological site coverage is much greater in extent than the pollen site coverage that was available for use in this synthesis.

3. Results

3.1. Land cover and demographic change

3.1.1. Britain

Significant changes in the pollen-inferred land-cover record are identified as those that persisted for more than one 200 year time slice, and phases that correspond with changes in inferred-population are highlighted. The land-cover reconstruction for the whole of Britain over the last 9000 years (Fig. 3a) shows an overall trend from dominance of deciduous woodland during the early Holocene to increasing landscape openness and diversification during the late Holocene. The percentage of pollen samples assigned to the deciduous woodland LCC reached values of ~95% prior to ~7500 cal. BP, and declined to values below 20% after 2000 cal. BP. The onset of this change can be traced back to the early Neolithic, but the main transformation began in the late Neolithic,

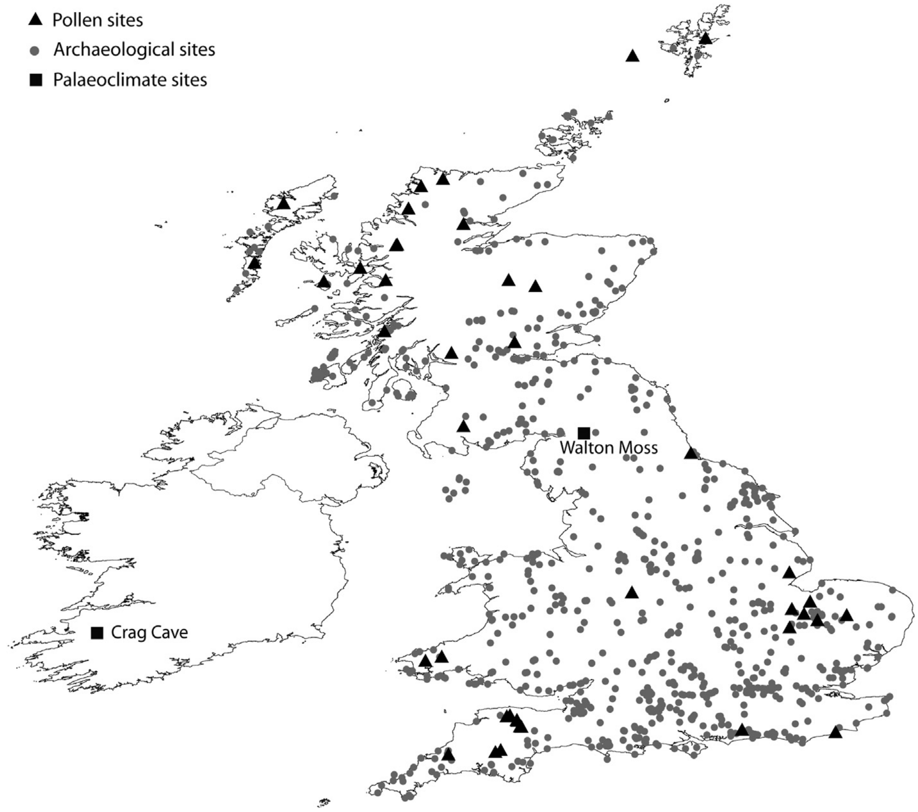

Fig. 2. Distribution of archaeological and pollen sites across the British Isles with locations of palaeoclimate records from Crag Cave and Walton Moss.

around 4400 cal. BP. At the scale of Britain as a whole, forest cover appears to have decreased progressively between then and Medieval times.

The pollen-based land-cover record has been compared with the archaeological site radiocarbon date density record for the opening millennia of this long process of landscape transformation. The land-cover reconstruction and inferred demographic record from ^{14}C-dated archaeological sites show remarkably similar patterns between 9000 and 3400 cal. BP (Fig. 3b). Prior to 6400 cal. BP, deciduous woodland accounted for over 75% of Britain's land-cover according to the pollen data used in our reconstruction. Archaeologically this corresponds to late Mesolithic times, and is associated with low and stable ^{14}C density values for inferred population levels. A small demographic increase can be inferred from the archaeological ^{14}C date record at ~7600 cal. BP, which is more clearly visible in Fig. 5 with its higher date resolution than Fig. 3, and is followed by a significant decrease in deciduous woodland at this time. Short-lived decreases in woodland also occurred around 8600–8400 and 8200–8000 cal. BP, but were not accompanied by any inferred population increases. These pre-Neolithic changes are consistent with other palaeoecological and bio-archaeological evidence for Late Mesolithic landscape disturbance in upland regions such as Dartmoor and the Pennines, for example, by use of fire (e.g. Caseldine, 1999; Blackford et al., 2006).

From 6400 cal. BP, there appears to be a more significant demographic shift to higher population levels, simultaneous with a decline in deciduous woodland and an increase in semi-open arboreal land-cover. The period from 6400 to 6000 cal. BP could thus represent either an initial "pioneering" agricultural stage at the Mesolithic–Neolithic transition, or be an artefact of ^{14}C dating imprecision for both archaeological and palynological records. In the light of the high-resolution dating work of Whittle et al. (2011) and Brown's (2007) direct dating of Neolithic cereal grains, it seems more likely to be the latter, as interpolating sample ages between ^{14}C dates for pollen records reduces chronological precision in comparison with the dating of individual cereal grains or archaeological sites. What is clear is that population levels peaked during the subsequent stage between 6000 and 5300 cal. BP, during which time deciduous woodland declined and semi-open land-cover increased further. This shift was also accompanied by the loss of wet woodland/fenland-cover types and increased heath and pasture/meadow LCCs in the pollen records used here. Both pollen and archaeological evidence therefore imply that Britain's woodland cover, previously almost continuous, became a landscape mosaic during the early Neolithic with abundant deciduous woodland, but also with significant areas of grassland, arable land and heathland, whose importance would have varied regionally. Between 5300 and 4400 cal. BP the archaeological ^{14}C record implies a reduced mid-late Neolithic population, and this is matched by indications of woodland re-establishment in the pollen record between 5400 and 5000 cal. BP. From 4200 to 4000 cal. BP renewed late Neolithic woodland clearance coincides with further population increase, which continued into the early Bronze Age.

For the period 9000–3400 cal. BP, there is a significant negative correlation between the inferred deciduous woodland land-cover and ^{14}C date density records ($r = -0.884$, $p = 0.001$) and a significant positive correlation between the semi-open pasture and ^{14}C date density records ($r = 0.777$, $p = 0.008$). None of the other land-cover types are significantly correlated with the inferred population record. This indicates that as population increased woodland cover declined and semi-open pasture land-cover increased in extent.

3.1.2. Scotland

In order to investigate the scale dependence of these results, we have also analysed the data for Scotland alone, where there is

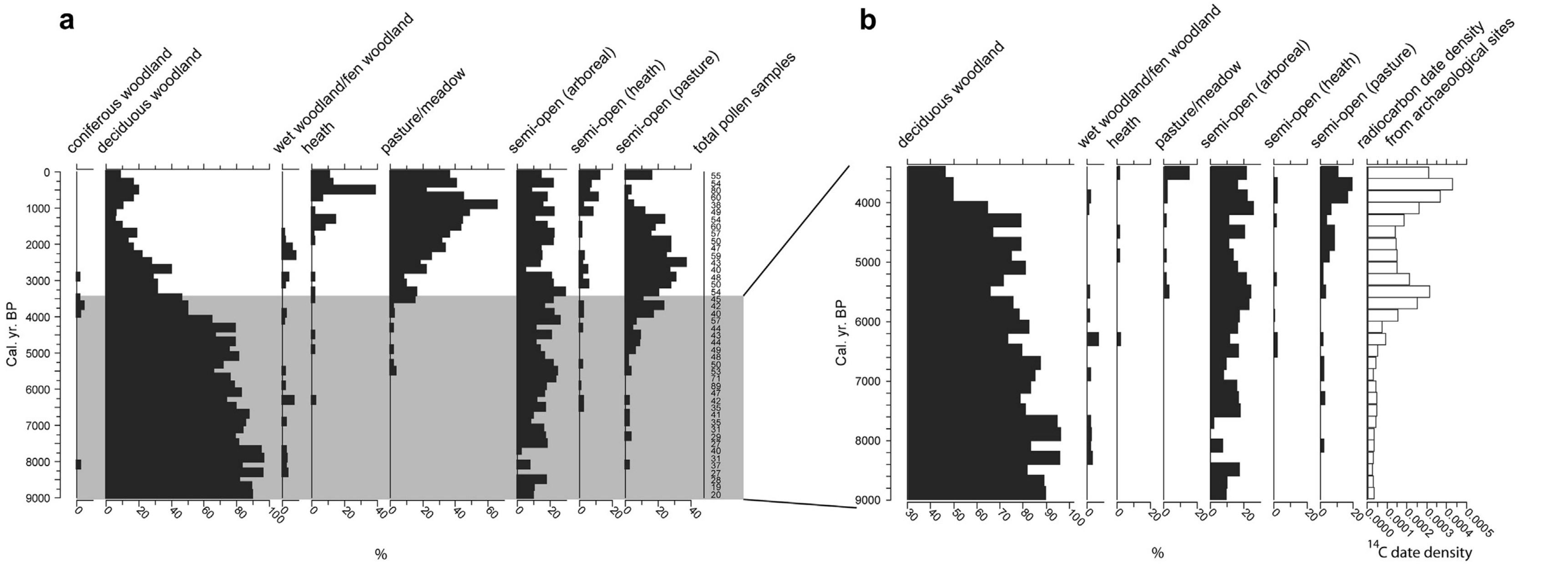

Fig. 3. a) Pollen-inferred land-cover reconstructions for Britain (0–9000 cal yr BP) per 200 year time slice, b) pollen land-cover reconstructions compared with ^{14}C date distributions from archaeological sites (9000–3400 cal yr. BP) per 200 year time slice.

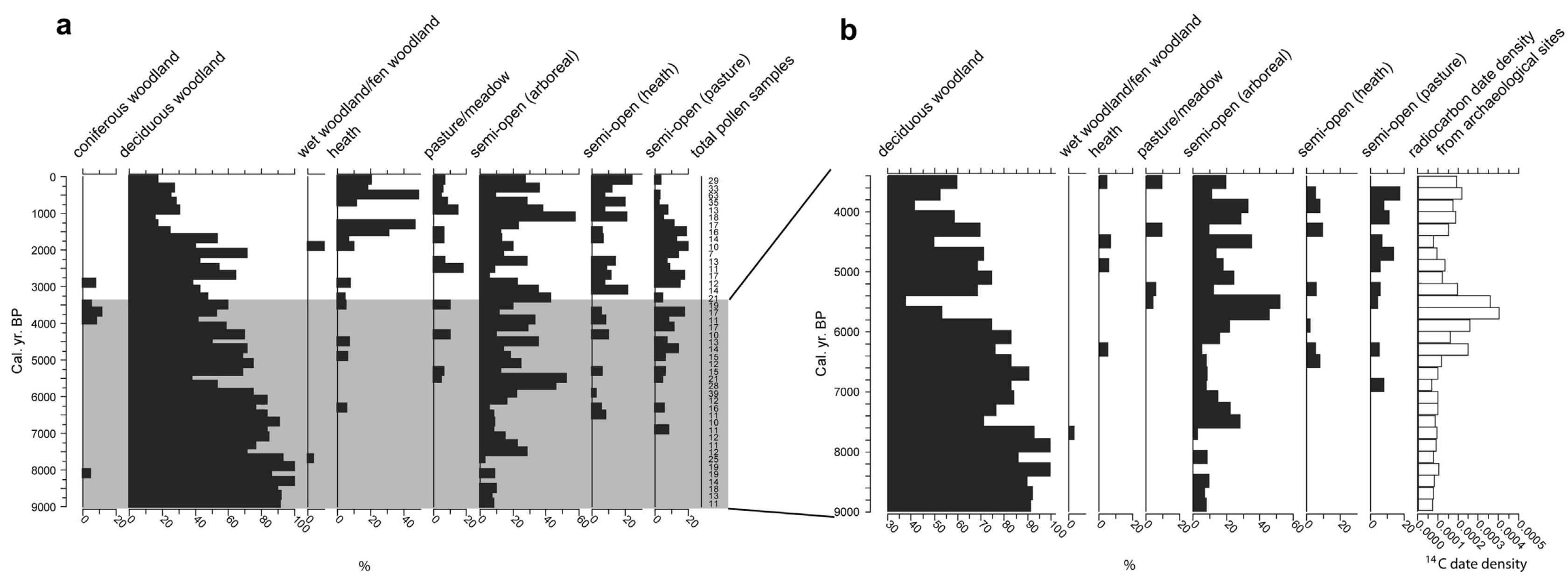

Fig. 4. a) Pollen-inferred land-cover reconstructions for Scotland (0–9000 cal yr BP) per 200 year time slice, b) pollen land-cover reconstructions compared with ^{14}C date distributions from archaeological sites (9000–3400 cal yr. BP) per 200 year time slice.

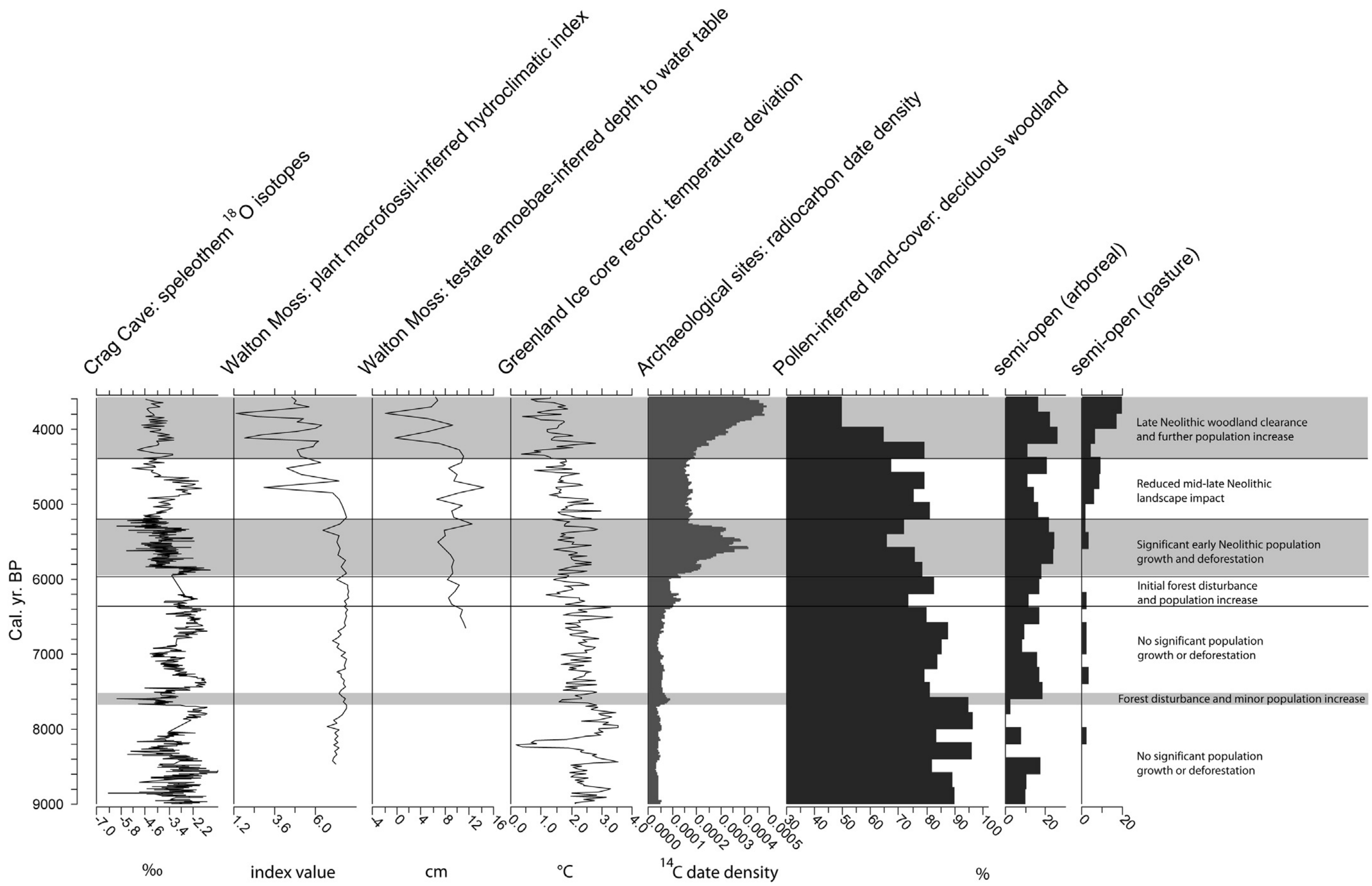

Fig. 5. Palaeoclimate records from Crag Cave, Walton Moss and the Greenland ice core record compared with an annual record of ^{14}C date distributions from archaeological sites and pollen-inferred land-cover change (200 year time slices) between 9000 and 3600 cal yr. BP. Zones relate to transitional periods identified in the pollen and archaeological records and shaded areas illustrate periods of significant increases in population levels.

relatively good spatial congruence between pollen and archaeological sites (Fig. 2), particularly for the west and central lowlands. The land-cover record is based on pollen data from 19 sites and archaeological ^{14}C date densities on 211 sites. There are ≥10 pollen samples used in all but one of the 200-year time intervals used for the Scottish land-cover reconstruction. In most other areas of Britain, there are an insufficient number of pollen sites or samples in our analysis to allow meaningful regional land-cover reconstruction. Significantly, the land-cover and archaeological site records for Scotland show the same overall pattern of change as for Britain as a whole for the period 9000–3400 cal. BP, although with minor differences in timing (Fig. 4). Within the Scottish record there is a significant decrease in deciduous woodland between 5800 and 5400 cal. BP from ~80% to ~40%, matched by an increase in semi-open land-cover and followed by a more gradual long-term decline in woodland after 4200 cal. BP. The Scottish record of archaeological ^{14}C date densities indicates a marked rise in population between 6200 and 5600 cal. BP, which is slightly earlier than the inferred reduction in deciduous woodland land-cover. In any event, it suggests that the overall trend of landscape change prior to, during and immediately after Neolithic times applied to most, if not all, of Britain.

3.2. Palaeoclimate, land-cover and population change

The close temporal correspondence between archaeological ^{14}C date density and pollen-inferred land-cover records for the period of the British Neolithic implies that a relationship exists between the two, namely, that early farming societies were an important agent of mid-Holocene land-cover change. However, vegetation was also subject to other drivers, particularly climate change. In consequence, we compare our land-cover reconstructions with selected palaeoclimate records for the period 9000–3600 BP. We use a high-resolution well-dated stalagmite oxygen isotope ($\delta^{18}O$) record from Crag Cave (southwest Ireland) (McDermott et al., 2001), a palaeoclimate record from Walton Moss peat bog (Cumbria, England) (Mauquoy et al., 2001), and palaeo-temperatures inferred from the Greenland $\delta^{18}O$ ice core record (Vinther et al., 2009). The Crag Cave speleothem $\delta^{18}O$ sequence has been interpreted as a record of temperature change. Within this record McDermott et al. (2001) identified cooling events at 7730, 7010, 5210 and 4200 cal. BP, which are suggested to reflect weaker North Atlantic thermohaline overturning. The Greenland ice core sequence provides a record of temperature deviation and reveals a number of shifts, the most significant of which occur ~7600, 6500, 6300, 4300 cal. BP. The climate record from Walton Moss is based on testate amoebae-inferred depth to water table and a plant macrofossil-inferred hydroclimatic index (Hughes et al., 2000).

The palaeoclimate records from Walton Moss and Greenland do not show any trends that correspond with shifts in the ^{14}C date demographic or land-cover records (Fig. 5), particularly any change which could explain the loss of woodland cover between 6400 and 5400 cal. BP. The stable isotope record from Crag Cave shows a partial similarity with both archaeological and pollen-inferred trends; for example, a shift to more negative isotope values around 7700–7400 and 5800–5200 cal. BP. For the latter, the initial

woodland reduction phase (6000–5400 cal. BP) would then correspond to overall cooler conditions, while the subsequent forest recovery phase (5400–4400 cal. BP) would equate to warmer temperatures. At first sight, this pattern is counter-intuitive, since a warmer climate in Britain is more likely to be favourable to the spread of arable farming in particular. The major periods involving increased population evident in the archaeological site ^{14}C density record (Fig. 5: shaded time periods) correspond with transitional periods (highlighted by black lines) in the pollen-inferred land-cover record, involving decreased woodland and increased semi-open land. By contrast, climate records do not show any clear overall relationship, a conclusion also reached by Schulting (2010) who presented a number of contradictory palaeoclimate records focused on the 6000/5800 cal. BP time period.

4. Discussion

4.1. The Neolithic agricultural transition in Britain

Common trends and timing in land-cover and population density change for the period 9000–3400 cal. BP imply that increases in human population levels and the advent of Neolithic farming systems were the primary cause of the mid-Holocene decline in woodland and increase in open land in Britain. Although this conclusion is far from new at a local scale, it has not been universally accepted at the scale of Britain as a whole, where climate change has been seen by some authors as the most important driver of mid-Holocene shifts in vegetation cover and composition (e.g. Huntley, 1990, 1999; Cayless and Tipping, 2002; van Geel and Mauquoy, 2010).

Corresponding patterns of change in the land-cover and demographic records are highlighted in Fig. 5. These include a first step in demographic growth and opening of the forest during the later Mesolithic, around 7600 cal. BP (~5600 BC), after which population and vegetation appear stable until ~6400 cal. BP. From 6000 to 5400 cal. BP, archaeological ^{14}C date densities are consistent with an 'S'-shaped demographic growth curve; this was associated with a decline in pollen samples assigned to the deciduous woodland LCC from ~85% to ~65%. Thus, the initial impact of the Neolithic transition was substantial and took place over no more than a few centuries, rather than being a slow and gradual process of landscape acculturation. This is consistent with Brown (2007) and Rowley-Conwy (2004) who proposed a rapid rather than gradual transition from Mesolithic to Neolithic lifestyles. Brown (2007) reviewed evidence from dated charred cereal grains from archaeological sites in Britain and Ireland, which appeared from 6000 cal. BP and became prominent between 5800 and 5500 cal. BP. This provides evidence for relatively rapid spread of the 'Neolithic package' during a two century pioneer phase around 6000–5800 cal. BP. None the less, at fine spatio-temporal scales, the initial Neolithic transition across Britain and Ireland would have been complex due to various factors affecting population movement and land-use (e.g. social and cultural trends, etc.) and some elements of hunter–gatherer lifestyles would have remained; for example, there is evidence for continued exploitation of wild plant resources during this time (Brown, 2007). Following this 'first wave', archaeological ^{14}C date densities indicate a middle Neolithic retrenchment of population while pollen-inferred land-cover indicates secondary re-afforestation, at times reaching values of over 80% for deciduous woodland between 5400 and 4200 cal. BP. This population retrenchment and probable societal re-organisation would be consistent with resource over-exploitation and depletion, but could equally well be explicable in terms of social tensions and conflicts, or other causes. Following the reduced mid-late Neolithic landscape impact, there was renewed woodland clearance and population increase from 4400 cal. BP onwards, a period which led into the new technologies, trade, societal organisation and environmental impact of the Bronze Age.

The most significant changes in the land-cover record correspond to the trend in inferred population levels between 9000 and 3400 cal. BP, with demographic peaks corresponding to the lowest values of deciduous woodland during this time period, notably 5600–5400 and 4200–4000 cal. BP. The increase in woodland and decline in semi-open arboreal land-cover following the population decline around 5300 cal. BP implies that woodland became re-established when human population levels decreased, most likely associated with a reduction in agricultural activity and land clearance. None the less, the percentage of pollen samples assigned to the deciduous woodland LCC remained above ~60% throughout the Neolithic period, highlighting the fact that Britain remained a predominantly forested landscape until Bronze and Iron Age times. While the overall trends in forest cover during the period from 9000 to 3400 cal. BP seem robust, the absolute percentage values should be treated with caution, since the pseudo-biomisation approach does not factor differential plant and pollen productivity into the pollen transformation and thus some taxa are under- or over-represented.

Whittle et al. (2011) used an archaeological single ^{14}C date grouping approach and identified Neolithic practices as having appeared rapidly ~4050 cal. BC (6050 cal. BP) in Kent and "reaching" the North-western areas of the British Isles ~3700 cal. BC (5700 cal. BP). Patterns identified by Whittle et al. (2011) such as a later Neolithisation in the North and Northwest of Britain and Ireland, have not been identified in the pollen-inferred land-cover and ^{14}C date density records, which is probably due to the limited regional analyses possible within this study and the lower chronological resolution in the records used, as noted above.

4.2. Holocene palaeoclimate change

Climate change has been invoked as a causative factor in the human colonisation and transformation of land for agricultural purposes during the Neolithic transition (e.g. Macklin et al., 2000; Cayless and Tipping, 2002; van Geel and Mauquoy, 2010). However, our analysis shows few obvious matches between demographic and land-cover trends on the one hand, and climate shifts on the other, suggesting that the relationship between climatic, cultural and land-use changes was not straightforward. The lack of clear relationships with the palaeoclimate records could relate to chronological discrepancies. The Walton Moss record, for example, has limited chronological precision. According to Schulting (2010) the palaeoclimate sequences from northern England, including Walton Moss (Hughes et al., 2000), have not been analysed at sufficient resolution or dated with enough precision to determine whether or not, for example, the period 6000–5800 cal. BP experienced a wet or dry phase.

Other researchers have investigated relationships between archaeological/palynological and palaeoclimate records in later prehistory (e.g. Dark, 2006). For hunter–gatherer communities in S. Finland, Tallavaara and Seppä (2012) argued that climate had an important role in population dynamics through mediating food availability, although this relationship appears to break down following the emergence of agriculture. Our analysis also suggests a relationship between climate change, late Mesolithic populations and forest cover, especially ~7700–7600 cal. BP, which would merit further study. By contrast, the well-known 8.2 ka climatic cooling event appears to have had no detectable demographic consequences for the British Mesolithic (Fig. 5).

According to Schulting (2010) the plants and animals involved in the adoption of farming in northwest Europe during the Neolithic

were not adapted to the climate of this region. He hypothesised that the rapid spread of agriculture across areas such as the British Isles was aided by favourable climatic change at this time, which permitted adoption of the Neolithic "package". A shift to drier, more continental conditions ~6000–5800 cal. BP, for example, would have favoured cereal cultivation during this period, particularly in areas such as the west coast of Scotland. In support of this hypothesis, Verrill and Tipping (2010) identified mid-Neolithic agricultural decline in pollen records from western Ireland during a shift from drier to wetter climate, and suggested that an earlier period of drier climate allowed adaptation of mixed agriculture in Britain and Ireland ~6000 cal. BP. However, after analysing a number of palaeoclimate records, Schulting (2010) found that the extent and nature of climate change and the link between climate and the adoption of mixed agriculture around 6000–5800 cal. BP was not straightforward. Numerous sites showed a warmer/drier period at this time, whereas other sites revealed a cooler/wetter period, and some indicated no marked climatic shift (Schulting, 2010). The lack of coherence between climate records in Schulting's analysis suggests that their real chronological precision is unlikely to be better than about ±200 yr. He concluded that the transition to mixed farming in Britain is currently best explained as a cultural process, with climatic impacts being of marginal importance. Similarly, Lemmen and Wirtz (2014) found that at a European scale, climate events were not as important as endogenous factors in explaining the socio-cultural dynamics of the Neolithic transition.

4.3. Regional comparisons

The Neolithic did not begin simultaneously everywhere in the British Isles and the timing of its appearance would have varied regionally (Whittle et al., 2011). According to Whittle et al. (2011), the first Neolithic 'things and practices' in the archaeological record appeared in Britain ~6100 cal. BP (4100 cal. BC) and spread outwards from the southeast corner of England (though see Bocquet-Appel et al., 2012). The early Neolithic is suggested to have begun in northeast Scotland around 5950–5765 cal. BP (3950–3765 cal. BC) (Whittle et al., 2011). This corresponds to the demographic increase inferred from ^{14}C date densities and slightly precedes the pollen-inferred decrease in woodland evident in Fig. 4. The most significant decrease in woodland cover in the Scottish record occurred between 5800 and 5400 cal. BP with values decreasing to ~40% of pollen samples. Additionally, early Neolithic agricultural activity may have been concentrated in valley bottoms, which may be less easily detected in regional pollen diagrams (Brown, 1997). A few differences are evident when comparing the Scottish record with the amalgamated record for Britain, the main difference is that pollen samples assigned to deciduous woodland do not decline to values below 60% during 9000–3400 cal. BP in the British record. This is likely to be a consequence of averaging values across all sites, which would have masked more extreme regional differences, such as the possibility that the west coast of Scotland represents a range margin for deciduous woodland (Fossitt, 1996). More detailed regional analyses are currently limited by the restricted spatial coverage of pollen records across Britain available from the European Pollen Database and the low spatial congruence evident between pollen and archaeological sites.

5. Conclusion

The comparisons between pollen-inferred land-cover and archaeo-demographic change presented here have implications for understanding of the Neolithic transition and for the approaches used to investigate anthropogenic activity and environmental change during the mid-Holocene. The multi-archive approach employed here has allowed large-scale human population and vegetation change to be investigated together and provides insights into the impacts of changing demography upon land-cover. The close correspondence between the two archives, apart from confirming the validity of the summed radiocarbon distributions as a demographic proxy, implies that population dynamics and land-cover change were intrinsically linked during the Neolithic. The most significant of these changes is evident ~6000–5400 cal. BP during the initial Neolithic transition. Comparison with a number of palaeoclimate records has not revealed any obvious patterns, implying that climate may not have been the main pace-maker of landscape change at this time. However, the lack of correspondence is also likely to be associated with differences in the chronological precision and geographical location of the available climate records. In order to further investigate the links between land-cover, population and palaeoclimate, additional high-resolution records are required with good chronological precision, along with sites that are suitable for both pollen analyses and archaeological investigation.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jas.2012.10.025.

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