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Human activity was a major driver of the mid-Holocene vegetation change in southern Cumbria: Implications for the elm decline in the British Isles

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Abstract

The dramatic decline in elm (*Ulmus*) across a large swathe of northwest Europe in the mid-Holocene has been ascribed to a number of possible factors, including climate change, human activity and/or pathogens. A major limitation for identifying the underlying cause(s) has been the limited number of high-resolution records with robust geochronological frameworks. Here, we report a multiproxy study of an upland (Blea Tarn) and lowland (Urswick Tarn) landscape in southern Cumbria (British Isles) to reconstruct vegetation change across the elm decline in an area with a rich and well-dated archaeological record to disentangle different possible controls. Here we find a two-stage decline in *Ulmus* taking place between 6350-6150 cal a BP and 6050-5850 cal a BP, with the second phase coinciding with an intensification of human activity. The scale of the decline and associated human impact is more abrupt in the upland landscape. We consider it likely that a combination of human impact and disease drove the *Ulmus* decline within southern Cumbria.

Introduction

One of the most striking features in the mid-Holocene pollen record of northwest Europe is the widespread substantial decline in *Ulmus* (Pennington, 1991; Ralska-Jasiewiczowa, 2003). Multi-site evidence for the mid-Holocene shows a complex pattern of elm decline across Europe (Gandouin *et al.*, 2009), with evidence for the decline as early as 6640 cal a BP (northwest Poland; Latalowa, 1992) whilst other sites show multiple phases across more than a millennium (6480-5360 cal a BP in northwest Denmark; Andersen and Rasmussen, 1993). The British Isles shows the greatest range with the earliest (albeit a possible isolated event) occurring ~7300 cal a BP (Batchelor *et al*., 2014) and as late as ~5100 cal a BP (Anderson, 1998) with also the greatest magnitude decline, with up to 18% of the total pollen sum, resulting in almost complete removal of *Ulmus* from the woodland assemblage (Parker *et al.*, 2002). Despite high variability in timing, there is a general tendency of the ages associated with the decline to cluster around 6000-5900 cal a BP (Whittington *et al*., 1991; Innes *et al*., 2006; Albert and Innes, 2015). The precise mechanisms behind this change remain contentious (Hirons and Edwards, 1986; Peglar and Birks, 1993; Robinson, 2000; Parker *et al.*, 2002). A widely considered driver of the decline in *Ulmus* is the spread of pathogens. It is known that the elm bark beetle (*Scolytus scolytus*) is able to carry a fungus (*Ophiostoma ulmi*) which can kill vegetation, particularly *Ulmus* (Parker *et al.,* 2002). The fungus can either weaken an individual, or in extreme circumstances kill trees (Richens, 1983). Girling (1979), and Girling and Greig (1985) provide evidence to show that the beetle was present during the mid-Holocene (at Hampstead Heath, London) but this has not been clearly demonstrated during the timing of the elm decline (Parker *et al.*, 2002) and cannot fully account for the spatially and temporally complex nature of the event. Clark and Edwards (2004) provide evidence (from Aberdeenshire) that *S. scolytus* was contemporary with the elm decline. Nevertheless, the presence of the beetle does not necessarily demonstrate a widespread disease epidemic.

It is possible that other factors, or combination of factors (acting together as multi-stressors) may have played a role in the widespread mid-Holocene *Ulmus* decline. While pedogenic development has also been suggested as a contributing factor to the broader mid-Holocene vegetation changes in northwest Europe (Ralska-Jasiewiczowa *et al.*, 2003), others have argued that reductions in the nutrient content of soils may have inhibited the regeneration of elm in some landscapes (Pennington, 1965; Sturludottir and Turner, 1985). Alternatively, climate change may have played a significant role but the limited (if any) response of other species has suggested this is unlikely as a single driver (Parker *et al.*, 2002), particularly as the decline is evident across much of northwest Europe when there is clear evidence of regional climate variability (Kaplan and Wolfe, 2006; Wanner *et al*., 2008; Mauri *et al*., 2015). However, climatic variability cannot be completely dismissed given recent advances in our understanding of species-specific responses to short-term (on the order of a few years) and long-term climate variability that may have significant impact on taxa already near a threshold in either temperature or moisture availability (Boyd *et al*., 2015).

Unfortunately, understanding the nature of the vegetation change during the mid-Holocene is made particularly complex because of the close timing with the transition from hunter-gathering to farming (the Mesolithic-Neolithic transition) (Turney and Brown, 2007). Whilst the nature of the transition phase is still keenly debated (Rowley Conwy 2004; Thomas, 2004; Davison *et al.,* 2009; Ellis *et al*., 2013) it is generally thought that modification of the landscape began during late-Mesolithic culture (Simmons, 1975). The close timing between the elm decline and the Mesolithic-Neolithic Transition complicates the interpretation of the environmental record (Parker *et al.*, 2002) and has received considerable focus. While some workers have argued there is little correlation between the decline of elm and human activity (Ralska-Jasiewiczowa *et al.*, 2003) there is clear evidence for human activity in the landscape prior to the dramatic fall in elm pollen in many key sites. For instance, in Denmark, multiple elm declines have been recognised through the Holocene with limited evidence for the role of human activity (Andersen & Rasmussen, 1993; Rasmussen, 2005). In contrast, in the British Isles, lithics have been identified in the Lower Thames Valley at the same time as the elm decline (Batchelor *et al*., 2014) while in North Yorkshire, the elm decline coincides with repeated fire disturbance (Innes *et al.*, 2010). Although the timing of the decline appears suspiciously close to changing anthropogenic activity in northwest Europe (Pennington, 1991; Parker *et al.*, 2002), the dating is often relatively poor and the palaeo-ecological evidence for anthropogenic activity is not always clear. Importantly, early forms of agriculture (e.g. herding of livestock and stalling overwinter) may have only required the pollarding of certain trees for winter feed and not complete removal of all woodland vegetation (Garbett 1981; Moe and Rackham, 1992; Peglar and Birks, 1993), making the detection of human impact challenging.

Thus, while disease may have played a dominant role in the decline of elm, and appears to account for the spatially and temporally complex pattern across Europe, other factors such as climate and human activity may have acted together as a multi-stressors. Detailed high-resolution sequences in archaeologically-rich areas are required to address this question. Nowhere is this more relevant than the British Isles, where the timing and large magnitude of the elm decline provide an opportunity to test competing hypotheses.

North-west England has considerable potential for improving our understanding of the nature of the elm decline, with a rich environmental, climatic and archaeological record spanning the mid-Holocene (Oldfield & Statham, 1963; Pennington 1964; Tipping 1994; Bradley & Edmonds, 1993; Evans, 2008). Crucially, during the early-Holocene the Cumbrian landscape was still recovering from the end of the last glaciation, with limited soil development (Pennington, 1964) and the delayed migration of tree species into the region (beginning with *Betula*, then *Corylus* and later followed by *Quercus* and *Ulmus*; Birks, 1989). By the end of the Mesolithic period Cumbria was mostly covered in deciduous woodland (including *Quercus*, *Ulmus*, *Alnus*, *Tilia* and *Betula*) with the high slopes giving way to scrub and grass (Pennington, 1969). A number of high-resolution environmental records suggest the region saw substantial changes in the vegetation matrix during the mid-Holocene (Pennington, 1991). However, as with the archaeological evidence, the very limited number of well-dated environmental records means synthesis of the environmental history (including climate) and archaeological evidence has not been possible so far.

Study area and sites

This study focuses on southern Cumbria in north-west England which contains a diverse range of landscapes including the upland mountains of the central Lake District National Park, lowland valleys, and coastal environments. Each of these landscapes has been the focus of previous Mesolithic and Neolithic archaeological research (Bradley and Edmonds, 1993; Bonsall *et al*., 1994; Evans, 2008). Of particular note, is that within the area, the Mesolithic-Neolithic Transition is thought to occur at a similar time to the elm decline (Pennington, 1964, Evans, 2008). For this reason, it is important that local to regional scale analysis forms the basis for the environmental interpretation. Furthermore, there is a wide range of environmental records for the mid-Holocene, particularly palynological records from lakes. However, many of these existing records lack the high-resolution sampling required to highlight the detail of vegetation changes, and in most cases are not sufficiently dated to allow inter-site comparison. The two contrasting south Cumbrian sites investigated for a high-resolution, multi-proxy study are Blea Tarn (Langdale) and Urswick Tarn (Furness). The sites were chosen based on their proximity to locations of human activity and presence of existing palaeo-environmental records. No charcoal data was reported from either of the tarns during previous work.

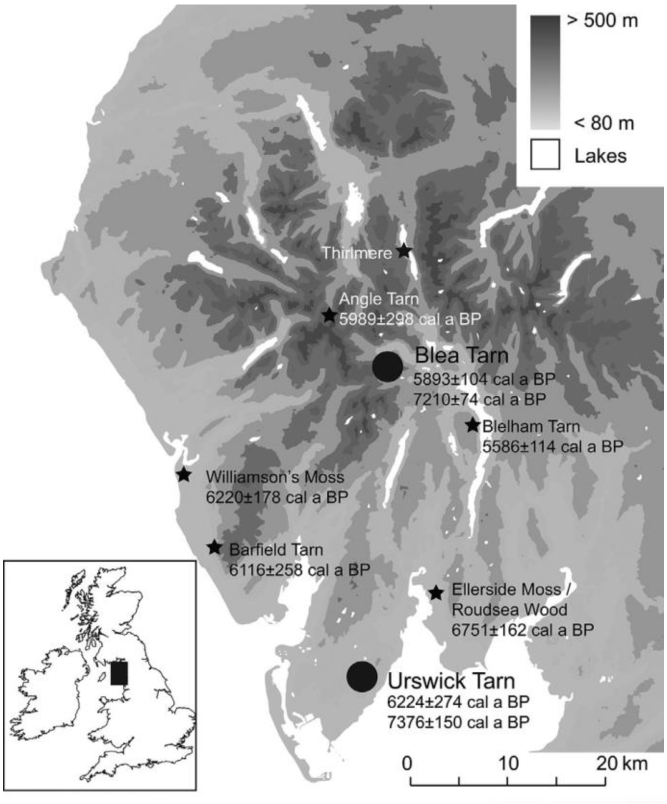


Figure 1. Location of Blea Tarn and Urswick Tarn, southern Cumbria, British Isles. Shading denotes altitude, and lakes are shown in white. Note that the shoreline is contemporary. Radiocarbon ages of the elm decline are marked based on data from this study and other studies mentioned in the text.

Blea Tarn, Langdale

Langdale is near the centre of the uplands of the Lake District centred on the Langdale Pikes. The 'U'-shaped valley of Great Langdale is flanked by peaks rising 550 m above the valley bottom. The regional archaeological evidence is focussed around the extraction of stone from the Langdale Pikes for making axes during the Neolithic (Bradley & Edmonds, 1993, Evans, 2008). These were sites of large-scale stone workings in a landscape that appears to contain little archaeological evidence of earlier Mesolithic activity, nor substantial Bronze Age use (Bradley and Edmonds, 1993).

Blea Tarn (54°25'N, 03°05'W) (Figure 1), is located in a hanging valley above the Great Langdale Valley between Great Langdale and Little Langdale. The palynological record at Blea Tarn has previously been investigated (Pennington, 1964; 1965; 1973; 1986; Tutin, 1969), but the sampling and dating resolution are limited. The mid-Holocene record highlights classic Transition markers including the elm decline and rise of *Plantago lanceolata*. *Quercus* is thought to remain relatively stable during the period around the Neolithic, whilst in contrast *Betula* and *Pinus* both show a slight fall at a similar point to the elm decline (Pennington, 1975). After the elm decline, *Plantago lanceolata* increases along with some Poaceae, which are interpreted as a result of disturbance episodes (Pennington, 1991). Although Poaceae is recorded, there is no evidence of Cerealia-type pollen in the Blea Tarn record. Pennington (1965) suggests that it is likely cereal cultivation did not reach the central uplands at all, with Cerealia-type pollen only found as far as Thirlmere. The decline in pine and birch is suggestive of clearance by fire of higher altitude vegetation (with lower altitude woodland comprising oak, elm and hazel), and a similar pattern is seen at Angle Tarn (Pennington, 1975).

Urswick Tarn, Furness

The Furness Peninsula in the south of Cumbria is surrounded by Morecambe Bay and the Leven estuary on the southeast shore, the Irish Sea to the west, and the Duddon Estuary along the northwest shore. A limestone ridge runs across the Peninsula. The Furness Peninsula contains some of the earliest Palaeolithic archaeology in Cumbria (at Bart's Shelter and Bonfire Scar Cave, Hodgkinson *et al.*, 2000; Evans, 2008) alongside evidence of Mesolithic, Neolithic and later activity. It is likely that this lowland and coastal area was settled by humans throughout the mid-Holocene providing a contrasting history of occupation to upland Langdale which exhibits an intensive but relatively short-lived period of human activity.

The selected study site on Furness is Urswick Tarn (54°09'N 3°07'W) (Figure 1) at an altitude of 36 m.a.s.l. A pollen record for the site (Oldfield, 1963, Oldfield and Statham, 1963) represents one of only two early to mid-Holocene vegetation records available for the region. Unfortunately the record was not dated and the temporal resolution of the record was relatively low. The lowest sediments show high levels of *Betula* and Coryloid-type with some *Pinus*. This is followed by a rise in *Ulmus,* which replaces some *Betula*. *Quercus* then increases significantly at the expense of *Betula* and some Coryloid-type along with *Salix*. *Ulmus* also shows a dramatic decline to around 50% of previous levels. *Alnus* then becomes more dominant whilst *Pinus* declines and Coryloid-type remains low. This is followed by the main-phase *Ulmus* decline that is marked by a near exclusion of *Ulmus* and appearance of *Plantago lanceolata,* whilst *Pinus* also demonstrates a further decline. This indicates that the elm decline here can be split into two phases. Firstly, a primary elm decline, is signalled by a drop in *Ulmus* which is not marked by any rise in weed pollen and instead may be reflecting a general reduction in woodland. This is followed by the second phase, which is thought to be typical of the 'Landnam' phase where land clearance appears to occur on a broader basis than simply elm (Oldfield, 1963; Oldfield and Statham, 1963). Cerealia-type pollen is only present in the upper section of the sequence at Urswick Tarn, possibly from the late-Neolithic or early-Bronze Age sediments. The lack of early-Neolithic Cerealia-type pollen could be due to its absence, or possibly due to issues with separating cereal pollen from wild grass (Dickson, 1988).

Methods

Sediment cores were collected from each site for the development of high-resolution, well-dated environmental reconstructions spanning the elm decline. The Blea Tarn 3m sequence was collected from open water using a Mackereth Corer (Mackereth, 1958). The presence of natural springs in the base of Urswick Tarn necessitated the collection of lake sediment from the marginal sediments using a Russian, 'D'-section corer.

Each of the sediment sequences was dated using AMS radiocarbon (^{14}C) dating which is detailed in Table 1. An age-depth model was generated using a P_sequence deposition model (which allows for a degree of natural variability in deposition rate) and the IntCal13 radiocarbon calibration dataset (Reimer *et al*., 2013) in the software OxCal (Bronk Ramsey and Lee, 2013). The age depth model for Blea Tarn given in Figure 2a includes inferred ages from Pennington (1975).

Sediment was prepared for the pollen analysis using the modified Moore & Webb (1978) technique as follows. Sediment was disaggregated in NaOH, sieved at 106 µm and 15 µm, treated with hydrofluoric acid (HF), hydrochloric acid (HCl) wash and Acetolysis treatment before mounting in glycerine. Grains were identified at 400x magnification and 630x or 1000x oil immersion for critical identifications. At least 400 terrestrial tree and shrub grains were counted in each sample. Charcoal particles were identified from the same sediment preparations as pollen (Tolonen, 1986; Edwards and Whittington, 2000; Tinner and Hu, 2003) and classified as 106 > 50 µm or 15 < 50 µm. By splitting the charcoal particles into two size fractions it is possible to gain a sense of the proximity of the fire, as larger particles are likely to be deposited nearer the source. The concentration of pollen and charcoal was calculated using an exotic spike (Stockmarr, 1971). Samples were initially prepared across the full sequence gained from each site, with additional samples (up to a resolution of 0.5 cm) subsequently analysed across the period of interest.

Results and Discussion

Nature of the elm decline in South Cumbria

The radiocarbon chronologies produced for each site (Figure 2) allow direct comparison between the sites and with other studies, yet they also highlight changes in the depositional nature of the sites. The age-depth model for Urswick Tarn (Figure 2b) contains a change in sedimentation at 255 cm. One rejected age at 277 cm is also shown in Figure 2b but is considered an outlier and excluded from the age-depth model. The age-depth model for Blea Tarn (Figure 2a) has been adjusted to account for a reduction in sedimentation rate inferred from the total pollen concentration and dating from Pennington (1975).

The pre-disturbance landscape at each site consists largely of mixed woodland including *Corylus*, *Betula*, *Quercus* and *Alnus* (Figure 3). There is a period of relative vegetation stability between around 7100-6800 cal a BP where the percentage pollen changes show much less fluctuation (Figure 3a, zone 1b; Figure 3b, zone 3). *Betula*, *Pinus* and *Ulmus* remain in similar proportions at both sites. *Quercus* shows a slight decline whilst *Corylus* experiences a slight rise and fall. Datasets produced by Oldfield and Statham (1963) and Pennington (1964) both show signs of this possible stability, although neither site shows all species mentioned above to be stable. Furthermore, Pennington (1998) highlights that the woodland assemblage across Cumbria shows signs of changing species proportions, but with general stability in the level of arboreal vegetation.

The fall in *Ulmus* pollen influx is three times greater at Blea Tarn than Urswick Tarn (Figure 3). This is partially the influence of the overall differences in total pollen influx rates between the sites, but also suggests that the upland decline was far more rapid and severe than in lowland environments. In general the mid-Holocene pollen influx at Urswick Tarn is far less variable between adjacent samples than Blea Tarn. This is likely to be a partial artefact of lower influx at Urswick. Nevertheless, it is possible that this is a reflection of the pollen catchment of each site. As Peglar and Birks (1993) note, high variability could be the impact of local individuals contributing a higher proportion of the pollen influx whereas lower variability may be representing pollen from the wider region where differences in individual pollen productivity is averaged. Uncertainty about the pollen catchment area is a key restriction in the interpretation of clearance events as a pollen sequence is likely to cover a broader area to that which

Site/ Depth (cm)	Lab code	^{14}C a BP	δ^{13}C	Material	Cal a BP (range)	Cal a BP (mean)
Blea						
180	AA-96270	5056±42	-29.7	Bulk organic	5891-5747	5810±59
185	Wk-34364	5037±25	-28.8±0.2	Bulk organic	5896-5717	5811±56
190	Wk-34365	5143±26	-28.8±0.2	Bulk organic	5986-5970 (3.1%) 5944-5885 (76.8%) 5810-5760 (15.5%)	5893±52
198	Wk-34366	5173±27	-28.8±0.2	Bulk organic	5990-5960 (23.8%) 5954-5901 (71.6%)	5937±30
215	Wk-34367	5410±27	-28.8±0.2	Bulk organic	6286-6183	6232±36
237	AA-96269	5783±43	-30.0	Bulk organic	6650-6531	6567±37
245	Wk-34368	5830±29	-29.0±0.2	Bulk organic	6733-6556	6640±47
270	Wk-34369	6276±32	-28.7±0.2	Bulk organic	7270-7160	7210±37
280	AA-96268	6428±45	-30.1	Bulk organic	7417-7321	7386±32
Urswick						
195	Wk-34370	5005±29	-27.4±0.2	Wood	5852-5662	5692±33
243	AA-96271	5721±87	-29.7	Wood	6633-6415	6550±51
249	Wk-34371	5779±32	-29.8±0.2	Wood	6638-6539	6661±39
256	Wk-34372	6329±37	-29.0±0.2	Wood	7310-7180	7173±58
277	Wk-34373	6858±31	-27.8±0.2	Bulk organic		
285	Wk-34374	6531±37	-26.5±0.2	Bulk organic	7472-7423	7466±28
305	Wk-34375	6917±31	-27.7±0.2	Bulk organic	7785-7695	7710±23
328	AA-96272	7066±56	-29.8	Deciduous leaf	7952-7848	7924±39

Table 1. AMS ^{14}C ages for Blea Tarn and Urswick Tarn, Cumbria, UK. AA lab codes were analysed at University of Arizona radiocarbon lab; Wk lab codes were analysed at University of Waikato. The presence of detrital wood fragments in the sediment core from Urswick Tarn resulted in a reduction of sediment available for analysis at certain depths and therefore ^{14}C analysis was carried out on wood macrofossils where necessary.

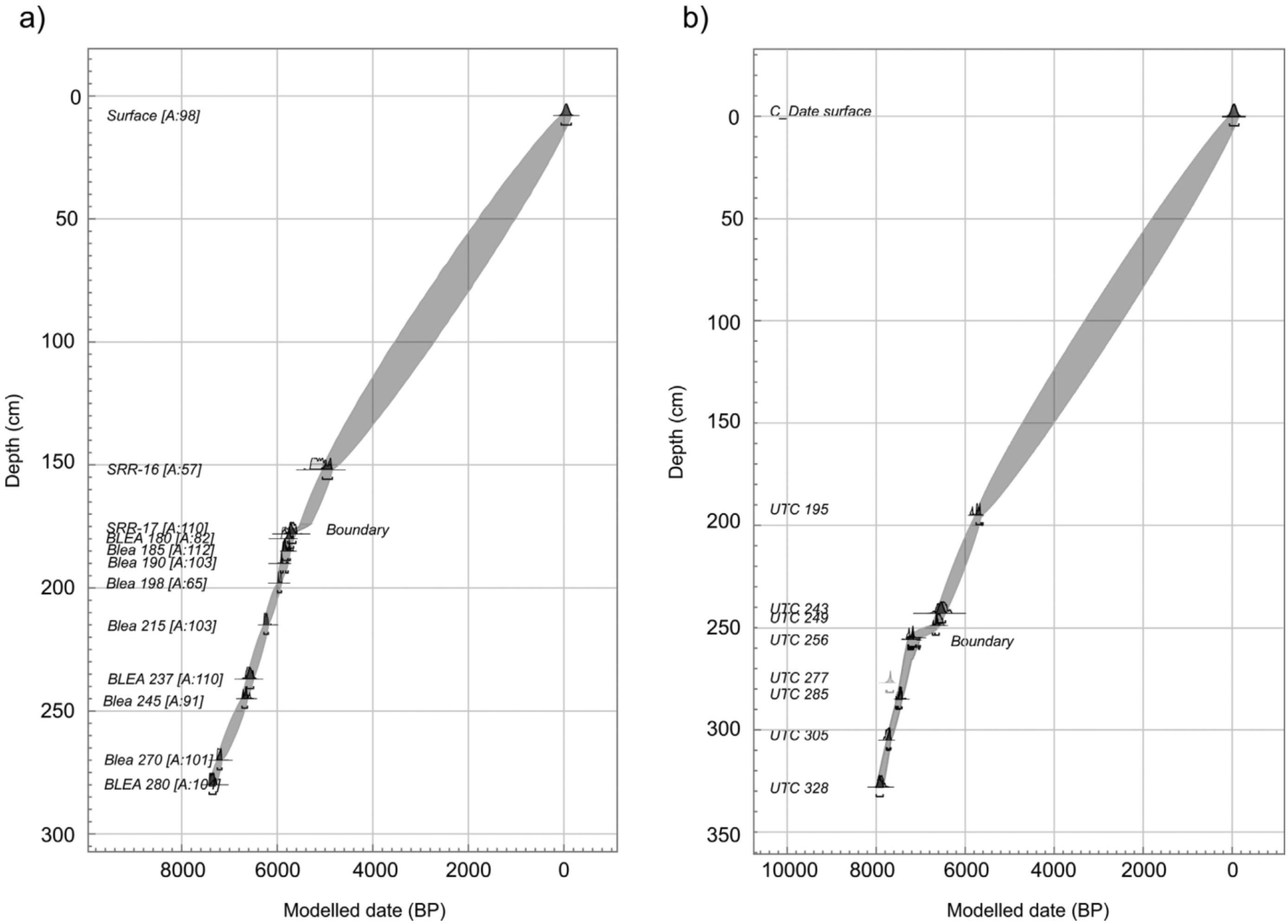


Figure 2. Age depth models from OxCal for a) Blea Tarn, and b) Urswick Tarn (including outlier at 277 cm).

has been cleared (Robinson, 2014) and therefore the pollen dataset is likely to mask the magnitude of clearance in some woodland patches. Furthermore, stressed plants may also influence the pollen productivity, and therefore a species under threat from a changing environment or succumbing to disease may be evident within the pollen record if pollen of a particular species alters without evidence for other species expanding. These factors could mask the level of natural recovery of the species after a decline.

Previous studies have dated the decline to 6116±258 cal a BP (all ages show 2σ errors) at Barfield Tarn (Pennington, 1970), 5721±174 cal a BP at Blea Tarn (Pennington, 1973), 5989±298 cal a BP at Angle Tarn (Tutin, 1969), 5586±114 cal a BP at Blelham Tarn (Pennington and Lishman, 1984), 6220±178 cal a BP at Williamson's Moss, Eskmeals (Tipping, 1994) and prior to 6751±162 cal a BP at Roudsea Wood (Birks, 1982). The ages show some variability but appear to suggest that upland sites (Blea, Angle and Blelham Tarns) show the decline first which is then followed by lowland sites a few hundred years later. A notable exception to this is the particularly early decline at Roudsea Wood (Birks, 1982). Nevertheless, the ages in themselves do not reveal the speed, magnitude, and any associated environmental change, of the *Ulmus* decline. The evidence from this study finds declines taking place at 7400-6900 and 6250-6100 cal a BP (Urswick Tarn), and 7300-7100 and 5900-5800 cal a BP (Blea Tarn, Figure 3).

At Urswick Tarn we find evidence of a two-phase elm decline (Figure 3), but the structure of the event is subtly different to that reported by Oldfield and Statham (1963) who described a rapid reduction to very low levels in the first phase, followed immediately by a longer phase of reduction to even lower values. Due to the very small degree of change during this second phase, it is very difficult to identify the change clearly from Figure 3 in Oldfield and Statham (1963). The separation of the two phases is presented in slightly more detail in Oldfield (1963), although the two phases are only separated by what appears to be a single sample showing a recovery phase. At Roudsea Wood, Birks (1982) shows an early start to the decline however, the resolution of the sampling is not sufficient to identify whether there is a separate second phase of decline. In the Urswick dataset from this study, the end of the initial phase of decline takes place over around 500 years (from around 7400 cal a BP) and contains a degree of variability (Figure 3b, zone 3). This is followed by a short hiatus for around 100 years before the second phase takes around 150 years (from 6250 cal a BP) and shows a smooth, rapid decline. This second decline marks what Oldfield (1963) and Oldfield and Statham (1963) describe as the Landnam phase of clearance. Evidence from other sites in southern Cumbria show a clearer two-phase decline over this period and so it is reasonable to expect it may be present at Urswick Tarn. Nevertheless, earlier and more significant declines are present at Urswick, and to a lesser extent at Blea. Arguably, the main phase of decline at Blea Tarn could potentially be split into two phases in a similar way to the primary decline in Oldfield's (1963) datasets; there is a slight reduction between 7300-7100 cal a BP (although not to as great an extent as Urswick) followed by a sharper decline at 5900-5800 cal a BP. This is not as clear as a two-stage decline suggested by Pennington (1971). The earlier phase of decline could simply be due to natural succession of the woodland. In Oldfield and Statham's (1963) dataset the decline is reciprocated with an increase in *Pinus*, whilst at Blea Tarn in Pennington's (1964) dataset, *Corylus* appears to show greatest response. In the datasets produced in this study, *Quercus* and *Corylus* respond to the decline at Urswick, whilst *Quercus*, *Corylus* and *Alnus* all appear to increase in response to the decline in *Ulmus* (Figure 3).

The temporal offset between the elm decline phases at Blea Tarn and Urswick Tarn highlights the need for high-resolution analysis and dating of sediments. It is only then possible to identify the phases as distinct events chronologically. Whilst the offset does not appear substantial in terms of the broader record, when discussed in relation to human activity, an offset of 250 years suggests a relatively slow spread of the elm decline, regardless of whether it is primarily due to disease or human impact.

Human activity

It is clear that Urswick Tarn exhibits one of the earliest signs of the elm decline, which begins slightly after the first phase recorded at Williamson's Moss (6300-6100 cal a BP; Tipping, 1994) (Figure 1). There are differences between the possible interpretations of the elm decline at Williamson's Moss and Urswick Tarn; the first phase is attributed strongly to human impact at Williamson's Moss (Tipping, 1994) whilst the second phase is seen as a possible continuation. At Urswick Tarn, the first early phase at around 7600-7200 cal a BP shows signs of possible human involvement, whilst the second more rapid phase may be more clearly linked to human activity. The well-dated archaeological evidence from Williamson's Moss (Bonsall *et al.*, 1994) adds significant weight to the human impact theory. Both these sites are in lowland, near-coastal landscapes but separated by 27 km (straight line distance). It is foreseeable that human interaction across this area would have occurred, either passing on knowledge to other groups, or managing the landscape themselves. Further evidence for human activity at the elm decline comes from a fine resolution study (0.2 cm) at Ellerside Moss in southern Cumbria (Garbett, 1981). This indicates an initial period of (proposed) leaf-fodder gathering (around 20 years) followed by a main phase of decline lasting around 20 years. This suggests the

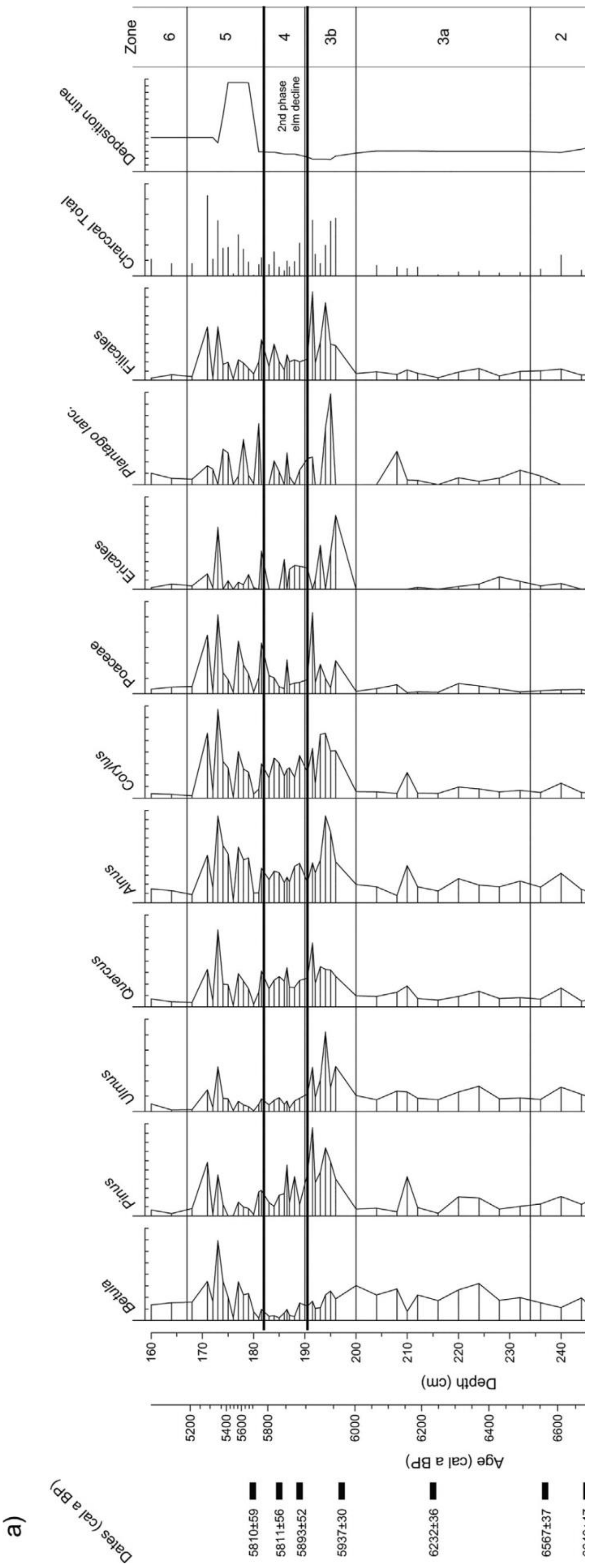
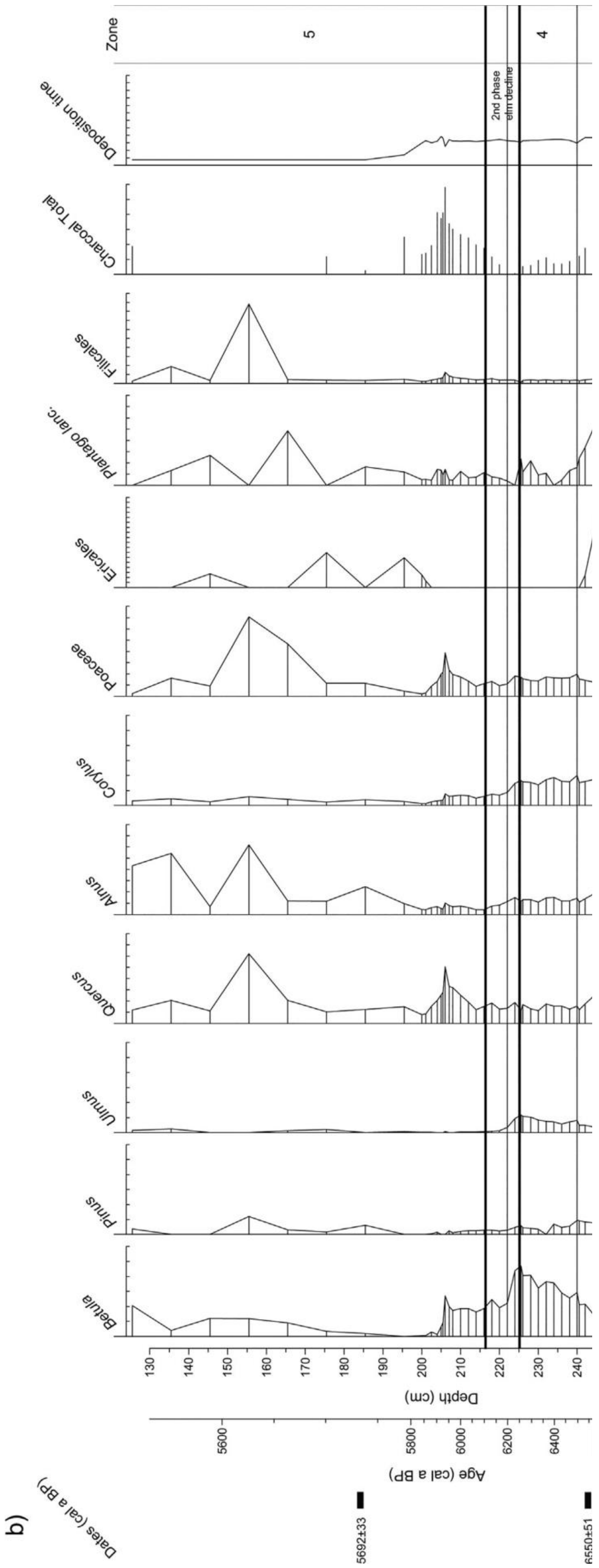


Figure 3. Pollen and charcoal influx data for selected taxa from a) Blea Tarn; and b) Urswick Tarn. Zones were determined using CONISS (constrained incremental sum of squares clustering; Legendre & Birks, 2012).


b)
Dates (cal a BP)
5692±33
6550±51
Age (cal a BP)
5600
5800
6000
6200
6400
Depth (cm)
130
140
150
160
170
180
190
200
210
220
230
240
Betula
Pinus
Ulmus
Quercus
Alnus
Corylus
Poaceae
Ericales
Plantago lanc.
Filicales
Charcoal Total
Deposition time
2nd phase
elm decline
Zone
5
4

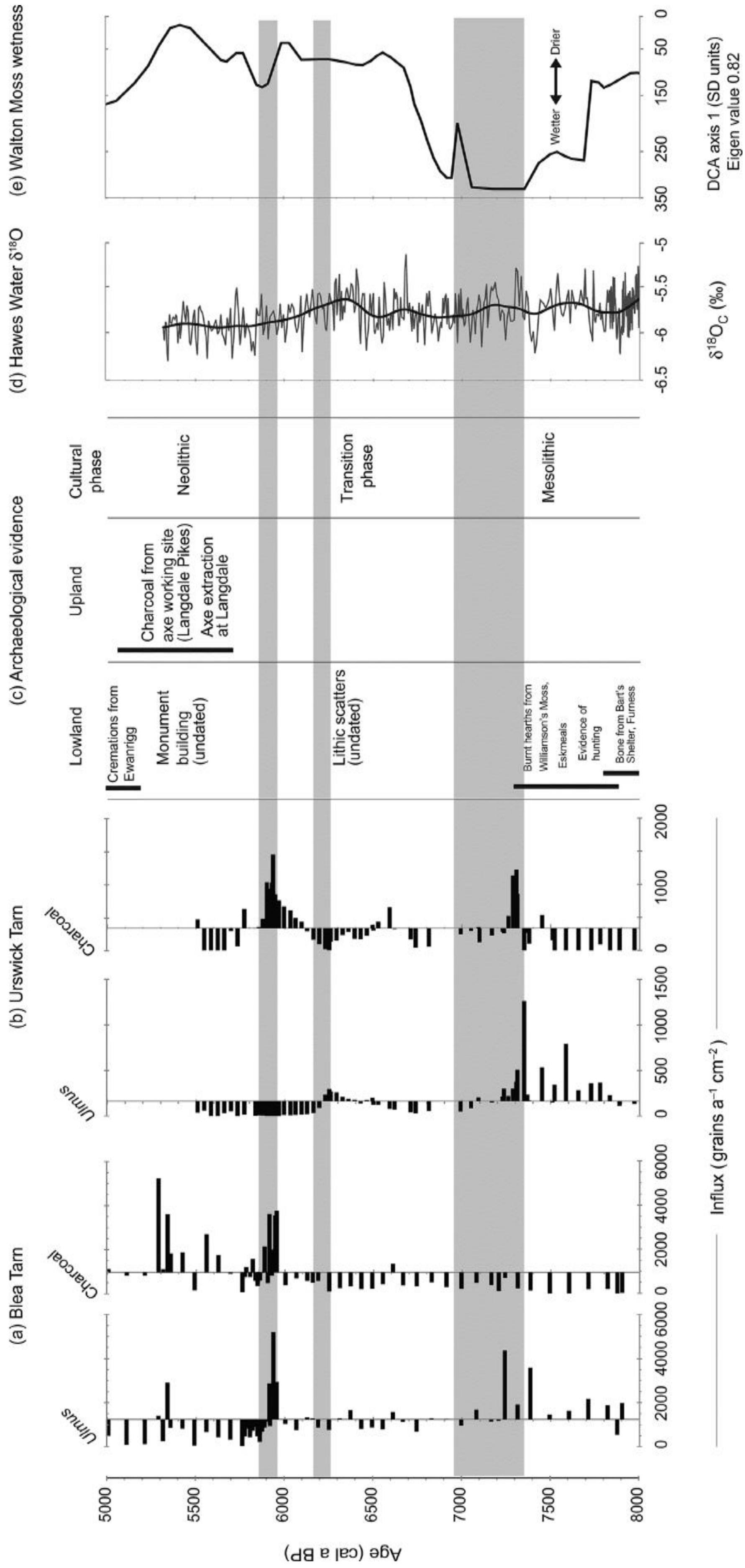


Figure 4. Summary of elm decline evidence and regional climate variability: a) Blea Tarn *Ulmus* and charcoal influx (deviation from mean); b) Urswick Tarn *Ulmus* and charcoal influx (deviation from mean); c) summary of dated archaeological evidence; d) Hawes Water δ^{18}O (Marshall *et al.*, 2007); e) Walton Moss wetness indicator (Hughes *et al.*, 2000). Grey bands highlight each of the main declines in *Ulmus*.

whole of the elm decline took place over less than 50 years (Garbett, 1981). This conclusion must be treated with caution, as the dating on the core is from 3 inferred radiocarbon ages from other sites in Cumbria and Lancashire.

Importantly, the similar timing of the decline could also suggest a natural driver. At Williamson's Moss, the loss of elm was followed by the appearance of *Plantago lanceolata* after around 6100 cal. BP, which suggests the likely presence of post-clearance ground (Tipping, 1994). As seen in Figure 3, the early presence of *Plantago lanceolata* coincides only with the decline of *Pinus*, *Alnus* and *Corylus* at Blea Tarn, and with *Pinus* and *Betula* at Urswick. This early (possible) clearance phase shows a similar signal to that recorded in North Yorkshire (Simmons and Innes, 1987). From other studies in Cumbria there appears to be little sign of any early *Plantago lanceolata*, although there are vegetation changes which could be (partially) due to clearance events (Simmons and Innes, 1987).

The second phase at Urswick follows the first phase very closely, still prior to the upland region. The second phase at Williamson's Moss begins (around 5500 cal a BP) after the decline at Blea Tarn finishes. This may provide critical evidence for the nature of human activity where sites show a near-synchronous first phase with a similar response, but a completely different timing of the second phase. The timing of these two phases is much later than the two identified at Urswick Tarn, although both phases are similar in their nature, even showing the slight recovery a few hundred years before the second decline. The similarity between the patterns of decline at both sites may suggest they are the same event identified at different sites; however, the timing offset of several hundred years implies they could be separate events and highlights the risk of correlating sites without due regard for dating.

The greater magnitude of decline at Blea Tarn may suggest that the *Ulmus* population in the Langdale region was more vulnerable if disease or environmental change is assumed to be the primary driver of the decline. Alternatively, the pattern at Blea Tarn could also suggest that use of *Ulmus* leaves as animal fodder forms a key part of the cause. If humans were attempting to sustain a (small) population in the upland region, including herding animals, then a major effort to harvest food for the livestock could sufficiently weaken the *Ulmus* population and result in the major rapid decline. *Ulmus* leaves are one of the most nutritious species of fodder within Europe (Hejcman *et al.*, 2014). However, Hejcman *et al.* (2014) also note that in general annual twigs from woody species provide far less nutrition than open grassland could and therefore until the landscape was opened up, the potential for herding livestock over winter was substantially limited. If humans had used the leaves of *Ulmus* as animal fodder, and this coincided with the onset of disease that killed off the rest of the tree, then this would have resulted in a substantial quantity of dead and dying wood (Waller, 2013), which could have been burned and contributed to the increased levels of charcoal. The slight offset between pollen decline and increase in charcoal is consistent with evidence from elsewhere in the British Isles (Grant and Waller, 2010; Waller, 2013).

The charcoal records suggest that humans were present in the local region during the elm decline phases (Figure 3). Indeed, there is a substantial increase in charcoal around the time of the elm decline at both Blea Tarn and Urswick Tarn (Figure 4). Widespread burning would appear unlikely though, as other species do not show a coincident decline. The charcoal therefore, is likely to be as a result of small-scale clearances. Beyond Cumbria, research by Innes *et al.* (2013) on very fine-resolution peat samples from north east Yorkshire appears to show evidence for multi-phase disturbance of vegetation and multiple burning peaks. Removal of woodland and subsequent burning took place in two phases between 6850-5950 cal a BP. This is followed by the main phase of the elm decline (5437±136 cal a BP, Innes *et al.*, 2013). Ryan and Blackford (2010) also find evidence of clearance through burning but note that it is unknown whether fires originated naturally (with opportunistic use by humans) or were deliberately started by humans. There is also evidence to suggest that clearances were left to regenerate naturally (Innes *et al*., 2013; Robinson, 2014).

Climate

When broader climatic variability is considered, it is clear that climate cannot be excluded as a driving factor of the elm decline. Localised climate records are limited for the region and so specific attribution of a climatic shift coinciding with the elm decline in Cumbria is not possible within this study. The main evidence for regional climate change for Cumbria is from the bog wetness indicators (Hughes *et al.*, 2000) which does appear to show a shortlived wet period beginning around 5900 cal a BP. Although this shift is significant compared with the previous ~700 years, it is still much drier than at 7500 cal a BP (Hughes *et al.*, 2000; Figure 4). Importantly, this appears to have coincided with a regional decrease in summer temperature (Renssen *et al.*, 2009; Mauri *et al.*, 2015), and an increase in winter precipitation (Mauri *et al.*, 2015). In contrast to this, evidence from Ireland suggests a drier phase commencing at around 5900 cal a BP (Turney *et al.*, 2005) coincident with a warming captured by oxygen isotope data from Hawes Water (Marshall *et al.*, 2007) around the time of the elm declines at Urswick and Blea Tarn (Figure 4). It should be noted, however, that there is a substantial degree of spatial variability in both temperature and precipitation across Europe (Mauri *et al.*, 2015). Conflicting records suggest climatic changes may not have been substantial enough to account for the elm decline and associated vegetation changes on a broad scale, but could have been enough to weaken the *Ulmus* population. This weakening could then have left *Ulmus* more vulnerable to disease or human impact.

Disease

Alongside the likelihood of human impact and climate, the possibility of disease cannot be excluded. Parker *et al.* (2002) note that if the elm bark beetle was the primary driver of the elm decline, then the spread could be very rapid with the beetle expanding at a rate of 4 km y^{-1} with the death of individual trees occurring relatively rapidly. Nevertheless, this does not mean that in certain environments the beetle would have expanded at its maximum rate and therefore the high fells of central Cumbria could have seen a delayed arrival of *S. scolytus.* There are still issues in accepting the disease hypothesis, in particular that the elm bark beetle would not have favoured dense woodland (Girling and Grieg, 1985) which Parker *et al.* (2002) develop to suggest that this would indicate that initial human clearances may have allowed the beetle to expand at a greater rate than it would naturally. This link can be expanded further on the basis that the elm bark beetle also favours weakened, diseased or damaged trees (Parker *et al.*, 2002) and therefore if humans had been harvesting leaf fodder, or pollarding trees, then this may account for the greater susceptibility of individual trees to *S. scolytus* (Moe & Rackham, 1992).

Wider implication for the elm decline

The records from Blea Tarn and Urswick Tarn and existing vegetation records (Tipping, 1994) appear to show multiple phases of elm decline within southern Cumbria in contrast to a rapid, single-phase event reported in the British Isles (such as at Diss Mere, Peglar and Birks, 1993), highlighting the complex nature of the elm decline. Even on the regional scale, the nature of the decline appears to have been highly variable, suggesting that the timing and magnitude of the decline was highly susceptible to local drivers. Climatic change as a primary driver appears unlikely given the heterogeneous nature of the decline across the British Isles and Europe as a whole (Batchelor *et al.*, 2014).

Mesolithic clearances and working of woodland landscapes (Warren *et al.*, 2013) suggests that humans had sufficient knowledge of woodland management that could have allowed a larger-scale clearance during the onset of the Neolithic. Evidence from northern central Europe suggests little correlation between the timing of the elm decline and the Neolithic Transition, however (Ralska-Jasiewiczowa *et al.*, 2003). Furthermore, in the British Isles, there appears to be a general spread of Neolithic practices from the south east (Whittle *et al.*, 2011; Woodbridge *et al.*, 2014), yet the elm decline shows little evidence of a parallel advance north (Parker *et al.*, 2002). For this reason, it is likely that the degree of human influence on the decline was spatially variable. Our evidence from Cumbria does appear to suggest that the elm decline coincides with a change in the degree of human impact. However, it is the broadly synchronous nature of the elm decline that suggests that disease was a key driver.

Conclusions

Disease, human impact and regional climate variability have all previously been attributed to the mid-Holocene decline of *Ulmus* across much of north-west Europe. Which of these factors (if any) was the dominant driver is highly uncertain and may well have been different on a regional or local scale. Here we report multi-proxy evidence from two high-resolution sequences in an archaeologically-rich area spanning this crucial period. The records obtained from Blea Tarn and Urswick Tarn (Cumbria, northwest England) demonstrate a relatively early age for the elm decline in the British Isles. Crucially, we find little evidence for a climate role. Instead, the multiphase nature of the decline in lowland Cumbria suggests human clearance of vegetation was targeted possibly towards trees dying from disease, or was pre-emptive before the area was actually attacked by disease. The evidence reported here emphasises the significant impact humans played in mid-Holocene landscapes.

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