SUPPLEMENTARY INFORMATION
Plant controls on Late Quaternary whole ecosystem structure and function

Appendix 1 Study Sites

Quidenham Mere. Quidenham Mere, in the southeast of England, was surrounded by a chalk grassland at the end of the glacial period (Jeffers et al. 2011). Summer temperatures at Quidenham Mere during the Pleistocene – Holocene transition were more akin to those in continental Europe than the rest of the British Isles (Brooks & Langdon 2014). Thirty-nine herb plant taxa are represented at Quidenham Mere (Appendix Fig1) and their dynamics are largely consistent with the grasses (Poaceae) and sedges (Cyperaceae). Eighteen taxa were included in the summary herb pollen accumulation rate values but not shown here because their values were less than 1% of the total amount. Those not shown include: Anemone, Armeria, Campanula, Drosera, Dryas, Epilobium, Geum, Helianthemum, Linum, Ludwigia, Matricaria, Melampyrum, Mentha, Mercurialis, Ononis, Polemonium, Prunella, and Rubiaceae. The initial rise in herb biomass included at least 15 taxa, while the peak included at least six more.
Appendix Fig. 1. Herb and grass pollen accumulation rates (grains cm\(^{-2}\) yr\(^{-1}\)) at Quidenham Mere. The summary data for each growth form are presented in colour while the data for the component taxa within the group are presented in black. Note that the y-axis values vary between graphs.
There were 14 shrub taxa at Quidenham Mere (Appendix Fig2) although nine of these were at insufficient quantities for plotting (i.e. pollen accumulation rates were less than 1% of the summary value of the plant functional type). Those not shown include: *Buxus*, *Calluna*, Ericaceae, *Empetrum*, *Ephedra*, *Ilex*, *Olea*, *Viburnum*, and *Viscum*. While *Salix* was present throughout the record, there was a distinct shift from *Juniperus* to *Corylus* as the dominant shrub in the plant community at the start of the postglacial period.

**Appendix Fig2.** Shrub pollen accumulation rates (grains cm$^{-2}$ yr$^{-1}$) at Quidenham Mere. The summary data for each growth form are presented in colour while the data for the component taxa within the group are presented in black. Note that the y-axis values vary between graphs.

There were 13 genera of trees at Quidenham Mere and these were predominantly broadleaved (Appendix Fig3). Four genera, *Acer*, *Juglans*, *Picea*, and *Taxus* were not included in the graph due to insufficient quantities. The initial woodland included *Betula* and *Pinus*, while later woodland development was dominated by *Quercus* and *Ulmus*. 
Appendix Fig3. Tree pollen accumulation rates (grains cm\(^{-2}\) yr\(^{-1}\)) at Quidenham Mere. The summary data for each growth form are presented in colour while the data for the component taxa within the group are presented in black. Note that the y-axis values vary between graphs.

Detrended correspondence analysis (conducted with the decorana function in the vegan package version 2.4-5 in R) of the individual plant taxa records at Quidenham Mere show that herb and shrub pollen influx span the breadth of the two primary axes of variation, while tree pollen influx shows relatively more consistent variation within the functional type (Appendix Fig4).
Appendix Fig4. Plot of species scores from detrended correspondence analysis of pollen accumulation rates for herbs (yellow), grass (brown), shrubs (orange) and trees (green) at Quidenham Mere.

Dubh-Lochan. Dubh-Lochan is located in the Scottish Highlands and throughout the analysis period supports plant assemblages dominated by a mix of coniferous and deciduous tree species (Froyd 2006). The site is occupied by a Juniperus scrub community in the early Holocene, followed by Betula-Corylus woodland from ~10,400 – 9000 cal. yrs BP. Pinus sylvestris is dominant at the site from 9000 – 7200 cal. yrs BP, after which a mixed woodland consisting of Pinus sylvestris, Betula, Corylus avellana, Alnus glutinosa and Quercus develops. Total pollen percentage for grasses and other herbaceous species ranges between 2 – 11 % (Froyd 2002).
Mean July air temperatures around Dubh-Lochan were relatively stable during the early Holocene and were higher than those reported for Quidenham Mere for the same time periods (Jeffers et al. 2015). Sixteen herb plant taxa are represented at Dubh-Lochan (Appendix Fig5) and their dynamics are consistent with the grasses and sedges. Ten taxa were included in the summary herb pollen accumulation rate values but not shown here: Apiaceae, Caltha, Compositae, Fabaceae, Plantago, Rosaceae, Scrophularia, Succisa, Thalictrum, and Urtica. All but Ranunculaceae were present throughout the record.
Appendix Fig5. Herb pollen accumulation rates (grains cm$^{-2}$ yr$^{-1}$) at Dubh-Lochan. The summary data for each growth form are presented in colour while the data for the component taxa within the group are presented in black. Note that the y-axis values vary between graphs.

There were 11 shrub taxa at Dubh-Lochan (Appendix Fig6) although five of these were at insufficient quantities for plotting. Those not shown include: Ericaceae, *Hedera*, *Ilex*, *Lonicera*, and *Viburnum*. *Juniperus* and *Empetrum* declined abruptly near the start of the record and were replaced by *Corylus* and *Calluna* (albeit at much lower densities than *Corylus*).
Appendix Fig6. Shrub pollen accumulation rates (grains cm$^{-2}$ yr$^{-1}$) at Dubh-Lochan. The summary data for each growth form are presented in colour while the data for the component taxa within the group are presented in black. Note that the y-axis values vary between graphs.

There were nine genera of trees at Dubh-Lochan (Appendix Fig7) although three genera - *Populus*, *Sorbus*, and *Tilia* - were not included in the graph due to insufficient quantities. The initial woodland was dominated by *Betula* and *Pinus*, as at Quidenham Mere. These populations were largely replaced by *Alnus* and *Quercus* around the mid-Holocene (~7,300 cal. yrs BP).
Appendix Fig 7. Tree pollen accumulation rates (grains cm⁻² yr⁻¹) at Dubh-Lochan. The summary data for each growth form are presented in colour while the data for the component taxa within the group are presented in black. Note that the y-axis values vary between graphs.

Detrended correspondence analysis of the plant taxonomic data at Dubh-Lochan shows overlap across the range of variation in herb, shrub and tree pollen influx (Appendix Fig 8).
Appendix Fig8. Plot of species scores from detrended correspondence analysis of pollen accumulation rates for herbs (yellow), grass (brown), shrubs (orange) and trees (green) at Dubh Lochan.

Lough Nadourcan. Lough Nadourcan, in the far north of Ireland, was an oligotrophic lake surrounded by blanket bog dominated by heathland plants at the Pleistocene – Holocene transition (Jeffers et al. 2012). Temperature dynamics in this part of Ireland were strongly influenced by the North Atlantic as indicated by strong similarities to patterns observed in Greenland during the Pleistocene – Holocene transition (Watson et al. 2010). Lough Nadourcan also had the most oceanic climate of all our study sites. Twenty-nine herb plant taxa are represented at Lough Nadourcan (Appendix Fig9) which were largely consistent with the dynamics of grasses and sedges. The six taxa not shown here include: Brassicaceae, Centaurea, Dryas, Linum, Ononis, and Valeriana. The initial rise in herb biomass was dominated by Rumex, Plantago and Lamiaceae. Peak values of herb biomass included these taxa as well as Artemisia and other Compositae taxa. All but a few herb taxa were present through the entire series.
Appendix Fig9. Herb pollen accumulation rates (grains cm\(^{-2}\) yr\(^{-1}\)) at Lough Nadourcan. The summary data for each growth form are presented in colour while the data for the component taxa within the group are presented in black. Note that the y-axis values vary between graphs.
There were nine shrub taxa at Lough Nadourcan (Appendix Fig10) although two of these were at insufficient quantities for plotting. Those not shown include: *Ephedra*, and *Hippophae*. *Empetrum* was the dominant shrub at Lough Nadourcan until the early Holocene when the Ericaceae shrubs were replaced by *Salix*, *Myrica* and *Corylus*.

**Appendix Fig10.** Shrub pollen accumulation rates (grains cm\(^{-2}\) yr\(^{-1}\)) at Lough Nadourcan. The summary data for each growth form are presented in colour while the data for the component taxa within the group are presented in black. Note that the y-axis values vary between graphs.

Trees were present at low densities at Lough Nadourcan throughout the series, and only became dominant in the community in the early Holocene. There were nine genera of trees at Lough Nadourcan (Appendix Fig11) although three genera - *Abies*, *Carpinus* and *Fagus* - were not included in the graph due to insufficient quantities. *Betula* and (to a lesser extent) *Pinus* had the greatest densities of all genera.
Appendix Fig11. Tree pollen accumulation rates (grains cm$^{-2}$ yr$^{-1}$) at Lough Nadourcan. The summary data for each growth form are presented in colour while the data for the component taxa within the group are presented in black. Note that the y-axis values vary between graphs.

Detrended correspondence analysis of the individual plant taxa records at Lough Nadourcan show that herb pollen influx spans the breadth of the two primary axes of variation, while shrub and tree pollen influx have a relatively smaller range of variation (Appendix Fig12).
**Appendix Fig12.** Plot of species scores from detrended correspondence analysis of pollen accumulation rates for herbs (yellow), grass (brown), shrubs (orange) and trees (green) at Lough Nadourcan.

**Ballynahatty.** Ballynahatty is a fen peatland that was surrounded by grass and herbaceous plant taxa during the early Holocene period before deciduous shrubs and trees became established (Plunkett *et al.* 2008). Nine herb plant taxa are represented at Ballynahatty (Appendix Fig13), which were at much lower densities than the grasses and sedges. Three taxa were included in the summary herb pollen accumulation rate values but not shown here including: *Filipendula, Limonium*, and *Rosaceae*. The initial herb biomass peaks were primarily represented by Compositae, Ranunculaceae, *Rumex* and *Chamerion*. *Plantago* became the dominant herb taxon after the biomass of the initial taxa declined abruptly. Compositae and Caryophyllaceae were the remaining herb families represented in the final peaks in the series.
Appendix Fig13. Herb pollen accumulation rates (grains cm$^{-2}$ yr$^{-1}$) at Ballynahatty. The summary data for each growth form are presented in colour while the data for the component taxa within the group are presented in black. Note that the y-axis values vary between graphs.

There were six shrub taxa at Ballynahatty (Appendix Fig14) although two of these were at insufficient quantities for plotting. Those not shown include: *Hedera*, and *Juniperus*. *Corylus* was the dominant shrub genus at Ballynahatty throughout the series although *Empetrum*, *Calluna* and *Salix* also achieved relatively high densities early in the record.
Appendix Fig14. Shrub pollen accumulation rates (grains cm$^{-2}$ yr$^{-1}$) at Ballynahatty. The summary data for each growth form are presented in colour while the data for the component taxa within the group are presented in black. Note that the y-axis values vary between graphs.

There were seven genera of trees at Ballynahatty (Appendix Fig15). *Betula* was the dominant genera in the community throughout the series. *Quercus, Ulmus, Alnus* and *Fraxinus* biomass expanded after 9,000 cal. yrs BP.
Appendix Fig15. Tree pollen accumulation rates (grains cm$^{-2}$ yr$^{-1}$) at Ballynahatty. The summary data for each growth form are presented in colour while the data for the component taxa within the group are presented in black. Note that the y-axis values vary between graphs.

Detrended correspondence analysis of the individual plant taxa at Ballynahatty show a strong separation between herb pollen influx and shrub and tree influx (Appendix Fig16).
Appendix Fig16. Plot of species scores from detrended correspondence analysis of pollen accumulation rates for herbs (yellow), grass (brown), shrubs (orange) and trees (green) at Ballynahatty.

Long Lough. Long Lough is a small, inter-drumlin lake that comprised open water in the late glacial – early Holocene transition and was set within an area of open grassland until the arrival of woodland at the start of the Holocene. Twenty-seven herb plant taxa were represented at Long Lough (Appendix Fig17). Six taxa that were included in the summary herb pollen accumulation rate values but not shown here include: Apiaceae, Armeria, Circea, Lamiaceae, Solanum, and Stachys. The initial peak in herb biomass was dominated by Rumex, Artemisia and other Compositae taxa, as well as Caryophyllaceae; however all herb taxa were present throughout the record. The second peak also included Ranunculaceae, Galium and Filipendula (with other taxa at lower densities). Grasses and sedges were
relatively more abundant during the second peak (i.e. between 13,000 and 10,000 cal. yrs BP) than the first (14,000 to 13,200 cal. yrs BP).
Appendix Fig17. Herb pollen accumulation rates (grains cm$^{-2}$ yr$^{-1}$) at Long Lough. The summary data for each growth form are presented in colour while the data for the component taxa within the group are presented in black. Note that the y-axis values vary between graphs.

There were eight shrub taxa at Long Lough (Appendix Fig18); only *Hedera* is not shown due to insufficient quantities for plotting. *Corylus* was the dominant shrub taxon from the start of
the Long Lough series. *Juniperus* gradually increased alongside *Empetrum* and other Ericaceae taxa and *Salix* for the remainder of the record.

Appendix Fig18. Shrub pollen accumulation rates (grains cm\(^{-2}\) yr\(^{-1}\)) at Long Lough. The summary data for each growth form are presented in colour while the data for the component taxa within the group are presented in black. Note that the y-axis values vary between graphs.

There were seven genera of trees at Long Lough (Appendix Fig19) and only *Taxus* was not included in the plot due to insufficient quantities. All tree genera were present throughout the series at Long Lough, although the densities were lower than for shrubs (Appendix Fig18).
Appendix Fig19. Tree pollen accumulation rates (grains cm\(^{-2}\) yr\(^{-1}\)) at Long Lough. The summary data for each growth form are presented in colour while the data for the component taxa within the group are presented in black. Note that the y-axis values vary between graphs.

Detrended correspondence analysis of the individual plant taxa at Long Lough show that herb pollen influx spans the full extent of variation in the dataset, while shrub and tree influx is relatively more constrained (Appendix Fig20).
Appendix Fig20. Plot of species scores from detrended correspondence analysis of pollen accumulation rates for herbs (yellow), grass (brown), shrubs (orange) and trees (green) at Long Lough.

Appendix 1 References


