WEBBIA Journal of Plant Taxonomy and Geography

Firenze University Press
www.fupress.com/webbia

OPEN ACCESS

Citation: Kelly Hemmings (2022) Ancient woodland indicator species: can old herbarium specimens supplement recent records to inform ecological managment? *Webbia. Journal of Plant Taxonomy and Geography* 77(2): 327-336. doi: 10.36253/jopt-13400

Received: July 19, 2022

Accepted: October 24, 2022

Published: December 15, 2022

Data Availability Statement: All relevant data are within the paper and its Supporting Information files.

Competing Interests: The Author(s) declare(s) no conflict of interest.

Editor: Riccardo M. Baldini

ORCID
KH: 0000-0001-7658-7803

Ancient woodland indicator species: can old herbarium specimens supplement recent records to inform ecological management?

Kelly Hemmings

School of Agriculture, Food, and Environment, Royal Agricultural University, Cirencester, UK
E-mail: kelly.hemmings@rau.ac.uk

Abstract. Old herbarium specimens have become increasingly well-recognised as a rich source of ecological baseline data. For long-continuity plant communities, such as ancient woodland, these records may be particularly important for present day ecological management. To evaluate this potential, searches for pre-1950 Ancient Woodland Indicator (AWI) herbarium specimens collected in East Gloucestershire, UK, were conducted using digital open access sources and the physical Royal Agricultural University herbarium. In total 305 specimens were retrieved from twelve herbaria, with small regional collections being particularly important sources. The earliest specimen dated to 1834. There was a significant association between old specimen availability and year of collection, due to a peak in the late-1800s and early-1900s. Over half of the AWI species for the region were represented, although some taxonomic bias was evident. To determine if old AWI specimens contributed any new location records, 246 unique specimens with detailed georeferences were mapped and compared to the locations of 1950-1999 and 2000-2021 biological records. One third of the pre-1950 specimens had not been recorded in the same locality since collection of the old specimen, indicating either a gap in recent records or floristic change. However, length of time since specimen collection was not a predictor of a 1950-2000 or 2000-2021 record in the same locality. Overall, it is highly recommended that policy-makers, land managers, and field surveyors consult old AWI herbarium records for ancient woodland identification, management, and restoration.

Keywords: Ancient forest, connectivity, continuity forest, herbaria, inventory, natural history, restoration, old growth forest.

INTRODUCTION

Ecological records >50 years old have previously been overlooked in their relevance to present-day conservation action (Willis et al. 2007). Recently, increased digitisation and accessibility have greatly increased interest in the application of old herbarium data to biodiversity conservation (e.g. James et al. 2018; Hedrick et al. 2020; Albani Rocchetti et al. 2021; Baldini et al. 2022; Heberling 2022). Herbaria often provide the earliest species distribution data available to inform current ecological decision-making (Meineke et al. 2018;

Lang et al. 2019). In particular, preserved specimens and georeferenced metadata (taxonomic identification, collection date, and locality) can provide useful baseline biogeographical data for spatio-temporal studies (Lavoie 2013; Le Bras 2017).

Ancient woodland in the UK is land that has been continuously wooded since at least 1600 (1750 in Scotland) (Reid et al. 2021). This comprises four land-use types: ancient semi-natural woodland; plantations on ancient woodland sites; ancient wood pasture and parkland; infilled ancient wood pasture and parkland (for definitions see DEFRA et al. (2022)). These vary in terms of canopy openness, floristic composition, silvicultural or pastoral uses, and planted or natural regeneration, but the uniting factor is centuries-long wooded continuity (Peterken 2018). Since the date threshold, and often long before, the land has been wooded, and even if felled, replanted without any other intervening land-use: it is therefore uninfluenced by agricultural inputs or cultivation (DEFRA et al. 2022). As such, ancient woodland has a high conservation value and is widely considered to be irreplaceable (UK Government 2021; Reid et al. 2021). The ancient woodland concept arose to distinguish this important habitat - along with its distinctive ecology, ecosystem services, and cultural heritage - from newer woodlands established on other land-uses (Peterken 2018). Concepts analogous to ancient woodland are recognised internationally (e.g. Kirca et al. 2018; McMullin and Wiersma 2019).

Ancient woodland has been subject to habitat loss and change, covering just 2.5% of the UK's land area today (Reid et al. 2021). From the 1800s to mid-1900s many ancient woodlands were degraded or lost due to the enclosure of the countryside, shifts in land use during the agricultural and industrial revolutions, and the introduction of modern forestry practices (Rotherham 2022). Most notably, between the 1950s and 1980s, 39% of ancient semi-natural woodland area was converted to plantation forestry and a further 9% was lost to agriculture (Reid et al. 2021). Even today, with its value well-known, threats from infrastructure and development exist with the addition of new environmental and climatic challenges (Rackham 2008; Razzaque and Lester 2021). In response, the legal protection of ancient woodland features prominently in the UK National Planning Policy Framework and forestry policy, as does responsibility for its restoration and connectivity (DEFRA et al. 2022; Ministry of Housing, Communities and Local Government 2019; UK Government 2021). Therefore, accurate identification of ancient woodland is necessary to meet legislative requirements as well for its intrinsic value.

Ancient Woodland Indicator (AWI) species richness has long been one of the evidence source used in the identification of ancient woodlands (Peterken, 1974). These are vascular plant species that are particularly, but not exclusively, associated with ancient woodland, for example English Bluebell (*Hyacinthoides non-scripta*), Herb Paris (*Paris quadrifolia*), and Lily-of-the-Valley (*Convallaria majalis*) (Glaves et al. 2009). Numerous studies have evidenced a strong affinity between these understorey plant species and ancient woodland (e.g. Peterken 1974; Wulf 1997; Kelemen et al. 2014; Swallow et al. 2020). They typically exhibit life traits associated with habitat continuity such as long lifespan, late maturity, and rhizomatous regeneration (Hermy et al. 1999). In addition, many have short-distance dispersal strategies, and do not easily colonise more recently established woodland (Hermy et al. (1999). As such, AWI species lend themselves to uses beyond their initial purpose, including site prioritisation for defragmentation and protected area planning (Dyderski et al. 2017) or as target species for conservation management (Brown et al. 2015). The AWI concept is embedded in policy and practice but its strengths and limitations should be noted (Rotherham 2011; Sansum and Bannister 2018; Webb and Goodenough 2018).

Currently, old AWI herbarium specimens are not explicitly listed among the evidence sources for ancient woodland identification in the UK (Glaves et al. 2009) nor the Ancient Woodland Inventory (Sansum and Bannister 2018). However, they have contributed to the creation of regional AWI lists (Glaves et al. 2009). As ancient woodland is a long continuity ecosystem, the inclusion of old herbarium AWI records along with recent biological records and survey data could be extremely valuable. This approach would account for the past vegetation community that may have more clearly supported the evidence for ancient woodland status, for example if an AWI species had become locally extinct due to habitat change. Old AWI herbarium records have been successfully employed in a small number of studies to identify former ancient woodland sites by corroborating recent biological records and old cartographic evidence (e.g. Rotherham 2022). Although herbarium specimen mapping has been widely-employed in biogeographical studies (Lavoie 2013), it remains an under-explored and under-utilised technique in the context of ancient woodland. Seemingly no systematic analysis of its application has previously been undertaken.

The aim of this study was to examine the potential of old AWI herbarium specimens to inform ancient woodland identification and ecological management at a landscape scale. To achieve this, the objectives were twofold: (1) to investigate the availability of old (pre-

1950) AWI specimens and their temporal and taxonomic coverage; (2) to analyse the proportion of these specimens with a recent (1950–1999 or 2000–2021) biological record in the same locality.

MATERIALS AND METHODS

The study focused on Vice-county 33 (VC33), East Gloucestershire, located in the South-West of the UK (Figure 1). Vice-counties were created in 1852 for the purpose of biological recording and their boundaries have since remained constant. VC33 is centred on 51.49 N, 1.58 W (Figure 1), elevation 20-275 metres above sea level, with dominant geological substrates of oolitic Limestone and Lias clay (British Geological Survey 2021).

AWI species for VC33 were determined from standard lists for South-West England (Rose 1999) and neighbouring counties Avon, North Somerset, South Gloucestershire, and Worcestershire (Kirby 2004), as compiled by Glaves et al. (2009) This selection method aligned with Swallow et al. (2020). Taxonomic names followed Stace (2019).

Figure 1. Location of Vice-county 33 East Gloucestershire, UK.

Old AWI specimens were defined as pre-1950 as this pre-dates major shifts in countryside management associated with mid-1900s agricultural intensification and extensive felling of ancient semi-natural woodland for plantation forestry. To obtain pre-1950s VC33 AWI specimens, searches for published digitised herbarium accessions were conducted primarily via the Herbaria United database (2006–) (herbariaunited.org) and a small number via the Global Biodiversity Information Facility database (2001–) (GBIF.org) (as available on 31/05/2021), as well as inspection of the unpublished accessions list of the Royal Agricultural University herbarium. To account for nomenclatural changes, synonyms were included in searches. Respective digital and physical accessions were retrieved and a metadata list (identification, location and date) was created. At this stage, all specimens, including duplicates, were included.

Unique records with sufficiently detailed georeference data were mapped in QGIS (QGIS.org 2020). When species-location-year duplicates existed across the herbaria, only one was retained for mapping and analyses. For species-location duplicates, only the most recent was used. Named point landmarks or properties could be often assigned with greater than 1km^2 accuracy. Names of area features such as large woodlands were taken as the centre point of that location (Aedo et al. 2015).

The locations of pre-1950 specimens were compared to post-1950 digitally available biological records. QGIS was coded to display: (a) pre-1950 herbarium specimen only i.e. no 1950–2021 record in the same locality; (b) most recent record in the same locality 01/01/1950 –31/12/1999, and; (c) most recent record in the same locality 01/01/2000–31/05/2021. Post-1950 mapped digital records were obtained with permission from the Botanical Society of Britain and Ireland (BSBI) Distribution Database (2000–) (https://database.bsbi.org/) (Pescott et al. 2018). Record search criteria included specimens and observations. Taxon aggregates were included but hybrids were excluded. For 2000–2021 records 1km or finer resolution was used. Records located within the 1km square containing a old specimen point record or within the 1km squares covered by an area record or intersected by its boundary were counted as being in the same locality. Where point records were within a contiguous habitat such as a woodland, these were treated as area records. For 1950–1999, most available records were 2km resolution – these were only counted as the same locality when they substantially overlapped a large area feature e.g. large woodland, or if an old specimen point record was central.

To test if the number of old herbarium AWI specimens available was associated with year of collection, a chi-squared test of association was conducted. To establish if year of specimen collection had any bearing on availability of a 1950-2021 or 2000–2021 record in the same locality, a generalised linear model with binary logistic response was applied. SPSS (IBM corp. 2019) was used for all analyses.

RESULTS

In total, 305 AWI specimens dating between 1835 and 1949 from VC33 were obtained from 11 digitised published collections plus the unpublished Royal Agricultural University herbarium (Figure 2). The majority of specimens were housed in Gloucester City Museum (128), followed by the South London Botanical Institute (47), and the Royal Agricultural University (39). The latter herbarium was particularly distinct in the early date of its AWI specimens relative to the other herbaria (Figure 2). This collection held 24 AWI species and all specimens were unique location or date contributions.

Across all herbarium collections, 65 AWI species out of a potential 111 for the region were represented, including forbs, graminoids, pteridophytes, and some ligneous species. The most commonly collected species were of the following Families: Orchidaceae (five species, 45 specimens); Ranunculaceae (five, 42); Violaceae (two, 35) (Appendix 1). Nearly half of the species (32) were represented by only one or two specimens. The most represented species was *Cephanlanthera damasonium* (22 specimens).

Of the 305 specimens retrieved, 51 were duplicates and eight specimens were not locatable due to vague georeferences. Mapping of the pre-1950 herbarium specimens revealed a clustered distribution, largely aligned with current ancient woodland configuration (Figure 3). Of the 246 geolocatable herbarium specimens: 80 (32.5%) had no 1950–2021 record in the same locality; 31 (12.6%) had been most recently recorded in the same locality between 1950 and 1999; 135 (54.9%) had been most recently recorded in the same locality between 2000 and 2021 (Figures 3, 4).

There was a statistically significant association (p=0.030) between year of collection category and number of old AWI specimens retrieved, with more specimens available between 1890 and 1929 (Figure 4 and Table 1). However, year of specimen collection was not a significant predictor of a 2000–2021 record being available for the same locality, nor for the wider time period of 1950–2021 (Table 1).

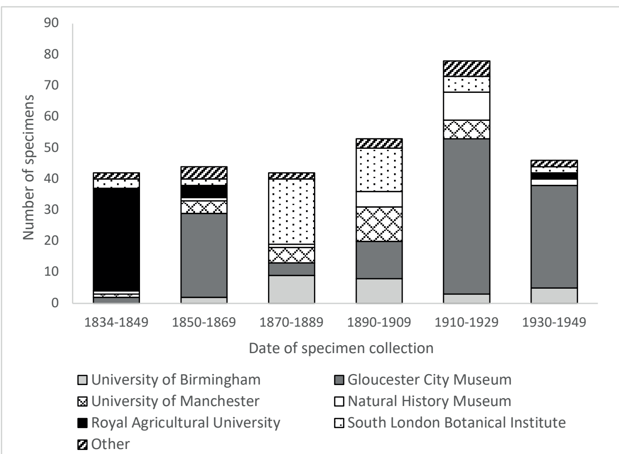

Figure 2. Number of pre-1950 Vice-county 33 Ancient Woodland Indicator specimens in herbarium collections, available via herbariaunited.org and GBIF.org as of 31/05/2021 and previously unpublished Royal Agricultural University specimens (n=305). Other = Royal Botanic Gardens, Kew; Aberystwyth University; University College Dublin; Bolton Museum; Royal Botanic Garden, Edinburgh; University of Pisa. All specimens, inclusive of duplicates of species collected in same location within same date, and specimens collected in same location but in different years.

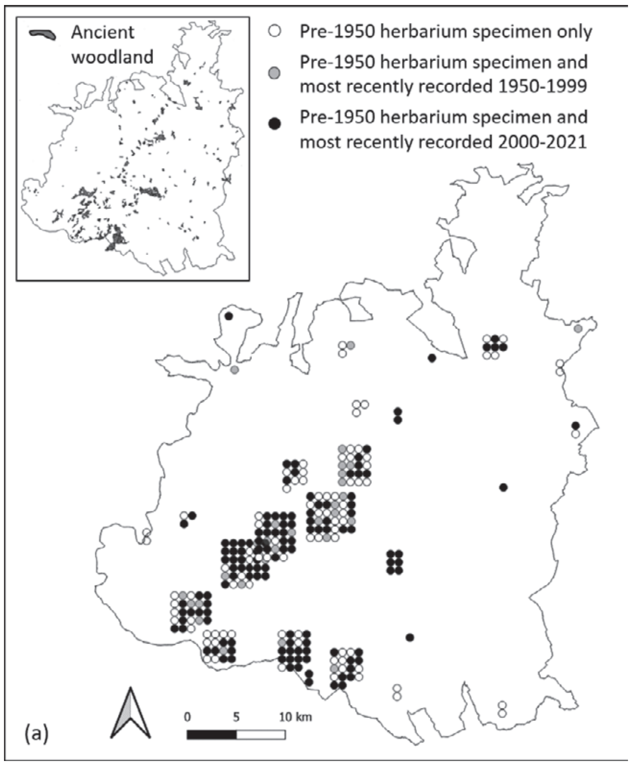

Figure 3. Geolocated pre-1950 herbarium Ancient Woodland Indicator species specimens in Vice-county 33, East Gloucestershire, UK. Each point represents one specimen. Data points are displaced from a central point and displayed in a grid pattern for ease of interpretation. Ancient woodland land cover map (Open Government Licence, Natural England 2021).

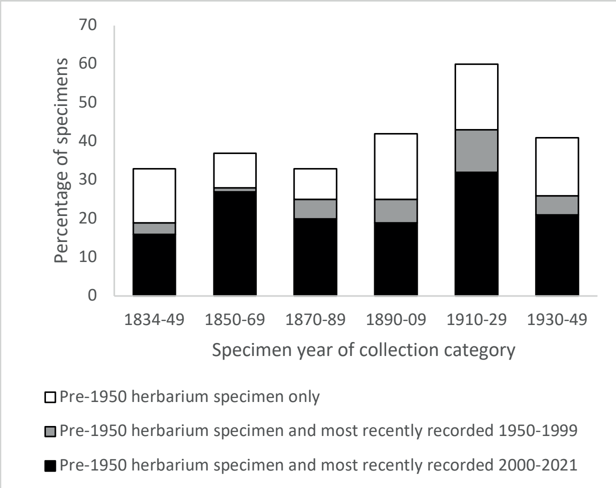

Figure 4. Number of pre-1950 Ancient Woodland Indicator specimens by date of collection (n=246), exclusive of duplicates and vague georeferenced specimens: pre-1950 specimen only with no record in same locality since 1950; most recently recorded in same locality between 1950 and 1999; most recently recorded in the same locality 2000–2021.

DISCUSSION AND CONCLUSIONS

The herbarium accession search results yielded 305 pre-1950 AWI specimens for the region. Crucially, this was sufficient to detect spatio-temporal patterns and trends, even after duplicates were discounted. Eighty-seven percent of the specimens were digitally accessed, emphasising the importance of herbarium digitisation (Soltis 2017). Specimen availability was reliant on very few herbaria: 94% of specimens were retrieved from just six collections and the remaining six each contributed <10 specimens. Two of the three highest contributors of old AWI specimens were small collections with a regional focus; Gloucester City Museum and the Royal Agricultural University. Small herbaria (<100,000 specimens (Lavoie 2013)) have been well-recognised in the literature for their contribution to biodiversity data (Colombo et al. 2016; Marsico et al. 2020) and the results reinforce that such collections should not be overlooked.

Table 1. Influence of old AWI specimen collection year on (a) number of available old herbarium AWI specimens (n=305), chi-squared test of association, and (b) likelihood of a 2000-2021 or 1950-2021 record in the same locality as the old specimen (n=246), generalised linear model.

	Chi (d.f.)	p
(a) Association between number of old herbarium AWI specimens and year category	12.341 (5)	0.030
(b)		
Year of herbarium specimen collection as predictor of 2000–2021 record in same locality	0.454 (1)	0.500
Year of herbarium specimen collection as predictor of 1950–2021 record in same locality	0.243 (1)	0.622

Although the first UK herbarium was established in 1621 (Smith 2018), close to the ancient woodland date threshold of 1600, the earliest specimen retrieved for this study dated to 1834. Specimen availability was fairly even through the mid-late 1800s, but statistical testing showed that temporal coverage of specimens was not evenly distributed over the full 1834-1949 period. This was mainly due to a peak in specimen numbers between 1890 and 1929. This pattern aligns with the wider collecting trend of British and Irish flora, which was most prolific in the late 1800s to early 1900s (Groom et al. 2014).

Old herbarium specimens represent 'hard won' data, limited by contemporary transport and recording technologies. They are also finite and the best available data for their time (Meineke et al. 2018). However, it is important to caveat their limitations. Biological recording is well-known to be prone to taxonomic and location biases, over- and under-sampled locations and false absences (Daru et al. 2018; Troudet et al. 2017). Just over half of the possible AWI species for this region were represented at least once among the specimens. However, specimen collection appears to have been influenced by axiophyte theory (Walker et al. 2010) with charismatic plants such as Orchidaceae more frequently collected than, for example, Cyperaceae. In terms of location bias, the majority of the old AWI specimens were collected from larger ancient woodlands. The ancient woodland concept, in its current sense, did not exist at that time (Peterken 2018), but the quality of woodland vegetation may have influenced choice of collection location.

The 32.5% of the old AWI specimens without a record in the same locality between 1950 and 2021 are particularly valuable as they provide potentially unique species-location data. Ancient woodlands are commonly identified using a range of desk-based evidence, including existing biological records, as field surveys are too resource-intensive to carry out on every site (Glaves et al. 2009; Natural England 2022). Therefore, old AWI herbarium data could add a useful evidence source to the UK Ancient Woodland Inventory or similar undertakings at any scale, particularly as herbaria are increasingly digitally available. This technique would be especially applicable when AWI richness thresholds (for example 8, 10, or 12 species (Glaves et al. 2009)) form part of the evidence for ancient status. In the present study, herbarium georeference data was often sufficiently detailed to pinpoint a named woodland. In such situations, the inclusion of old herbarium records could influence the classification of a woodland as ancient, and consequent levels of protection.

Old AWI specimens, with or without a corresponding recent record, may assist in the identification of lost, remnant or overlooked wooded sites. Mapping showed some small clusters of old AWI specimens located outside of named woodlands. Feasibly, some of these could indicate former ancient wooded commons, wood pastures or lost woodlands (Rotherham 2017). These, along with ancient woodland remnants of less than 2 hectares and ancient hedgerows, have been increasingly recognised for their intrinsic value, as well as their potential for connectivity, restoration, or wilding (e.g. Groenewoudt et al. 2022; Lenoir et al. 2021; Rotherham 2017; Sansum and Bannister 2018). Ancient woodland ecological planning depends not only on extant and mapped habitats, but also the historic landscape configuration (Kimberley et al. 2016). The 54.9% of old AWI specimens with a 2000–2021 record in the same locality could represent relict populations of such sites. To triangulate the evidence of 'ancientness', old herbarium records could be applied in combination with a range of other environmental indicators such as the palynological record (e.g. Dark 2021) and soil profile analysis (e.g. Rotherham 2022). Bergès and Dupouey (2019) advocate the exploration of all types of historical ecological documents to better inform ancient woodland management.

It might have been expected that the oldest AWI specimens would be significantly less likely to have a recent record in the same locality due to local extinctions in light of the threats to ancient woodland. However, statistical testing showed that year of herbarium specimen collection was not a significant predictor of whether or not a 1950–2021 or 2000–2021 record was available. In addition, the majority of old AWI specimens did have a corresponding recent record in the same locality, either between 2000 and 2021 (54.9%) or 1950 and 1999 (12.6%). Further, a proportion of the old AWI specimens without a recent record in the same locality may have been false absences. Therefore, known local losses of AWI species are in the minority. This suggests that ancient woodlands have largely maintained the necessary environmental conditions required to support ancient woodland flora: the oldest specimens with corresponding 2000–2021 records indicate a persistent population over around 180 years. Conversely, there is evidence of an extinction debt of over 100 years for woodland plants after habitat alteration (Vellend et al. 2006). A greater length of time and ground-truthing would be required to elucidate these population dynamics.

Old AWI herbarium specimens could also assist in resource allocation for species and habitat conservation prioritization (Kricsfalusy and Trevisan 2014). The use of old herbarium data to assess the likelihood of species presence where no recent record exists has met with success in other ecosystems and species groups (e.g. Lienert et al. 2002; Applequist et al. 2007; Aedo et al. 2015). Old AWI specimens without a corresponding recent record should not be treated as an absence or loss without ground-truthing. Old herbarium data may also guide targeted population surveys for conservation status assessment, for example to designate Red List status. In addition, AWI individual species have been increasingly employed as target species or success indicators of ancient replanted woodland restoration (Palo et al. 2013; Brown et al. 2015), rewilded woodlands (Broughton et al. 2021), and ancient woodland soil translocation mitigation (Craig et al. 2015). Old AWI herbarium records could expand the species presence baseline against which success is measured.

In conclusion, these findings strongly support the use of old AWI herbarium specimens in addition to more recent records for the purposes of ancient woodland identification and management for nature recovery. The digital availability of old herbarium records provides a rich source of high-granularity data that adds to the evidence for ancient status of extant woodlands and may elucidate the locations of lost ancient wooded sites, both of which are important for woodland restoration and connectivity. Further they provide scope for targeted field assessments of scarce or protected AWI species. When using such data, caution should be applied given the biases of biological recording and specimen collection. However, the unique value of old herbarium specimens outweighs these limitations. Future research into the application of old herbarium records to ecological management in other ecosystems and species groups is warranted.

ACKNOWLEDGMENTS

With thanks to the Wild Flower Society for a grant that enabled initial retrieval of AWI specimens in the Royal Agricultural University herbarium. I am also grateful to the Botanical Society of Britain and Ireland for enhanced access to the BSBI Distribution Database. With kind thanks to the reviewers of this work. I am also indebted to the organisations whose the publicly available digitised collections enabled this research.

REFERENCES

Aedo C, Medina L, Barberá P, Fernández-Albert, M. 2015. Extinctions of vascular plants in Spain. Nordic Joyrnal of Botany. 33(1): 83-100. https://doi.org/10.1111/njb.00575

Albani Rocchetti G, Armstrong CG, Abeli T, Orsenigo S, Jasper C., Joly S, Bruneau A. Zytaruk M, Vamosi, JC. 2021. Reversing extinction trends: new uses of (old) herbarium specimens to accelerate conservation action on threatened species. New Phytologist. 230: 433–45. https://doi.org/10.1111/nph.17133

Applequist WL, Mcglinn DJ, Miller M, Long QG, Miller JS. 2007. How well do herbarium data predict the locationof present populations? A test using Echinacea species in Missouri. Biodiversity and Conservation. 16(5): 1397-1407. https://doi.org/10.1007/s10531-006-6737-x

Baldini RM, Cristofolini G, Aedo, C. 2022. The extant herbaria from the Sixteenth Century: a synopsis. Webbia. 77(1): 23-33. https://doi.org/10.36253/jopt-13038

Botanical Society of Britain and Ireland Distribution Database. 2000- . BSBI [accessed 2022 Apr 25]. https://database.bsbi.org/

British Geological Survey. Apr 2022. Data from: geology of Britain viewer. [accessed 2002 Apr 25]. https://mapapps.bgs.ac.uk/geologyofbritain/home.html

Brown ND, Curtis T, Adams EC. 2015. Effects of clear-felling versus gradual removal of conifer trees on the survival of understorey plants during the restoration of ancient woodlands. Forest Ecology and Management. 348: 15-22. https://doi.org/10.1016/j.foreco.2015.03.030

Broughton RK, Bullock JM, George C, Hill RA, Hinsley SA, Maziarz M, Melin M, Mountford JO, Sparks TH, Pywell RF. 2021. Long-term woodland restoration on lowland farmland through passive rewilding. Plos One. 16(6), e0252466. https://doi.org/10.1371/journal.pone.0252466

Colombo B, Kaehier M, Calvente A. 2016. An inventory of the Bignoniaceae from the Brazilian state of Rio Grande do Norte highlights the importance of small herbaria to biodiversity studies. Phytotaxa. 278(1): 19-28. https://doi.org/10.11646/phytotaxa.278.1.2

Craig M, Buckley P, Howell R. 2015. Responses of an ancient woodland field layer to soil translocation: methods and timing. Applied Vegetation Science. 18(4): 579-590. https://doi.org/10.1111/avsc.12170

Dark P. 2021. Wildwood, Wood-Pasture and Rewilded Woods: Palaeoecological Perspectives from Ancient Woodland. In: Barnett, C., Walker, T. Environment, Archaeology and Landscape. Archaeopress. Oxford. 153-163.

Daru BH, Park DS, Primack RB, Willis CG, Barrington DS, Whitfeld TJ, Seidler TG, Sweeney PW, Foster DR, Ellison AM, et al. 2018. Widespread sampling biases in herbaria revealed from large-scale digitization. New Phytologist. 217(2): 939-955. https://doi.org/10.1111/nph.14855

Department for Environmental, Food, and Rural Affairs (DEFRA), Forestry Commission, Natural England 2022. Keeper's of Time: ancient and native woodland and trees policy in England. https://www.gov.uk/government/publications/keepers-of-time-ancient-and-native-woodland-and-trees-policy-in-england/keepers-of-time-ancient-and-native-woodland-and-trees-policy-in-england#glossary

Dyderski MK, Tyborski J, Jagodziński AM. 2017. The utility of ancient forest indicator species in urban environments: A case study from Poznań, Poland. Urban Forestry & Urban Greening. 27: 76-83. https://doi.org/10.1016/j.ufug.2017.06.016

Global Biodiversity Information Facility database. 2001- . GBIF [accessed 2022 Apr 25]. https/www.GBIF.org.

Glaves P, Handley C , Birkbeck J, Rotherham ID, Wright B. 2009. A survey of the coverage, use and application of ancient woodland indicator lists in the UK. Hallam Environmental Consultants Ltd., Biodiversity and Landscape History Research Institute/Geography, Tourism and Environment Change Research Unit, Sheffield Hallam University, Sheffield. Available from: https://core.ac.uk/download/pdf/4149223.pdf

Groenewoudt B, Eijgenraam G, Spek T, Kosian, MC. 2022. Mapping lost woodland. A modeling experiment based on place names and historical references aimed at inspiring reforestation. Rural Landscape. 9(1): 1-17. 10.16993/rl.82

Groom QJ, O'Reilly C, Humphrey T. 2014. Herbarium specimens reveal the exchange network of British and Irish botanists, 1856–1932. New Journal of Botany. 4(2): 95-103.

Heberling, JM. 2022. Herbaria as big data sources of plant traits. Int J Plant Sci. 183(2): 87-118. https://doi.org/10.1086/717623

Hedrick BP, Heberling JM, Meineke EK, Turner KG, Grassa CJ, Park DS, Kennedy J, Clarke JA, Cook JA, Blackburn DC. 2020. Digitization and the future of natural history collections. BioScience. 70(3): 243-251. https://doi.org/10.1093/biosci/biz163

Herbaria United database. 2006 - . Botanical Society of Britain and Ireland and Botanical Collection Manag-

ers Group. [accessed 2022 Apr 25]. http://herbariaunited.org/
Hermy M, Honnay O, Firbank L, Grashof-Bokdam C, Lawesson JE. 1999. An ecological comparison between ancient and other forest plant species of Europe, and the implications for forest conservation. Biological Conservation. 91(1): 9-22. https://doi.org/10.1016/S0006-3207(99)00045-2
IBM Corp. Released 2019. IBM SPSS Statistics for Windows, Version 26.0. Armonk, NY: IBM Corp
James SA, Soltis PS, Belbin L, Chapman AD, Nelson G, Paul DL, Collins M. 2018. Herbarium data: Global biodiversity and societal botanical needs for novel research. Applied Plant Science. 6(2), e1024. https://doi.org/10.1002/aps3.1024
Kelemen K, Kriván A, Standovár T. 2014. Effects of land-use history and current management on ancient woodland herbs in Western Hungary. Journal of Vegetation Science. 25(1): 172-183. https://doi.org/10.1111/jvs.12046
Kimberley A, Blackburn GA, Whyatt JD, Smart SM. 2016. How well is current plant trait composition predicted by modern and historical forest spatial configuration?. Ecography. 39 (1), 67-76. https://doi.org/10.1111/ecog.01607
Kirca S, Çolak, AH, Rotherham, ID. 2018. Executive summary. In: Çolak AH, Kırca S, Rotherham ID, editors. Ancient woodlands and trees: a guide for landscape planners and forest managers. IUFRO World Series, 37. Vienna: International Union of Forest Research Organizations (IUFRO) and Turkish Academy of Sciences; p 11-14
Kirby K. 2004. Table of ancient woodland indicator plants. In: Rose F. O'Reilly C, Smith D.P. and Collings. M, editors. The Wild Flower Key: How to Identify Wild Flowers, Trees and Shrubs in Britain and Ireland. London, UK: Warne; p. 558-561
Kricsfalusy VV, Trevisan N. 2014. Prioritizing regionally rare plant species for conservation using herbarium data. Biodiversity and Conservation. 23(1): 39-61. https://doi.org/10.1007/s10531-013-0583-4
Lang PL, Willems FM, Scheepens JF, Burbano HA, Bossdorf, O. 2019. Using herbaria to study global environmental change. New Phytologist. 221(1): 110-122. https://doi.org/10.1111/nph.15401
Lavoie C. 2013. Biological collections in an ever changing world: Herbaria as tools for biogeographical and environmental studies. Perspectives in Plant Ecology Evolution and Systematics. 15(1), 68-76. https://doi.org/10.1016/j.ppees.2012.10.002
Lenoir J, Decocq G, Spicher F, Gallet-Moron E, Buridant J, Closset-Kopp, D. 2021. Historical continuity and spatial connectivity ensure hedgerows are effective corridors for forest plants: Evidence from the species–time–area relationship. Journal of Vegetation Science. 32(1): e12845. https://doi.org/10.1111/jvs.12845
Lienert J, Fischer M, Diemer M. 2002. Local extinctions of the wetland specialist Swertia perennis L.(Gentianaceae) in Switzerland: a revisitation study based on herbarium records. Biological Conservation. 103(1): 65-76. https://doi.org/10.1016/S0006-3207(01)00121-5
Le Bras G, Pignal M, Jeanson ML, Muller S, Aupic C, Carré B, Flament G, Gaudeul M, Gonçalves C, Invernón VR et al. 2017) The French Muséum national d'histoire naturelle vascular plant herbarium collection dataset. Sci data. 4(1): 1-16. https://doi.org/10.1038/sdata.2017.16
Marsico TD, Krimmel ER, Carter JR, Gillespie EL, Lowe PD, McCauley R, Morris AB, Nelson G, Smith M, Soteropoulos D, et al. 2020. Small herbaria contribute unique biogeographic records to county, locality, and temporal scales. American Journal of Botany. 107(11): 1577-1587. https://doi.org/10.1002/ajb2.1563
McMullin RT, Wiersma YF. 2019. Out with OLD growth, in with ecological continNEWity: new perspectives on forest conservation. Frontiers in Ecology and the Environment. 17(3): 176-181. https://doi.org/10.1002/fee.2016
Meineke EK, Davis CC, Davies TJ. 2018. The unrealized potential of herbaria for global change biology. Ecological Monographs. 88(4): 505-525. https://doi.org/10.1002/ecm.1307
Ministry of Housing, Communities and Local Government. 2019. National planning policy framework. London: Ministry of Housing, Communities and Local Government. [accessed 2022 Apr 25]. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1005759/NPPF_July_2021.pdf
Natural England 2022. Ancient woodland inventory. Open government licence. [accessed 2022 Apr 25]. https://data.gov.uk/dataset/9461f463-c363-4309-ae77-fdcd7e9df7d3/ancient-woodland-england
Palo A, Ivask M, Liira J. 2013. Biodiversity composition reflects the history of ancient semi-natural woodland and forest habitats—compilation of an indicator complex for restoration practice. Ecological Indicators. 34: 336-344. https://doi.org/10.1016/j.ecolind.2013.05.020
Pescott OL, Humphrey TA, Walker KJ. 2018. A short guide to using British and Irish plant occurrence data

for research. Wallingford, NERC/Centre for Ecology & Hydrology. Available from: http://nora.nerc.ac.uk/id/eprint/520609/

Peterken GF. 1974. A method for assessing woodland flora for conservation using indicator species. Biological Conservation. 6(4): 239-245. https://doi.org/10.1016/0006-3207(74)90001-9

Peterken GF. 2018. Chapter I Ancient Woodland in Concept and Practice. In: Çolak AH, Kırca S, Rotherham ID, editors. Ancient woodlands and trees: a guide for landscape planners and forest managers. IUFRO World Series, 37. Vienna: International Union of Forest Research Organizations (IUFRO) and Turkish Academy of Sciences; p 15-25

QGIS.org, 2020. QGIS Geographic Information System. QGIS Association. http://www.qgis.org

Rackham O. 2008. Ancient woodlands: modern threats. New Phytologist. 180(3): 571-586. http://www.jstor.org/stable/25150608.

Razzaque J, Lester C. 2021. Why Protect Ancient Woodland in the UK? Rethinking the Ecosystem Approach. Transnational Environmental Law. 10(1): 135-158. https://doi.org/10.1017/S2047102520000333

Reid C, Hornigold K, McHenry E, Nichols C, Townsend M, Lewthwaite K, Elliot M, Pullinger R, Hotchkiss A, Gilmartin E, et al. 2021. State of the UK's Woods and Trees 2021. Grantham: The Woodland Trust.

Rose F. 1999. Indicators of ancient woodland-the use of vascular plants in evaluating ancient woods for nature conservation. British Wildlife. 10: 241-251.

Rotherham ID. 2011. A landscape history approach to the assessment of ancient woodlands. In, Wallace EB, editor. Woodlands: ecology, management and conservation,. New York: Nova Science; p. 161-184.

Rotherham ID. 2017. Searching for "shadows" and "ghosts" in the landscape. Arboricultural Journal. 39 (1): 39-47.

Rotherham ID. 2022. Challenges for the restoration of cultural values in UK woodlands. Forest Ecology and Management. 503, 119756. https://doi.org/10.1016/j.foreco.2021.119756

Sansum P, Bannister NR. 2018. A Handbook for updating the Ancient Woodland Inventory for England. Natural England Commissioned Reports NECR248

Smith JP. 2018. The Herbarium. Botanical Studies. 79. https://digitalcommons.humboldt.edu/botany_jps/79

Stace C. 2019. New Flora of the British Isles (4th ed). UK: C&M Floristics.

Soltis PS. 2017. Digitization of herbaria enables novel research. American Journal of Botany. 104 (9): 1281-1284. https://doi.org/10.3732/ajb.1700281

Swallow KA, Wood MJ, Goodenough AE. 2020. Relative contribution of ancient woodland indicator and non-indicator species to herb layer distinctiveness in ancient semi-natural, ancient replanted, and recent woodland. Applied Vegetation Science. 23(4): 471-481. https://doi.org/10.1111/avsc.12501

Troudet J, Grandcolas P, Blin A, Vignes-Lebbe R, Legendre F. 2017. Taxonomic bias in biodiversity data and societal preferences. Scientific Reports. 7(1): 1-14. https://doi.org/10.1038/s41598-017-09084-6

UK Government. 2021. The England Trees Action Plan 2021-2024. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/987432/england-trees-action-plan.pdf

Vellend M, Verheyen K, Jacquemyn H. 2006. Extinction Debt of Forest Plants Persists for More than a Century following Habitat Fragmentation. Ecology. 87(3): 542-554. https://doi.org/10.1890/05-1182

Walker K, Pearman D, Ellis B, McIntosh J, Lockton A. 2010. Recording the British and Irish flora 2010-2020. London: Botanical Society Britain and Ireland.

Willis KJ, Araújo MB, Bennett KD, Figueroa-Rangel B, Froyd CA, Myers N. 2007. How can a knowledge of the past help to conserve the future? Biodiversity conservation and the relevance of long-term ecological studies. Philosophical Transactions of the Royal Society London, B Bio Sci. 362(1478): 175-187. https://doi.org/10.1098/rstb.2006.1977

Webb JC, Goodenough AE. 2018. Questioning the reliability of "ancient" woodland indicators: Resilience to interruptions and persistence following deforestation. Ecological Indicators. 84: 354-363. https://doi.org/10.1016/j.ecolind.2017.09.010

Wulf M. 1997. Plant species as indicators of ancient woodland in northwestern Germany. Journal of Vegetation Science. 8(5): 635-642. https://doi.org/10.2307/3237367

Appendix 1. Pre-1950 herbarium specimens for Vice-county 33 East Gloucestershire: Family, species and number of specimens, inclusive of duplicates. Total 305 specimens.

Family	Species	Number of pre-1950 herbarium specimens
Adoxaceae	*Adoxa moschatellina*	4
Ranunculaceae	*Anemone nemorosa*	10
Ranunculaceae	*Aquilegia vulgaris*	3
Woodsiaceae	*Athyrium filix-femina*	6
Blechnaceae	*Blechnum spicant*	1
Campanulaceae	*Campanula trachelium*	1
Brassicaceae	*Cardamine amara*	4
Brassicaceae	*Cardamine impatiens*	2
Cypercaeae	*Carex montana*	1
Cypercaeae	*Carex paniculata*	3
Cypercaeae	*Carex pendula*	2
Cypercaeae	*Carex remota*	2
Cypercaeae	*Carex sylvatica*	2
Orchidaceae	*Cephalanthera damasonium*	22
Saxifragaceae	*Chrysosplenium alternifolium*	3
Saxifragaceae	*Chrysosplenium oppositifolium*	2
Colchicaceae	*Colchicum autumnale*	9
Apiaceae	*Conopodium majus*	2
Asparagaceae	*Convallaria majalis*	1
Thymelaeceae	*Daphne laureola*	2
Dipsacaeae	*Dipsacus pilosus*	3
Dryopteridaceae	*Dryopteris carthusiana*	1
Orchidaceae	*Epipactis helleborine*	8
Celastraceae	*Euonymus europaeus*	7
Euphorbiaceae	*Euphorbia amygdaloides*	1
Liliaceae	*Gagea lutea*	4
Rubiaceae	*Galium odoratum*	7
Geraniaceae	*Geranium sylvaticum*	2
Rosaceae	*Geum rivale*	4
Asteraceae	*Gnaphalium sylvaticum*	1
Ranunculaceae	*Helleborus foetidus*	15
Ranunculaceae	*Helleborus viridis*	11
Poaceae	*Hordelymus europaeus*	2

Family	Species	Number of pre-1950 herbarium specimens
Asparagaceae	*Hyacinthoides non-scripta*	2
Aquifoliaceae	*Ilex aquifolium*	2
Lamiaceae	*Lamiastrum galaeobdolon*	1
Fabaceae	*Lathyrus sylvestris*	2
Primulaceae	*Lysimachia nemorum*	3
Rosaceae	*Malus sylvestris*	2
Lamiaceae	*Melittis melissophylum*	1
Euphorbiaceae	*Mercurialis perennis*	1
Caryophyllaceae	*Moehringia trinerva*	9
Ericaceae	*Monotropa hypopitys*	12
Orchidaceae	*Neottia nidus-avis*	11
Orchidaceae	*Neottia ovata*	2
Orchidaceae	*Orchis mascula*	2
Oxalidaceae	*Oxalis acetosella*	8
Melanthiaceae	*Paris quadrifolia*	8
Aspleniaceae	*Phylittis scolopendrium*	2
Polypodiaceae	*Polypodium vulgare*	7
Dryopteridaceae	*Polystichum aculeatum*	4
Dryopteridaceae	*Polystichum setiferum*	1
Primulaceae	*Primula vulgaris*	4
Rosaceae	*Potentilla sterilis*	3
Rosaceae	*Prunus avium*	5
Ranunculaceae	*Ranunculus auricomus*	3
Apiaceae	*Sanicula europaea*	2
Crassulaceae	*Sedum telephium*	2
Veronicaceae	*Sibthorpia europaea*	1
Malvaceae	*Tilia cordata*	1
Veronicaceae	*Veronica montana*	1
Fabaceae	*Vicia sepium*	9
Fabaceae	*Vicia sylvaticum*	11
Violaceae	*Viola riviniana*	16
Violaceae	*Viola reichenbachiana*	19