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Open Structured Woodland and the Ecological Interpretation of Scotland's Ancient Woodland Inventory

RICHARD WHITTET[†], JOSEPH HOPE & CHRISTOPHER J. ELLIS
Royal Botanic Garden Edinburgh, 20A Inverleith Row, Edinburgh EH3 5LR, UK

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ABSTRACT *Following intensive human land use over millennia, European forest ecosystems record among the largest values of deforestation globally. This puts a premium on European ancient woodland, which has existed in the landscape minimally over several centuries. Ancient woodland in the UK was quantified in the Ancient Woodland Inventory (AWI). In cross-checking AWI sites in Scotland, it came to our attention that a proportion of 'Class 3' woodlands, which are thought to be of recent origin (regenerated since the nineteenth century), retain scattered tree symbols. This paper quantifies the degree to which Class 3 AWI sites may correspond to areas of scattered trees or open growth woodland. We show that a significant number (c. 50%) of Class 3 sites appear to have continuity of tree/woodland habitat; this may be particularly important for interpreting the distribution of ecological guilds such as tree-dependent epiphytic lichens and invertebrates. The study serves to re-emphasise that (i) technological limits and priorities of map makers, (ii) value systems of historical geographers, and (iii) biology of species, should be carefully considered and aligned during ecological research, so that potential anomalies, for example, the continuous existence of open structured woodland, can be fully recognised during application of systems such as the AWI.*

KEY WORDS: ancient woodland indicators, epiphyte, historical ecology, pasture woodland, woodland continuity

Introduction

Human deforestation since the mid-Holocene has resulted in fragmentation of one half of the global resource of temperate broadleaf and mixed forest, with the highest losses occurring in Europe (Millennium Ecosystem Assessment 2005). This places a premium on European 'ancient woodland', which is defined as having existed continuously in the landscape over relatively long periods of time, typically a minimum of several centuries. The link between woodland age and nature conservation value has been well documented (Peterken

Correspondence Address: Christopher J. Ellis, Royal Botanic Garden Edinburgh, 20A Inverleith Row, Edinburgh EH3 5LR, UK. Email: c.ellis@rbge.org.uk
[†]Current Address: Natural Environment Research Council Centre for Ecology and Hydrology, Edinburgh, Bush Estate, Penicuik, Midlothian EH26 0QB, UK.

1977; Rackham 1980), and woodland continuity is a recurring theme in conservation policy and research (Anon 2014a, 2014b). In terms of biodiversity conservation, there is a necessary distinction between 'ecological continuity' and 'stability'. Continuity implies the occurrence of woodland on the same site over an extended period of time, though stability is not guaranteed. Near-natural woodlands with long continuity can be a shifting mosaic of ecological conditions (Emborg *et al*. 2000), and in other cases, woodlands may have existed in the long term, but have undergone intensive management, and a process of simplification that reduces the overall biodiversity value, as is the case among Scotland's oak coppice woodland (Smout 2005; Smout *et al*. 2007). Nevertheless, it is only for woodlands with continuity, such as ancient woodlands, that high-quality habitat has the potential for long-term persistence (Whittet & Ellis 2013). Thus, certain ancient woodlands provide key habitats for species which are threatened by forest loss, from across taxonomic groups, for example, from mammals (Bright *et al.* 1994) to invertebrates (Assmann 1999). As documented for vascular plant indicators of ancient woodland (Hermy *et al.* 1999; Kimberley *et al.* 2013), such species may show ecological traits consistent with: (i) niche specialism, being dependent on particular microhabitats that are strongly associated with heterogeneous ancient woodlands including veteran trees, or (ii) dispersal limitation, such that their establishment requires a minimum period of woodland continuity to reach a threshold likelihood of colonisation, and population viability.

An increased awareness of the biological and cultural importance of ancient woodland prompted the Nature Conservancy Council to begin compiling an Ancient Woodland Inventory (AWI) for the UK in 1981 (cf. Walker & Kirby 1987; Spencer & Kirby 1992; Goldberg *et al.* 2007). Among the initial aims and scope of the inventory were to: (i) create a tool which would more accurately estimate the extent of ancient woodland remaining, (ii) contribute to the selection of Sites of Special Scientific Interest, (iii) assist in improving existing or targeting future surveying, and (iv) act as a baseline for future landscape change. The AWI has since become a key resource in conservation planning (Goldberg *et al.* 2007).

Separate ancient woodland inventories were compiled for Scotland, England, and Wales, utilising different combinations of evidence. In Scotland, the principal source of evidence

Table 1 Summary flow chart of map-based criteria for categorisation of sites within the AWI for Scotland

map series	nature and occurrence of tree symbols				
Roy Military Survey, 1747–1755	Semi-natural woodland	Plantation woodland	*Absent*	*Absent*	Semi-natural woodland
	↓	↓			↓
First Edition OS 'six-inch' series, 1843–1882	Semi-natural woodland	Plantation woodland	Semi-natural woodland	Plantation woodland	*Absent*
	↓	↓	↓	↓	↓
OS 1:25,000 maps, Contemporary	Semi-natural woodland	Plantation woodland	Semi-natural woodland	Plantation woodland	Woodland
	↓	↓	↓	↓	↓
Class	1a	1b	2a	2b	3
	Ancient semi-natural woodland	Ancient (of plantation origin)	Long-established semi-natural woodland	Long-established (of plantation origin)	Recent

was cartographic (Table 1), including the occurrence of wooded tree symbols on a chronological sequence of maps (Walker & Kirby 1987). Three time series were used: (i) the Roy Military Survey sheets, dating from 1747 to 1755, (ii) the first edition 'six-inch' Ordnance Survey series, with Scottish sheets dating from 1843 to 1882, and (iii) contemporary 1:25,000 Ordnance Survey maps. Sites were designated as Class 1a 'ancient' semi-natural woodlands if they could be demonstrated to have been repeatedly mapped since the time of Roy's Military Survey. These are typically regarded as being of the greatest importance in nature conservation. Class 2a sites appeared on the first edition 'six-inch' Ordnance Survey series, though with no evidence of their existence during the eighteenth century, and were designated 'long-established' semi-natural woodlands, rather than 'ancient'. These designations both accommodated plantation woodlands, which were categorised separately as Class 1b, or Class 2b. The final category Class 3 woodlands included those with a documented break in continuity during the nineteenth century, between their appearance on Roy's map and their existence during the present day. They are described as 'recent' woods (Roberts *et al.* 1992) and are unique to the Scottish inventory.

The defining attribute of ancient woodland is therefore its continuity of habitat. This can be particularly important for organisms which are dependent on the occurrence of trees themselves, such as epiphytes. Tree-dependent species may not survive *in situ* a period of clear-felling, for example, as is possible for vascular plants in a seed bank (Erenler *et al.* 2010). This dependency makes Class 3 woodlands especially significant, because the inferred break in continuity (cf. Table 1) creates a gap in the existence of the required habitat. It is therefore expected that Class 3 woodlands would be unavailable as a resource to ancient woodland epiphytic indicators and similar tree-dependent organisms. Nevertheless, in cross-checking the designation of sites within the AWI, it was noticed that scattered tree symbols on the first edition Ordnance Survey maps occurred within the boundaries of certain Class 3 woodlands. The assumption of a break in woodland continuity (Class 3 designation) for landscapes with scattered trees could have significant ecological ramifications, as scattered trees have recently been documented as keystone structures for biodiversity and ecosystem function (Manning *et al*. 2006).

This paper (i) quantifies the degree to which Class 3 woodlands include scattered tree symbols, and may therefore represent continuous open wooded habitat which is more consistent with a Class 1 designation (long continuity), and (ii) uses field survey to confirm the existence of veteran trees at such sites, consistent with a wood pasture hypothesis.

Methods

The occurrence of trees and woodland was compared between the contemporary 1:25,000 Ordnance Survey maps and the first edition 'six-inch' Ordnance Survey series using ArcMap v. 10 (ESRI 2012). These maps were combined with a random sample corresponding to 25% of all Class 3 woodlands ($n = 637$), which were overlaid onto the mapping data at a 1:5000 resolution. The ArcMap shapefiles were visually inspected, and Class 3 woodlands were categorised into an ordinal scale based on the occurrence of tree symbols on the Ordnance Survey's first edition series. Tree symbols on the first edition maps are known to have been plotted with characteristics providing information on the dominant vegetation structure, with differentiation of coniferous, mixed and deciduous woods, for example, and with tree symbols being used to indicate the approximate density of trees for the unit of vegetation (Harley 1975; Oliver 2005). The legend published by the Ordnance

Survey in 1897 distinguished between more open 'parkland' type landscapes, copses, and woods/forests, symbolised by the varied use of tree symbols. On the assumption that Class 3 polygon boundaries may overlap different combinations in the use of symbols for trees/woodland, a series of six levels was quantified: Level 0, No tree symbols present or if so, then extremely sparse and not exceeding 1–2% cover of the polygon area; Level 1, Very few tree symbols present, not exceeding 10% cover and too isolated to be interpreted as woodland; Level 2, Symbols occupying between 10% and 20% cover. This category was often applied where boundary trees or hedges were present or riparian trees ran through a proportion of the site; Level 3, Between 21% and 40% of polygon area covered with scattered tree symbols; Level 4, Between 41% and 60% of polygon area covered with scattered tree symbols; Level 5, Between 61% and 80% of polygon area covered with scattered tree symbols; Level 6, Between 81% and 100% of polygon area covered with scattered tree symbols. Level 6 was also applied in situations where a portion of a site included the symbol for closed-canopy woodland, with a recommendation to split this portion off as wrongly designated Class 1 ancient semi-natural sites.

It became apparent that many of the sites within the sample are now plantation woodland. This was determined by continuous and discrete boundaries on maps, the appearance of straight forest rides and coniferous symbols in regions where native pinewoods are not known, combined with satellite imagery (e.g. Google Earth) to extend the initial AWI methodology (Goldberg *et al.* 2007). All examined sites were coded for current condition as plantation or non-plantation. Sites were also categorised by their survey quality (Walker & Kirby 1989), to assess the reason for potential anomalies in the Class 3 designations. Original AWI metadata were examined first hand at the Scottish Natural Heritage (SNH) archives in Inverness. Data were added to the attribute table and queried within ArcMap, to test the relationship between tree cover category (Level 0–6) and the original surveyor definitions of quality (Walker & Kirby 1989, p. 27) on a subjective three-point scale (A–C):

> A, Good survey information covering the whole of the site; B, At least some information, but this may not be very clear, out of date, or of good quality for only part of the site; C, Sites where the woodland type is determined solely by the tree symbol on the OS 1:25,000 maps.

A sub-selection of Class 3 sites which Geographical Information System (GIS) analysis had shown to have scattered tree symbols were visited by Richard Whittet (Table 2), in order to

Table 2 Nine sites selected for field survey including the investigation of veteran trees and indicator species, suggestive of woodland continuity stretching into the nineteenth century

site name	national grid reference	survey quality category	assigned level of tree cover
North Rannoch	NN 586587	B	5
Glen Feshie	NJ 850027	B	2
The Bochel	NJ 226245	B	4
Braes of Meulach	NJ 335396	B	4
Glen Rinnes	NJ 310375	A	5
Easter Ness	NH 457159	A	6
Coill Innis Mhic Gille Ruaidh	NN 238897	A	6
Parallel Roads	NN 241873	C	5
Coille Bhrodainn	NM 868783	A	6

determine field evidence for scattered veteran trees. Sites were selected to encompass variability in the combined scores for survey quality category and the tree cover category. Walk-through surveys were conducted at nine Class 3 woodland sites to test whether direct field evidence existed to support continuity of over-mature and veteran trees as well as associated lichen and vascular plant indicator species.

Results

Of the Class 3 sites which were examined using GIS, 49% ($n = 313$) corresponded to Level 0, with no or very few scattered tree symbols (Figure 1(a)). These represent coherent Class 3 sites. There were fewer sites registered as the apparent anomaly increased, that is, moving from Level 0 to Level 6 sites, with increasing numbers of scattered tree symbols. Of the sites examined a high proportion appeared to be occupied by plantation forestry based on contemporary mapping (61%). Nevertheless, there remained a significant number of non-plantation (semi-natural) woodland sites which had been designated as Class 3, but which had evidence for the occurrence of tree symbols during the nineteenth century, representing the possible presence of semi-natural woodland habitat in some form.

Survey quality categories (Figure 1(b)) were available for 98% of sites ($n = 624$). The most commonly applied category was B ($n = 311$) although surprisingly, for Level 5 and Level 6 anomalies, there was a relatively greater proportion of sites which were considered to have been designated using the very best survey information (category A).

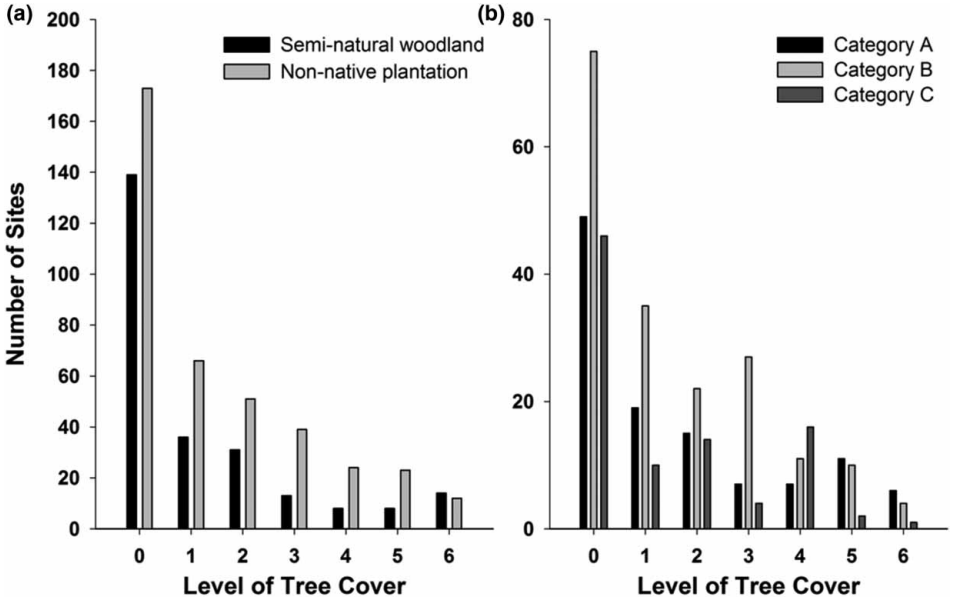

Figure 1 The number of Class 3 Ancient Woodland Sites (of Recent origin, cf. Table 1), matched against six different tree cover Levels quantified using the nineteenth-century Ordnance Survey six-inch series, and differentiating: (a) woodlands which exist as plantation or semi-natural on contemporary maps, and (b) survey quality information.

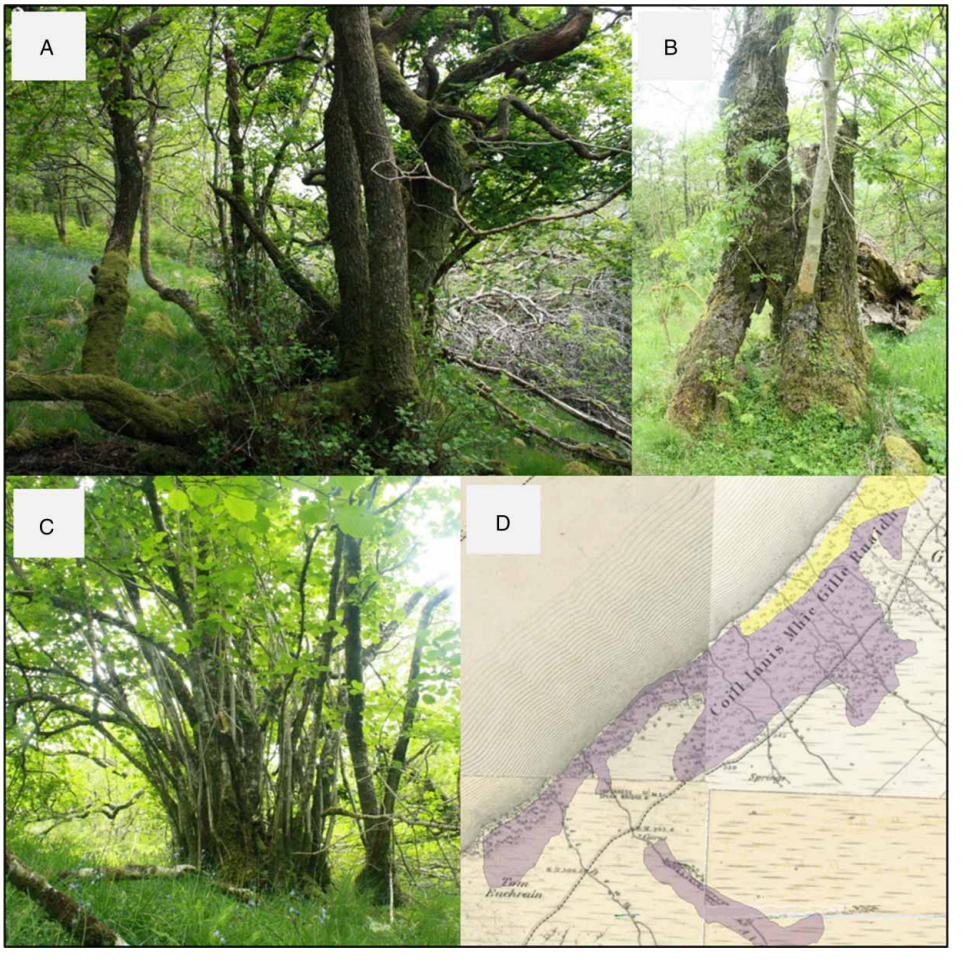

Figure 2 Examples of over-mature and veteran type trees and hazel stools observed at Coill Innis Mhic Gille Ruaidh (panels A–C), and D. The appearance of the site on the Ordnance Survey's First Edition map, showing scattered tree symbols amongst marshy areas within the boundaries of violet-overlay Class 3 polygon. Part D reproduced by permission of the National Library of Scotland, and Class 3 polygon reproduced under an open data licence, copyright Scottish Natural Heritage and containing Ordnance Survey data © Crown Copyright.

Field evidence confirmed the occurrence of large trees in the early or later stages of senescence (conventionally referred to as 'over-mature' and 'veteran', respectively) at eight of the nine sites investigated (cf. Figure 2); standing old senescent trees were absent from the Parallel Roads site, but large deadwood was present. Five of the nine sites included lichen indicators of ecological continuity (Coppins & Coppins 2002) on the over-mature or veteran trees, with lichens absent from sites close to sources of pollution, for example, Braes of Meulach and Glen Rinnes which lie close to Dufftown. All sites included some ancient woodland indicators when the lichens were complemented by the vascular plants (Table 3).

Table 3 A summary of indicator species positively identified at each of the AWI Class 3 woodland sites examined

site name	vascular plants	epiphytic lichens
North Rannoch	*Anenome nemerosa*	
	Primula vulgaris	
Glen Feshie	*Anenome nemerosa*	
	Melampyrum pratense	
The Bochel	*Anenome nemerosa*	*Peltigera collina*
	Chrysosplenium oppositifolium	
	Gymnocarpium dryopteris	
	Luzula pilosa	
	Lysimachia nemorum	
	Melampyrum pratense	
	Primula vulgaris	
Braes of Meulach	*Chrysosplenium oppositifolium*	
	Gymnocarpium dryopteris	
	Mercurialis perennis	
	Lysimachia nemorum	
Glen Rinnes	*Chrysosplenium oppositifolium*	
	Mercurialis perennis	
	Lysimachia nemorum	
Easter Ness	*Anenome nemerosa*	*Bryoria fuscescens*
	Lysimachia nemorum	*Lobaria amplissima*
		Lobaria pulmonaria
		Mycoblastus sanguinarius
		Ochrolechia tartarea
		Pannaria conoplea
		Peltigera collina
		Sphaerophorus globosus
		Usnea filipendula
Coill Innis Mhic Gille Ruaidh	*Chrysosplenium oppositifolium*	*Bunodophoron melanocarpum*
	Circaea lutetiana	*Hypotrachyna laevigata*
	Dryopteris aemula	*Leptogium burgessii*
	Lysimachia nemorum	*Lobaria pulmonaria*
	Mercurialis perennis	*Lobaria virens*
	Primula vulgaris	*Ochrolechia tartarea*
	Scrophularia nodosa	*Parmeliella triptophylla*
		Pyrenula occidentalis
		Sphaerophorus globosus
		Usnea filipendula
Parallel Roads	*Lysimachia nemorum*	*Bryoria fuscescens*
	Primula vulgaris	*Mycoblastus sanguinarius*
		Ochrolechia tartarea
		Usnea filipendula
Coille Bhrodainn	*Melampyrum pratense*	*Fuscopannaria sampaiana*
		Lobaria pulmonaria
		Lobaria virens
		Ochrolechia tartarea
		Pyrenula occidentalis
		Sphaerophorus globosus

Note: This list is not based on exhaustive survey but provides supplementary evidence in the immediate vicinity of over-mature and veteran trees (cf. Figure 2).

Discussion

Our results stress the need for a cautious approach in the ecological interpretation of Class 3 AWI sites. For ancient woodland species that are dependent on the occurrence of trees as a

habitat, such as epiphytes growing directly on the bark surface, the break in continuity represented by a Class 3 designation could be considered ecologically to have reset the starting point in terms of colonisation and establishment into the woodland habitat. Class 3 woodlands would not be expected to be suitable for certain of these species – that is, ancient woodland indicator epiphytes (Whittet & Ellis 2013) – in an enumeration of suitable habitat within the present-day landscape. However, in a significant proportion of cases, Class 3 woodland is shown to be spatially congruent with scattered tree symbols at various densities, suggesting that for many AWI Class 3 localities, some form of open woodland may have existed continuously over at least several centuries.

The anomalous alignment of scattered tree symbols with Class 3 localities can be interpreted in various ways. First, with respect to a Level 6 anomaly, it is reasonably expected that a project as ambitious as the AWI will contain a clearly acknowledged rate of measurement error, consistent with available technologies. At the time of the initial compilation of the AWI, site boundaries were traced from the source maps, using sets of coloured pencils (Goldberg *et al.* 2007), and transferred onto plates used by the inventory. Second, the original motivation of the AWI requires historical interpretation, because an understanding of what constitutes a valuable woodland resource, worthy of quantification, changes over time. Landscape ecologists have become increasingly sensitive to the biodiversity importance and conservation of landscapes with scattered trees such as wood pasture (Kirby *et al.* 1995; Bergmeier *et al.* 2010), maintained by a system of grazing among open woodland. It is a reasonable assumption that at the time of the original AWI in the 1980s, the conservation value of systems such as wood pasture had not achieved a prominence to justify an additional level of complexity in quantifying areas of scattered trees at various densities.

It is also important to recognise the limits of the Roy maps and their interpretation, in quantifying errors in woodland continuity. Our method assumed that Class 3 sites were present on Roy's maps (cf. Table 1) providing a minimum threshold for woodland continuity of c. 250 years for the Class 3 sites with scattered trees. First, there may be false absences: ancient woodlands which were not mapped by Roy, and which would be missing from the AWI. Roy's survey was commissioned by the British Government which recognised the need for Scotland to be 'thoroughly explored and laid open, by establishing military posts in its inmost recesses, and carrying roads of communication to its remotest parts' (Roy 1785). Woodland offered a strategic resource of fuel and shelter, so it is possible that greater care would have been taken when plotting woodland near roads and tracks (Walker & Kirby 1987), although small or isolated pockets of woodland in remote territory may have gone uncharted. Some woodland sites will presumably have been overlooked compared to the highly accurate first edition Ordnance Survey (Walker & Kirby 1987), which more reliably mapped individual or small numbers of trees occurring in exposed locations. Second, there may be false presences: for example, where presumed AWI Class 1 or Class 3 woodlands did not exist at the time of Roy's survey. Where woodlands are noted on Roy's maps, the precision of boundaries may have been relatively low, given that woodlands were usually sketched in by eye, or copied from existing maps (Walker & Kirby 1987; Fleet *et al.* 2011). The 'fair' copies, which were drawn after reconnaissance, were produced using pen-and-ink-wash; following the convention of the time, woodland was symbolised with a green wash (Skelton 1967). The green wash was used to infer woodland cover in the absence of actual tree symbols (Walker & Kirby 1989), creating a degree of uncertainty as to the existence of woodland in all cases. Thus, for the Class 3

sites included in this study on the basis of a false presence, and which have scattered tree symbols, the degree of continuity would span a lower period c. 150–250 years. This is still an ecologically relevant timescale, however, with studies for epiphytes showing a threshold tree age of c. 180 year (Fritz *et al*. 2008), or c. 140–220 years (Moning & Müller 2009) for the accumulation of specialist species demanding mature/veteran tree microhabitats.

It is apparent that scattered symbols associated with AWI Class 3 localities are consistent with high-value conservation habitat in some cases, including long-established wood pasture. This is based on our positive field evidence for widely spaced veteran trees with spreading canopies, large hazel stools and/or assemblages of indicator species, and this is consistent with wider evidence of extensive pastoralism in upland Scotland based around open structured woodland (Holl & Smith 2007). These results provide new opportunities for the application of historical maps in ecology and conservation. First, the abandonment of wood pasture, leading to shading through secondary succession, has been shown to have a significant negative effect on the diversity of species-rich groups such as epiphytic lichens (Leppik *et al.* 2011; Paltto *et al.* 2011) or invertebrates (Ranius & Jansson 2000; Horák & Rébl 2013). It may be possible to identify landscapes with long-established scattered trees from historical maps, hidden within areas of more recent regeneration or plantation, and to target these for survey and, where appropriate, conservation restoration. Second, the use of maps to identify individual sites with various densities of scattered trees – in this case, AWI Class 3 polygons – could be expanded conceptually to recognise the importance of the historical landscape matrix (Lindborg & Eriksson 2004; Ellis & Coppins 2007), and using habitat connectivity which quantifies woodland densities at contrasting spatial scales in the landscape. This would further benefit from the alignment of multiple types of evidence, with palaeoecological analysis now providing the opportunity to partition trends in woodland structure between the wider landscape and local woodland stands, as demonstrated for eastern Glen Affric (Froyd & Bennett 2006; Shaw & Tipping 2006), and at a sufficiently high resolution to provide a complement to the analysis of historical maps.

In summary, we emphasise the importance of considering how the technological and partly subjective nature of cartography, and its interpretation when cross-referencing over time, such as in the AWI, links to the ecological character of a species or guild under investigation. Decisions during map making, and in the quantification of mapped resources, may have different implications for species groups with different ecologies. On the one hand, a clearly defined Class 3 AWI site (Level 0 in our study) represents a break in woodland continuity; if sufficiently brief, the site may still retain soil properties (Wilson *et al.* 1997; Verheyen *et al.* 1999) or seed banks (Erenler *et al.* 2010) useful to the regeneration/restoration of ancient woodland. On the other hand, such a break in continuity can represent a complete hiatus for tree-dependent organisms including certain epiphytic lichens or invertebrates. In this latter case, the anomalous occurrence of scattered tree symbols among the Class 3 AWI sites is significant, and could signal the long-term continuity of open structured woodland, including sites of high nature conservation value.

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