# Can epiphytic lichens of remnant Atlantic oakwood trees in a planted ancient woodland site survive early stages of woodland restoration?

## Appendix A: Methods

### Climatic data for Scottish oak woodlands

Mean monthly temperature and rainfall data for Glencripesdale (data for the period 2007 to 2016 from the nearest meteorological weather station: 56°45'N, 5°44'W) is shown in Sup. Fig 1. Mean monthly temperature rarely exceeds 15°C or falls below 5°C and rainfall exceeds 100mm during nine months of the year, exceeding 200mm in three of these. Glencripesdale occurs within the area of the British Isles where the West Scotland Index of Ecological Continuity (WSIEC) for ancient deciduous woodlands applies (Coppins and Coppins 2002); the Eastern Scotland Index of Ecological Continuity (ESIEC) and the New Index of Ecological Continuity (NIEC) applies to oak woodlands in other parts of Scotland (Sup. Table 1).
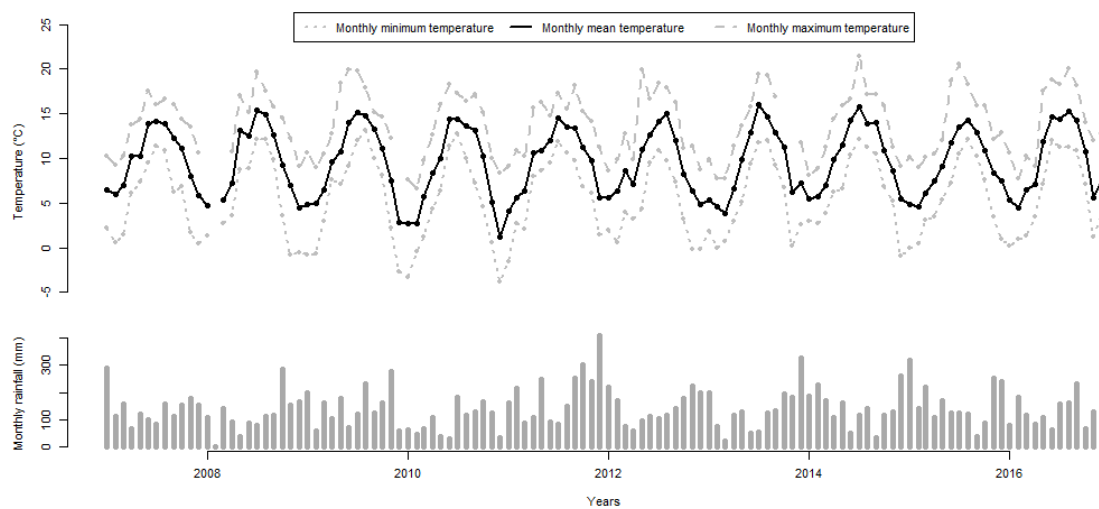


**Sup. Fig. 1: minimum, mean and maximum monthly temperatures and total monthly precipitations for the Glencripesdale site (Dunstaffnage met station) from 2007 to 2016 covering the years of the Planted Ancient Woodland Site restoration study from pre-conifer removal to nine years after conifer removal.**

**Sup. Table 1: Values and standard errors of Continentality (°C), Heat Moisture Index and Yearly Growing Degrees (sum of degrees above 5°C), calculated on climatic data ranging from 2007 to 2016 for 10 Scottish oak woodland sites including our study site. The letters indicate groups of mean values that differ at a 5% level determined by Tukey's Post Hoc test.**

| Oak Woodland | Met Station | Continentality (°C) | Yearly Growing Degrees (°C) | Annual Heat: Moisture Index |
|---|---|---|---|---|
| **Glencripisdale** | **Dunstaffnage** | **10.9a (±0.7)** | **1775bc (±100)** | **12c (±0.8)** |
| Loch Maree | Poolewe | 11.2a (±0.8) | 1437ab (±100) | 11.9c (±0.8) |
| Alvie | Aviemore | 13.2a (±0.6) | 1331ab (±100) | 18.3de (±0.8) |
| Dinnet | Aboyne | 13.2a (±0.6) | 1331ab (±100) | 22.1f (±0.8) |
| Comrie | Drummond Castle | 12.3a (±0.8) | 1025a (±100) | 14.8cd (±0.8) |
| Firkin wood | Benmore | 12a (±0.7) | 1631bc (±100) | 7.1a (±0.8) |
| Mugdock | Mugdock Park | 12.8a (±0.8) | 1091a (±100) | 11.3bc (±0.8) |
| Wood of Cree | Portpatrick | 10.6a (±0.8) | 1931c (±100) | 19.2ef (±0.9) |
| Glen Nant | Inverinan Beg | 12.8a (±0.8) | 1464abc (±112) | 7.6ab (±0.9) |
| Ledmore Wood | Urquhart | 11.9a (±1.1) | 1379abc (±159) | 22.5ef (±1.2) |

Three climatic indices[1] were calculated for 10 oak woodland sites, including Glencripesdale, in order to inform how we can extrapolate the results of our study site in terms of the likely effects on growing conditions created by sudden opening up of the tree canopy, to other oak woodlands experiencing a similar intervention. At Glencripisdale, the mean continentality is comparable to all the other woodlands considered. Climatic warmth, the amount of yearly growing degrees (for all days of mean temperature above 5°C, the sum of the degrees above 5°C) at Glencripesdale was similar to most oak woodland sites with only two sites being significantly cooler (Comrie and Mudock). However, when mean annual heat:moisture index is considered (high index values where low precipitation relative to temperature; low index values where high precipitation relative to temperature), Glencripisdale was similar to three sites (Loch Maree, Mugdock and Comrie), but index values were lower than for three (Alvie, Dinnet and Wood of Cree) and higher than for two (Benmore and Glen Nant). We consider that between 2007 and 2016 the climate of Glencripesdale, compared to other oak woodland sites in Scotland (data also from the nearest meteorological weather stations) (Sup. Table 1), is at the higher end of the range for climatic warmth but has a median value for Heat: Moisture index, indicating the effect of high levels of precipitation on maintaining an oceanic climate typical of oakwoods in western Scotland. The range of values for these climate indices is however small and rarely are the values for Glencripesdale significantly different from those of the other oak woodland sites. In this respect, Glencripisdale presented a somewhat median climate and our results could be extrapolated to a number of oak woodland sites.

## [1]Biologically relevant climate indices and supporting variables

| | |
|---|---|
| Continentality (°C; difference between MWMT and MCMT) | |
| Annual heat: moisture index (MAT+10)/(MAP/1000) | |
| Degree days above 5(°C) | |
| Mean annual temperature (°C) | MAT |
| Mean warmest month temperature (°C) | MWMT |
| Mean coldest month temperature (°C) | MCMT |
| Mean annual precipitation (mm) | MAP |

http://raster.climatebc.ca/download/List_of_climate_variables.pdf

## Chlorophyll fluorescence measures and calculation

Parameter settings of the pulse amplitude moderated (PAM) chlorophyll fluorimeter in this study used a controlled illumination protocol after dark adaptation of the thalli. The application of basic fluorimetry of dark-adapted samples (Fv/Fm) has been published for *Lobaria pulmonaria (*Palmqvist and Sundberg, 2000). In this investigation we employed more complex assessments of light utilisation by the *Lobarion* lichen species on remnants in PAWS and ASNW trees offering various microsites. After dark-adapting the lichen thalli for 30 min, maximal photochemical utilisation ($\Phi$PSII), after 90 seconds exposure to 400 $\mu$mol m$^{-2}$ s$^{-1}$ of constant illumination, was recorded. Quantum efficiencies of photosystem II photochemistry parameter, measured under illuminated conditions, were calculated following van Kooten and Snel (1990), where $\Phi\mathrm{PSII} \; = \; \mathrm{Fv'} \, / \, \mathrm{Fm'} * \mathrm{qp}$.

## Lichen cover sampling and data analysis

Atlantic oak woodland lichen communities present at the study site were identified in a pre survey in 2005 (Sup. Table 2), for full details see Thompson and Hope, 2005. To this list we have added the lichens that were recorded from the sample patches during our study (2007 to 2016). We assigned a conservatism coefficient to each lichen (see footnotes to Sup. Table 2) following the methodology of Reemts and Eidson (2019).

**Sup. Table 2: Epiphytic lichen species identified from a site inventory conducted in 2005 and their status as old woodland indicators to inform the identification of lichen indicator community patches monitored during this study and species' Conservatism score (see Reemts and Eidson, 2019).**

| | Instances in plantation gaps | Instances in SN woods | Substrates | Status | Conservatism coefficient (1 low- 10 high) |
|---|---|---|---|---|---|
| **Lichens** | | | | | |
| Degelia atlantica | 3 | 2 | C,Q | R | 4 |
| Degelia plumbea | 2 | 2 | C,Fx,Q | R | 4 |
| Dimerella lutea | 1 | -- | B | R | 4 |
| Hypotrachyna sinuosa | 2 | 1 | B | Eu | 7 |
| Hypotrachyna taylorensis | -- | 1 | B | Eu,WS | 9 |
| Lobaria amplissima | 1 | -- | Q | R,WS | 9 |
| Lobaria pulmonaria | 5 | 5 | Al,B,C,Fx,Q | R | 4 |
| Lobaria scrobiculata | 7 | -- | B,C,Q | R,WS | 9 |
| Lobaria virens | 15 | 4 | B,C,Fx,Q | R | 4 |
| Menegazzia terebrata | 5 | 1 | B | Eu | 7 |
| Nephroma laevigatum | 2 | -- | C,Fx | R | 4 |
| Pannaria conoplea | -- | 2 | C,Q | R | 4 |
| Pannaria rubiginosa | 1 | 1 | C,Q | | 3 |
| Parmeliella parvula | 1 | 1 | B | | 3 |
| Parmotrema crinitum | 1 | 1 | B | R | 4 |
| Peltigera collina | 1 | 1 | C,Q | R,WS | 9 |
| Sticta fuliginosa* | 5 | 2 | C,B,Q | R | 4 |
| Sticta limbata | 2 | 2 | C | R | 4 |
| Sticta sylvatica* | 5 | 1 | C,Fx,Q | R | 4 |
| Thelotrema lepadinum | 1 | 2 | Q | R | 4 |
| Additional lichen species encountered in the 2007 and 2016 survey of sample patches | | | | | |
| Squamules of *Cladonia* spp (*Cladonia luteoalba* has EU status) | | | | | 4 |
| *Ochrolechia androgyna* | | | | | 0 |
| *Platismatia glauca* | | | | | 0 |
| *Lichenoconium usneae* | | | | | 0 |

Abbreviations: Al = *Alnus*, B= *Betula*, C = *Corylus*, Fx = *Fraxinus*, Q = *Quercus*; Eu = Eu-Oceanic Calcifuge Woodland Index of Ecological Continuity, WS = West of Scotland Index of Ecological Continuity, R = The Revised Index of Ecological Continuity (Coppins & Coppins, 2002). The two, asterisked species are difficult to distinguish when immature, so confusion between these two taxa is possible. WS species are indicators for ancient deciduous woodlands and have the highest fidelity for Atlantic oakwoods, and these species are given the highest conservatism coefficient (9), Eu species are indicators for upland woodlands with oceanic climates, there is overlap in habitat with WS, they have been allocated a conservatism coefficient of 7. R species are strongly associated with ancient woodlands however these species may show lower fidelity in Western Scotland (Thompson and Hope 2005) so have been allocated a lower conservatism coefficent (4). A species may be allocated more than one conservatism coefficient, but the maximum value conservatism coefficient is attributed in calculation of the diversity metric.

Lichen patch location and extent was delineated by placing a PVC 0.04m² frame around each patch.

The frame was precisely relocated at each assessment time by means of three plastic nails set into the bark; for smaller lichen patches a half-frame measuring 0.02m$^2$ was used. The patches were photographed with a 10 megapixel, hand–held digital field camera. Setting up a tripod was not deemed feasible on the steep slopes and the lighting could not be homogenized, but these adjustments were not considered necessary for the assessment of lichen surface area.

Trimble's ©E-cognition carries out object-based classification as opposed to pixel-based and is mostly used in the analysis of high resolution spatial imagery (Darwish et al. 2003; Liu and Xia 2010; Myint et al. 2011). Each photo was primarily subjected to a personalised multi-resolution segmentation, for which ©E-cognition is renowned, in order to extract the individual elements as objects. These were classified by the software using a rule set which was constructed using various object features related to colour, shape and texture. A kappa-coefficient for agreement and an estimate of classification accuracy were calculated per class per photo by comparing the automatic and manual classification of objects sampled at random. These were extracted along with the total surface area per class. The classification was only accepted if the overall kappa-coefficient exceeded 0.7 and if the class-specific kappa-coefficient exceeded 0.6. Differences in cover were calculated between 2008 and 2016 for each lichen in each frame and expressed as a percentage of frame cover. Absolute differences lower than 3% are recorded but arbitrarily not considered of importance, as variability of the photographed area due to tree growth and segmentation error could not be completely removed.

References

Coppins AM, Coppins BJ (2002) Indices of ecological continuity for woodland epiphytic lichen habitats in the British Isles. British Lichen Society London

Darwish A, Leukert K, Reinhardt W (2003) Image segmentation for the purpose of object-based classification. IEEE, pp 2039–2041

Liu D, Xia F (2010) Assessing object-based classification: advantages and limitations. Remote Sens Lett 1:187–194. doi: 10.1080/01431161003743173

Myint SW, Gober P, Brazel A, Grossman-Clarke S, Weng Q (2011) Per-pixel vs. object-based classification of urban land cover extraction using high spatial resolution imagery. Remote Sens Environ 115:1145–1161. doi: 10.1016/j.rse.2010.12.017

Palmqvist K, Sundberg B (2000) Light use efficiency of dry matter gain in five macro-lichens: relative impact of microclimate conditions and species-specific traits. Plant Cell Environ 23:1–14. doi: 10.1046/j.1365-3040.2000.00529.x

Reemts, C.M. & Eidson, J.A., 2019. Choosing plant diversity metrics: A tallgrass prairie case study. *Ecological Restoration*, 37(4), pp.233–245.

# Appendix B –Results

*Interpretation of ground flora community composition using species traits*

**Sup. Table 3:** *Loadings for the first two Principal Components in an analysis of ground flora traits based on Ellenberg resource indicators for Light , Moisture and Nitrogen, and Grime's plant strategy types competitor C, stress-tolerator (S) and ruderal (R)*

| Trait | PC1 | PC2 |
|---|---|---|
| Moisture | 0.509 | |
| Nitrogen | 0.497 | |
| Light | 0.512 | |
| C | 0.304 | 0.664 |
| S | 0.260 | -0.561 |
| R | 0.269 | -0.482 |

## Lichen assessment
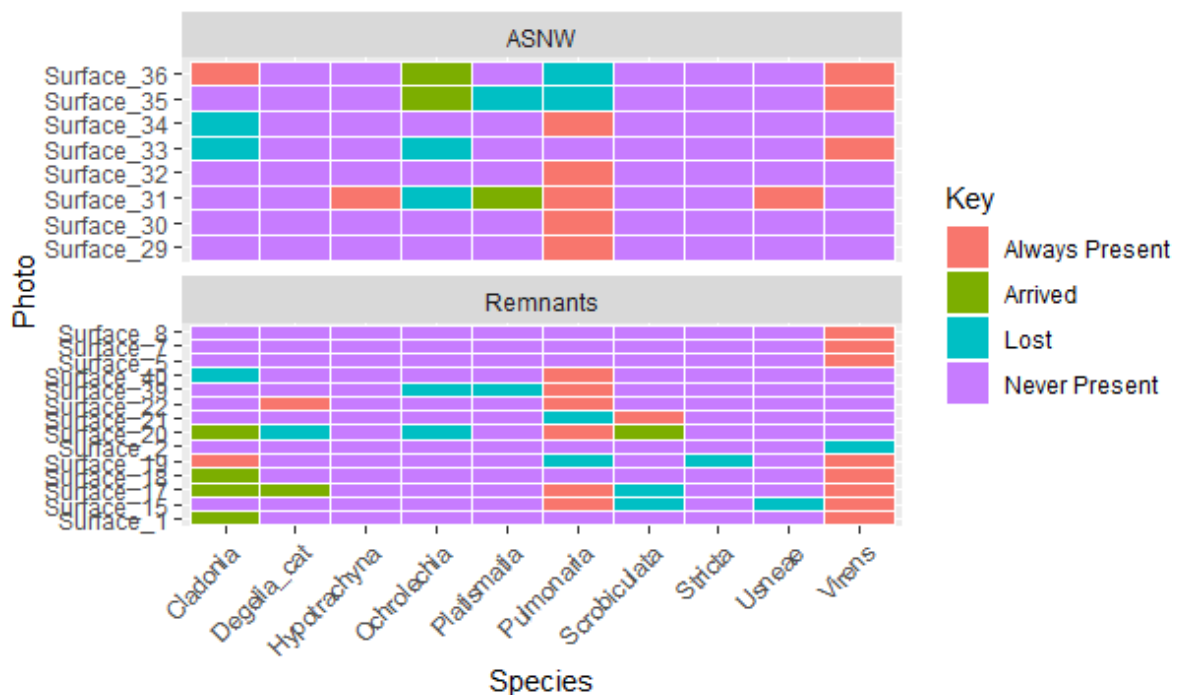


**Sup. Fig. 2: Presence of epiphytic lichens recorded in the sample patches (Photo) on trees in Ancient Semi-Natural Woodland (ASNW) (n=8) and Remnants (n=14) in 2007 and 2016 covering the years of the Planted Ancient Woodland Site restoration study from pre-conifer removal to nine years after conifer removal. Cladonia = Squamules of *Cladonia* spp; Degilia_cat = *Deglia atlantica*; Hypotrachyna = *Hypotrachyna sinuosa*; Ochrolechia = *Ochrolechia androgyna*; Platismatia = *Platismatia glauca*; Pulmonaria**

= *Lobaria pulmonaria*; Scrobiculata = *Lobaria scrobiculata*;  Stricta  = *Stricta limbata*; Usneae = *Lichenoconium usneae*; Virens = *Lobaria virens.*

**Sup. Table 4**: Lichen community diversity metrics of average conservatism and species richness and tests for differences between metrics assessed for Ancient Semi-Natural Woodland (ASNW) (n=8) and Remnants (n=14) and between the two years of assessment in 2007 and 2016.

| | | Average conservatism | | | | Species Richness | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean ± SE | | Test of difference between ASNW and Remnants (Mann-Whitney) | | Mean ±SE | | Test of difference between ASNW and Remnants (Mann-Whitney) | |
| | | ASNW | Remnants | U statistic | P value | ASNW | Remnants | U statistic | P value |
| **Year** | **2007** | 3.205 ±0.2818 | 4.129 ±0.3143 | 27.00 | p=0.0331 | 2.375 ±0.3239 | 2.0 ±0.2774 | 43.50 | p=0.3824 |
| | **2016** | 3.29 ±0.3240 | 4.19 ±0.4875 | 30.00 | p=0.0353 | 1.75 ±0.3134 | 1.5 ±0.2285 | 48.00 | p=0.5788 |
| Test of change over time - 2007 to 2016 (Mann-Whitney) | **U statistic** | 30.00 | 98.00 | | | 20.00 | 73.00 | | |
| | **P value** | p=0.8678 | p=0.9770 | | | p=0.1929 | p=0.2290 | | |