Reference: Knepp Wildland Carbon Project

Appendix 2 | 7 February 2024

Appendix 2 - Volumetric measurement of rewilded vegetation using UAV lidar data to support landscape-scale estimation of aboveground biomass
Authors:

Dr Alex Henshaw, Reader in Physical Geography, Queen Mary University of London

Zareena Khan, Research Associate, Queen Mary University of London

Prof Gemma Harvey, Professor of Physical Geography, Queen Mary University of London
1. Introduction

This report details an attempt to use high resolution 3D point cloud data of rewilded vegetation collected at Knepp in 2023, in combination with vegetation height data and published allometric equations, to estimate of new, rewilding-driven vegetation volume and above-ground biomass at the scale of the Southern Block. The upscaling workflow is used to estimate increases in vegetation volume and above-ground biomass from the project’s inception to 2019 and 2022, respectively.

2. Methodology

2.1. Data sets

Three data sets were employed to estimate the additional woody vegetation volume and above-ground biomass produced by rewilding-driven scrub regeneration and hedgerow and woodland expansion across Knepp’s Southern Block since the project’s inception:

1) A high-resolution, multiple return UAV lidar survey covering a 500 m x 500 m study area of Knepp’s Southern Block containing rewilded hedgerows, bramble, thorny and sallow scrub, isolated mature oaks and ancient woodland was obtained during March 2023 (see companion report for full survey and lidar processing details).
2) The Knepp WildVeg Geodatabase (Henshaw et al, 2021a): a geospatial data set developed from a 2019 Environment Agency aerial lidar survey and multispectral satellite imagery to quantify and classify vegetation regeneration (vegetation cover, height, density and type) approximately two decades following the initiation of rewilding at the site.
3) A raw point cloud from a UAV lidar survey conducted by FlyThru Ltd in September 2022.

2.2. Segmentation of rewilded vegetation patches and extraction of structural parameters

The georeferenced 3D point cloud from the 2022 UAV lidar survey was analysed using algorithms embedded in 3D Forest (Trochta et al., 2017), an open-source, non-platform-specific software application typically deployed to extract structural properties of mature trees in forest environments. The analytical workflow involved: 1) separation of the original point cloud into terrain and vegetation point clouds (Figure 1a and 1b); 2) segmentation of the vegetation point cloud into individual shrubs and trees (Figure 1c); 3) for a subset of 44 individual point clouds of isolated bramble patches, thorny scrub species, sallows and mature oaks, extraction of shrub/tree height, area (based on a 2D convex hull of each point cloud orthogonally projected to the horizontal plane at the base of the cloud), and volume (based on a 3D convex hull of each point cloud created by Voronoi triangulation) (Figure 2a-d).
2.3. Upscaling of volume estimates to landscape scale and estimation of above-ground biomass

Trade-offs between data collection/processing time and point cloud resolution and size combined with the structural complexity of scrub patches prohibited vegetation segmentation and parameter extraction for all individual vegetation units at the landscape scale. Instead, a pragmatic approach was employed in this study involving the development of allometric relationships between sampled shrub/tree height and volume (scaled according to projected planar area) to enable
upscaling based on vegetation height rasters covering the Southern Block from 2019 and 2022. Linear models were created based on parameters extracted from all individual vegetation point clouds and scrub-type specific subsets (Figure 3).

Figure 3: Allometric relationship[s between vegetation height and vegetation volume per square metre based on parameters extracted from individual point clouds using 3D Forest.

Estimation of rewilding-driven changes in woody vegetation volume was undertaken for two time periods: (i) 2001 to 2019 and (ii) 2001 to 2022. Vegetation height changes between 2001-2019 were computed using 3m resolution data from the Knepp WildVeg Geodatabase (see Henshaw et al., 2021b). To compute vegetation height changes between 2001-2023, the 2023 UAV lidar survey point cloud was processed to create a 25 cm resolution DTM (constructed using ground points) and a 25 cm resolution DSM (constructed using first return points). A vegetation height model was then produced by subtracting the DTM from the DSM. Vegetated pixels with height values < 30 cm were reclassified as null. The resultant height model was resampled to a resolution of 3 m in areas of potential hedgerow expansion to ensure comparability with baseline hedgerow height data from 2001. These areas were differentiated spatially from areas of potential new scrub within former arable and grassland fields. Shapefiles representing these areas were derived from the Knepp WildVeg Geodatabase. For the 2001-2019 analysis, it was possible to further differentiate between areas of new bramble, thorny and sallow scrub. Fields and other areas that have not been rewilded or consist of plantation woodland were excluded from this analysis. The spatial extent of the 2022 lidar survey was restricted due to UAV no-fly zones. As a result, the new in-field scrub and hedgerow expansion calculation areas used for the 2001-2023 analysis are smaller than those used for the 2001-2019 analysis. They cover approximately 81% and 68%, respectively, of the potential new scrub and hedgerow expansion areas analysed for the 2001-2019 time period (Figure 4).
Figure 4: New scrub and hedgerow expansion calculation areas used to estimate new vegetation growth between 2001-2019 and 2001-2022, respectively. Growth calculations for 2001-2022 restricted to yellow area.

Attempts to develop quantitative structural models (models that describe the branching structure of vegetation by fitting a hierarchical collection of cylinders to a point cloud) of bramble patches and smaller rewilded shrubs proved unsuccessful. This approach has been previously used in combination with wood density information to directly measure above-ground biomass without the need for destructive sampling (e.g. Calders et al., 2014). Instead, above-ground biomass for rewilded vegetation at Knepp was estimated using a volume-based linear model developed using destructive samples of hedgerows containing similar woody species to those found at Knepp (Lingner et al., 2018):

\[ DM = d_i \times V \]

where \( DM \) = dry mass of vegetation (kg), \( d_i \) = coefficient representative of all hedges sampled in the study (1.79 kg m\(^{-3}\)) and \( V \) = volume of vegetation (m\(^3\)). Lingner et al. (2018) quantified hedgerow volumes from 3D point cloud data using a similar convex hull-based approach to the method utilised in this study.
3. Results

3.1. Vegetation change 2001-2019

Figure 5 illustrates spatial variation in new scrub development and hedgerow expansion between 2001 and 2019. Estimated uplift in new scrub (by type and combined) and hedgerow volume and above-ground biomass are detailed in Table 1.

Figure 5: Estimated changes in vegetation height for new scrub and expanded hedgerow areas 2001-2019.

<table>
<thead>
<tr>
<th>Vegetation type</th>
<th>Change in volume (m³)</th>
<th>Dry mass (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bramble scrub</td>
<td>+160,495</td>
<td>+287</td>
</tr>
<tr>
<td>Thorny scrub</td>
<td>+489,828</td>
<td>+877</td>
</tr>
<tr>
<td>Sallow scrub</td>
<td>+933,245</td>
<td>+1,671</td>
</tr>
<tr>
<td>New scrub (combined)</td>
<td>+1,583,568</td>
<td>+2,835</td>
</tr>
<tr>
<td>Hedgerow</td>
<td>+489,043</td>
<td>+875</td>
</tr>
<tr>
<td>Total additional vegetation</td>
<td>+2,072,611</td>
<td>+3,710</td>
</tr>
</tbody>
</table>

Table 1: Estimated changes in vegetation volume and above-ground biomass 2001-2019.
3.2. Vegetation change 2001-2022

Figure 6 illustrates spatial variation in new scrub development and hedgerow expansion between 2001 and 2022. Estimated uplift in new scrub and hedgerow volume and above-ground biomass are detailed in Table 2.

Table 2: Estimated changes in vegetation volume and above-ground biomass 2001-2022.

<table>
<thead>
<tr>
<th>Vegetation type</th>
<th>Change in volume (m$^3$)</th>
<th>Dry mass (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New scrub (combined)</td>
<td>+1,957,712</td>
<td>+3,504</td>
</tr>
<tr>
<td>Hedgerow/woodland</td>
<td>+301,690</td>
<td>+540</td>
</tr>
<tr>
<td>Total additional vegetation</td>
<td>+2,259,402</td>
<td>+4,044</td>
</tr>
</tbody>
</table>

4. Discussion
• The analysis presented in this report confirms significant increases in new scrub vegetation and hedgerow/woodland expansion since the Knepp project’s inception.

• Taking into account differences in survey areas between 2019 and 2022, rewilded fields (excluding hedgerow and woodland areas) in the Southern Block supported approximately 8.9 t ha\(^{-1}\) of new above-ground biomass in the form of bramble, thorny and sallow scrub by 2019, and 13.6 t ha\(^{-1}\) based on 2022 data.

• The convex hull modelling approach utilised in this exercise was selected to maximise comparability with that taken by Lingner et al. (2018) to facilitate above-ground biomass estimation. Ongoing research at QMUL will seek to explore alternative approaches including concave model fitting and quantitative structural modelling of rewilded vegetation using higher resolution 3D point cloud data.

• The vegetation volume upscaling approach and above-ground biomass estimates presented here should be treated with caution and are subject to considerable uncertainty. Differences in survey resolution, indirect (rather than direct) volume and above-ground biomass quantification and spatiotemporal variation in vegetation morphology all have the potential to introduce errors into the final values. While the approach to vegetation volume calculation from 3D point cloud data utilised in this exercise and broad mixture of species found at Knepp is similar to that in Lingner et al. (2018), the management regime, age distribution and spatial configuration of vegetation and herbivore browsing pressures differ substantially between the field sites. Coincident 3D structural modelling using remote sensing approaches and destructive sampling of scrub at Knepp to develop site-specific allometric equations to support above-ground biomass estimation are recommended.

5. References


