Pilot study using drones and open-source tools to assess Scots pine regeneration in a remote location.

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1. Executive Summary

This report covers a pilot study funded by eLTER Transnational Access, which aimed to determine the suitability of using drones and an open-source workflow to monitor natural tree regeneration at the Cairngorm ECN site in the Cairngorms National Park, Scotland.

The method made use of a consumer grade drone and optical photogrammetry to create a digital surface model (DSM) of each sampling plot. DSMs were then processed through a QGIS workflow to identify and count trees to be compared against ground-truthed data.

We find that the method accurately detected c70 % of trees within the plots, and those missed were either small (generally < 50 cm in height) or growing in very close proximity to other trees. We suggest simple measures that could strongly improve the accuracy of detecting smaller trees, and which would result in a practicable, low-cost method for monitoring tree regeneration in mountainous terrain.

2. Introduction

Monitoring at wide spatial scales can be complex and labour / cost intensive. However, empirical assessments and monitoring outcomes are an essential component of ecological recovery projects (Wortley et al., 2013; Buters et al., 2019).

A potential solution to the problem may be the utilization of unmanned aerial vehicles (UAVs or drones). Consumer drones have improved significantly over the past decade, and now offer a practical solution to monitoring vegetation in both agricultural and natural systems, particularly in relation to forest regeneration (Mohsan et al., 2023). In-deed, Buters et al. (2019) demonstrated how consumer drones can be used to survey even very small vegetation such as seedlings.

Through its dedicated access scheme, the EU funded eLTER PLUS project opens up the eLTER Research Infrastructure (eLTER RI) to scientific research teams, and aims to attract a wide range of users from various disciplines. (https://elter-projects.org/transnational-remote-access-ta-ra). Funding via the eLTER Transnational Access was used to test whether the utilization of drones to monitor natural Scots Pine (*Pinus sylvestris* L.) regeneration onto upland moorland is a practical cost-effective solution for the ECN Cairngorm RI. This pilot project will be a first step, before possibly developing a long-term project of dynamic monitoring.

3. Method

3.1 Location

The survey took place between 15-17th October 2023 at the Environmental Change Network (ECN, www.ecn.ac.uk) long-term ecological and environmental monitoring station in the Cairngorms National Park, Scotland (fig 1; https://deims.org/5a04fee1-42aa-47e9-abfc-043a3eda12ac). The site forms part of the wider Invereshie and Inshriach National Nature Reserve (NNR), which is owned and managed by NatureScot. The site is primarily managed for nature, with a focus on reducing deer grazing pressure, which has led to a natural expansion of Scots pine (*Pinus sylvestris*) woodland onto adjacent moorland since the 1990s.

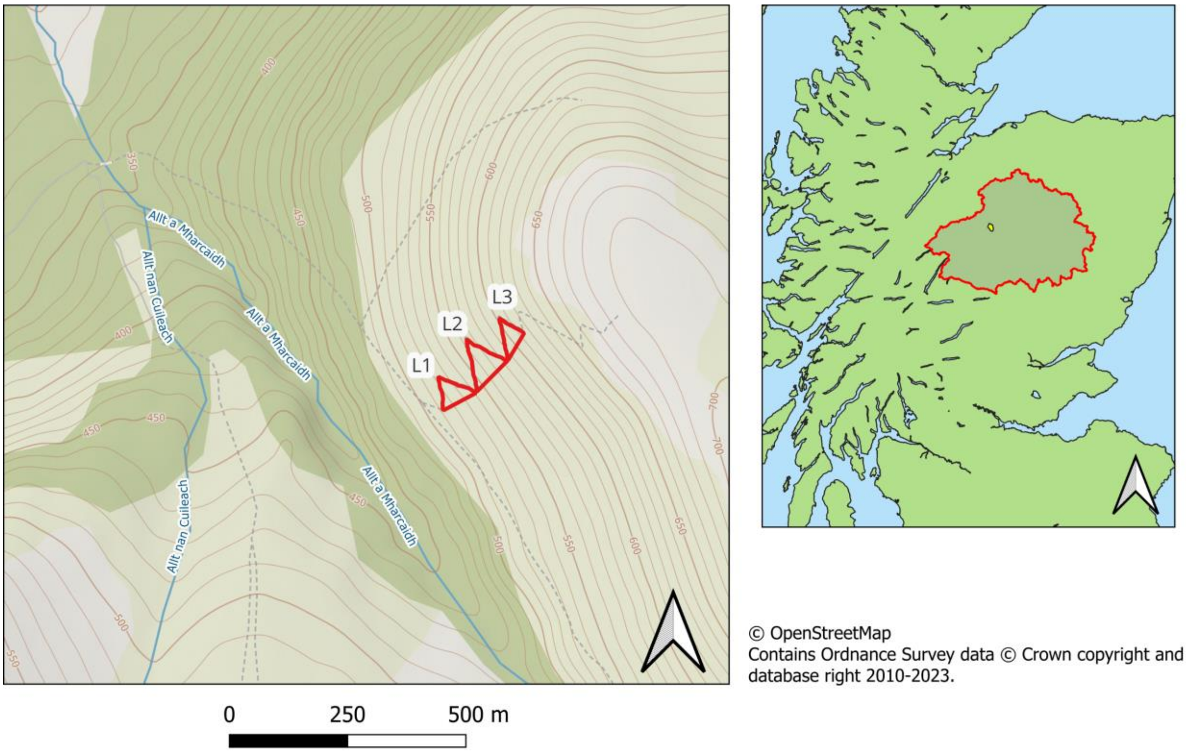


Figure 1. *Map of survey areas L1, L2 and L3 in the Allt a'Mharcaidh catchment, and their location within the Cairngorms National Park, Scotland.*

To test the suitability of using a drone to detect regeneration, an accessible section of the hillslope with regenerating trees was selected, covering an altitude range of 515 – 620 m. Due to being lower and closer to the existing treeline, the lower section (L1; 515 – 545 m) contained more individual, and larger, regenerating trees, whilst the middle section (L2; 545 – 590 m), includes more sporadic regeneration with trees of varying height. The uppermost section (L3; 590 – 620 m) contains mostly smaller scattered trees, with a few showing Krummholz growth forms.

For all sites the existing habitat contains dry shrub heathland, dominated by *Calluna vulgaris* and *Trichophorum cespitosum* interspersed primarily with Cladonia lichens, bryophytes and other ericaceous shrubs (figure 2).

Figure 2. *Example images highlighting characteristics of vegetation cover and tree size and density at the three surveyed plots. Images were taken viewing south-east toward the centre of each plot from the north-west corner.*

3.2 Drone and flight specifications

Flights and images were collected using a DJI Air 2S, which utilises a 20 MP camera with a fixed aperture of f/2.8 mounted on a 3-axis gimbal (further details at: https://www.dji.com/uk/air-2s/specs). Flight plans were created and executed using Map Pilot Pro (https://www.mapsmadeeasy.com/map_pilot/). Flight altitude was set at 20m above ground level, with each track running along the contour of the hillslope. Along track overlap was set to 61 % and sidelap to 80 %. The resulting image resolution had a pixel size of 0.6 cm, and a DSM resolution of 2.35 cm.

Image processing was done using Maps Made Easy (https://www.mapsmadeeasy.com) which includes various low-cost subscription options. However similar results can also be obtained at relatively low-cost using the open source WebODM (https://webodm.net/).

3.3 Automated detection of trees

Trees were detected using a workflow in QGIS (3.32.3). The digital surface model (DSM) was processed using the QGIS plugin 'Tree Density Calculator' (v1.5.7: Crabbé et al. 2020) with the following parameters:

- Image = DSM
- Sliding Window Size = 1.0 m
- All others left blank

Tree Density Calculator (TDC) works on the assumption that a treetop is the brightest part of a tree in remote sensing imagery. Using a sliding window, TDC moves over the image checking whether the central pixel is the brightest of the window. If so, the pixel is marked as a local maximum.

To avoid edge effects in the processing, the whole DSM was processed, which is larger than the actual survey area, with the resulting data then cropped by a shapefile of the area of interest (fig 3).

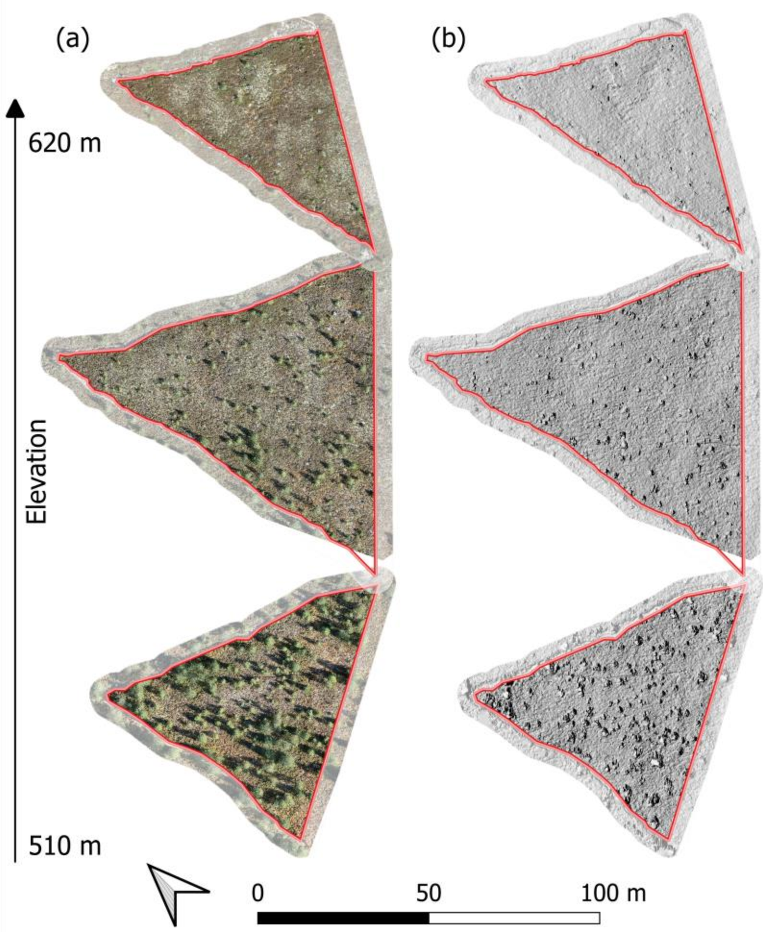


Figure 3. *Analysed extent of three survey areas used to map trees, L1 (lower), L2 (middle) and L3 (upper) showing the original image (a) and the DSM produced from photogrammetry (b). The shaded area around the perimeter of each image is the five meter buffer zone used to prevent edge effects in the processing.*

The output of TDC typically produces multiple points around each elevation spike in the DSM. These were grouped together to designate individual trees by initially setting a buffer ('Vector Geometry'>'Buffer') of 0.5m around each point, and then coalescing these together using 'Vector Geometry'>'Dissolve'. To provide a single central point for each tree, the centroid of the dissolved output was calculated using 'Vector Geometry'>'Centroids'. Enabling 'create a centroid for each part' further creates a line in the attribute table for each tree.

The XY data for each identified tree was added to the attribute table using 'Vector table'>' Add X/Y fields to layer', and each row (tree) given a unique identification number for future cross-validating in the field.

3.4 Ground truthing

For ground truthing, a ten meter wide transect, subdivided into $10m^2$ (0.01 ha) sections was run through the width of each survey area (fig 4) along the contour of the hillslope. This created three transects separated by 40 m of elevation (at 528 m, 568 m, and 608 m). All the trees within the transect were checked off against the TDC output by comparing to a printed output map (appendix 1). Any false-positives (trees on the map but not present on the ground), and false-negatives (trees present on the ground but not on the map) were recorded to allow for error rates to be estimated.

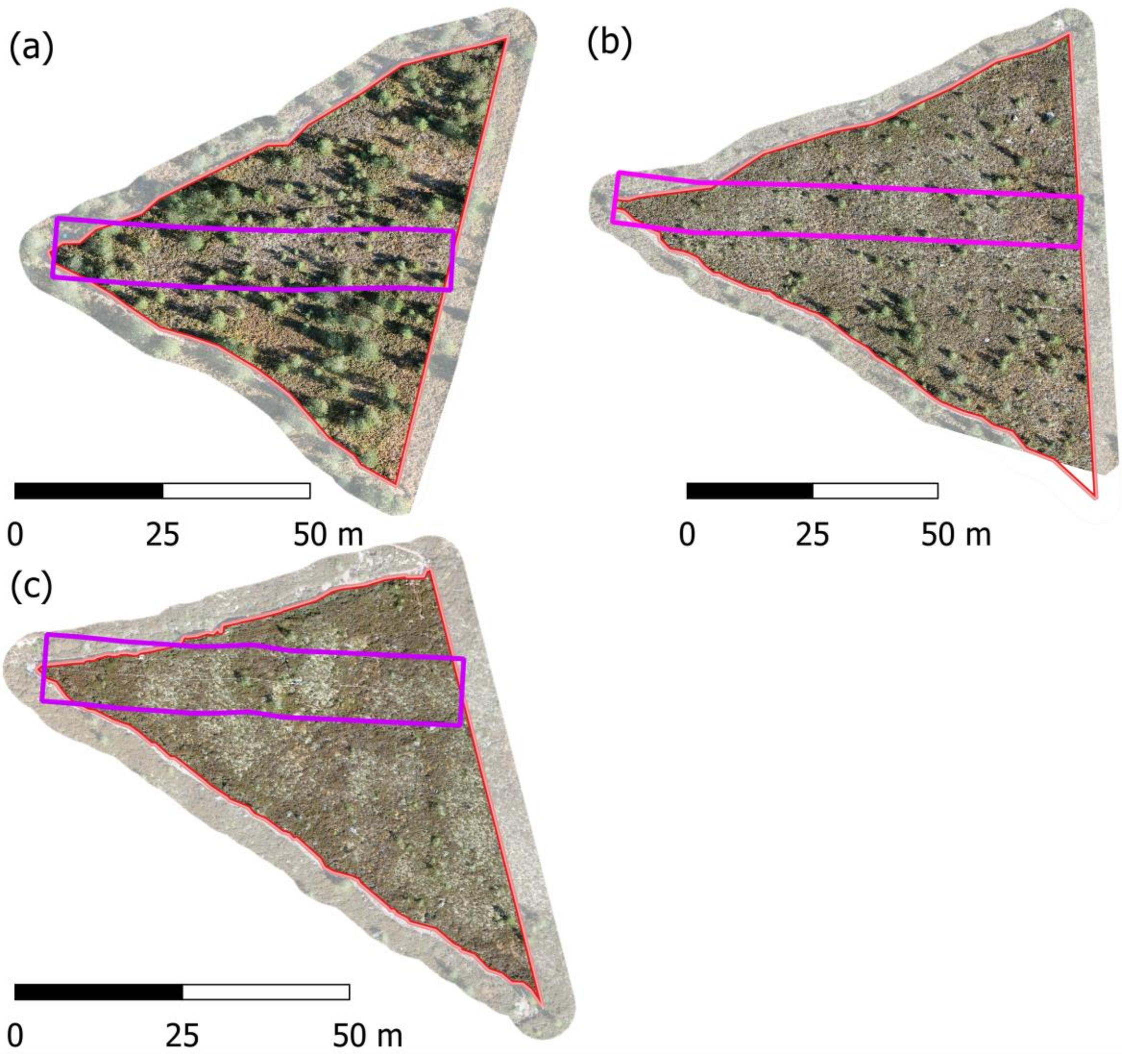


Figure 4. *A 10m wide transect across the contour at each of the three survey areas (a = L1, b = L2, c = L3) was used for ground truthing the output from digitally identifying trees.*

3.5 LiDAR data

A separate survey undertaken in 2023 by the NERC Centre for Landscape Regeneration at the University of Cambridge included a LiDAR (light detection and ranging) survey of the wider Cairngorms National Park. The point cloud density was 22 pts/m^2, and the derived DSM and DTM had a 25 cm resolution. The raster datasets provided covered the hillslope including the three plots sampled in the drone survey.

There were variable alignment issues between the three drone derived DSMs and the LiDAR derived DSM/DTM, which complicated comparisons of the TDC output. Rasters were aligned by measuring distances between several known points, converting to virtual raster in QGIS, then manually editing the position of the north-west corner of each in an open text editor (line: GeoTransForm; 1st value = X, 4th value = Y). Plots were edited as follows:

L1 = X – 1.6 m, Y + 0.2 m
L2 = X – 2 m, Y + 0.6 m
L3 = X – 1.1 m, Y + 1.1 m

3.6 Other regeneration data

Additional data for tree regeneration at the site was provided by NatureScot, who commissioned a in-person survey of regeneration across the wider Invereshie and Inshriach NNR during August and September of 2023 (Beck & Singh, 2024). The NatureScot survey was undertaken on a grid format with 100 m between plots, with three of these 0.01 Ha plots found to overlap with our areas of interest (one in each area), allowing for direct comparison of tree density within each plot. It is unknown whether there are alignment issues between the two surveys.

4. Results

4.1 Tree Density Calculator

At the full plot scale, the results of the TDC analysis showed decreasing tree density as altitude and distance from mature woodland increased (table 1), with tree density being 350 % higher in the closer lowest plot (1124 tree/ha) compared to the furthest higher plot (250 tree/ha).

Table 1. *Results from the QGIS Tree Density Calculator used to count regenerating pine trees from three drone derived digital elevation models*.

Plot	Area (ha)	Automated tree count	Trees (per ha)	Min distance from mature forest (m)	Mean elevation of plot
L1	0.26	297	1124	68	530
L2	0.41	226	553	152	568
L3	0.20	50	250	246	605

4.2 Ground truthing

Overall the TDC method recorded 144 trees across the three transects (table 2). During the subsequent ground surveys, 16 of these were found not to be trees (false positives; FP), whilst 55 additional trees were located (false negatives; FN). This gave the true total number of trees as 183, and the TDC method an overall sensitivity (TP/(TP+FN) of 69.2 % (table 3). The overall false negative rate is 30.8 % which means nearly a 3rd of present trees are missed by the TDC method.

There was some variation between the three transects (table 2), with the sensitivity of L1 and L2 being similar (71.9 % and 73.1 % respectively), whilst it was much lower (45.5 %) in L3.

Table 2. *The number of additional trees recorded during ground-truthing surveys at three 10 m wide transects through plots (L1-L3), compared with the output of the automated Tree Density Calculator.*

Plot	Area (ha)	Automated tree count	True positives	False positives	False negatives	Actual tree count
L1_10m	0.064	82	69	13	27	96
L2_10m	0.086	51	49	2	17	66
L3_10m	0.057	11	10	1	12	22

Of the 16 false positives recorded, four were due to over recording the number of trees within a dense thicket, and a further four were related to the wide spread of larger trees being recorded more than once. There were also two examples of a rock being mis-recorded as a tree. Only six of the 16 false positives were unattributable to an obvious factor. It is possible these mis-recordings represent undulations in topography and/or the surrounding ground layer vegetation.

The majority (73.3 %) of trees that were not detected by the automated TDC process (false negatives) were small trees of less than 75 cm height (figure 5), with nearly half under 50 cm in height. At higher altitudes the tree's present are generally much smaller than further down the slope, at our L3 plot 83% were <75 cm in height, and this likely accounts for the much lower sensitivity for the TDC method in the L3 plot compared to the two lower plots.

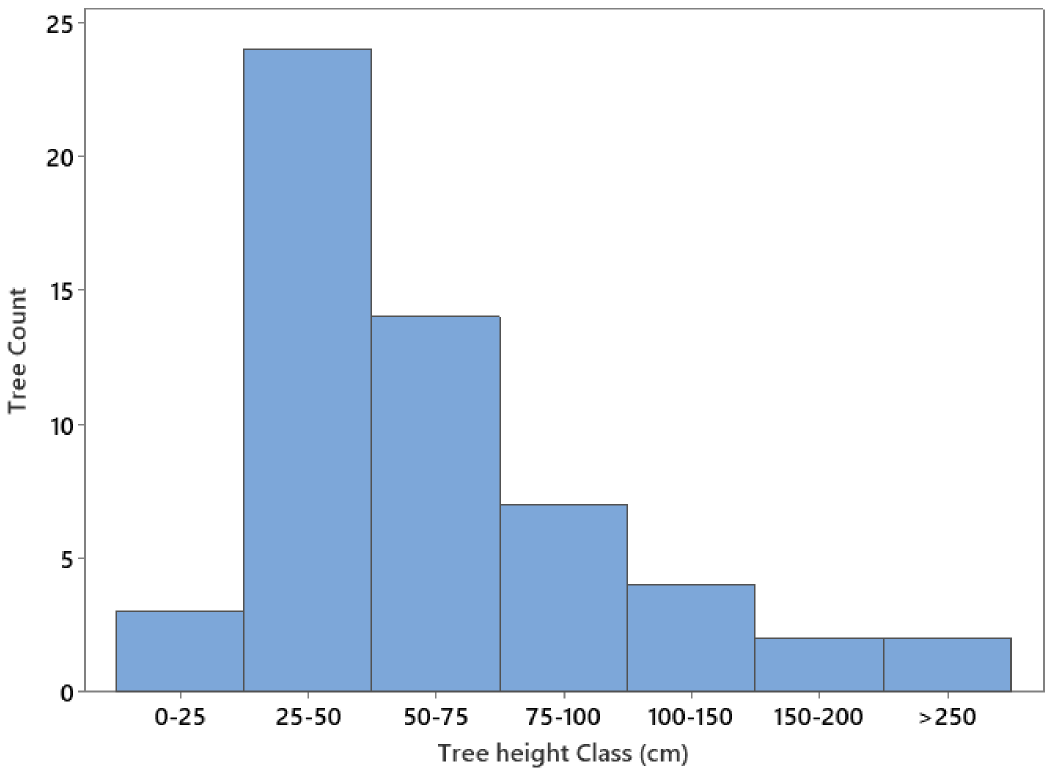


Figure 5. *The number of trees that were missed by the automated processing method, but subsequently recorded during ground surveys (false negatives), grouped by size classes.*

Further to this, a fifth (11) of the trees recorded as false negatives were found to be in very close proximity (<0.6 m) to other trees. This included the tallest tree (>2.5 m) that was missed by the TDC processing method.

4.3 Comparisons to LiDAR derived data

The LiDAR derived DSM, has a lower spatial resolution than the drone DSM, with each raster pixel measuring 25 cm compared to 2.35 cm for the drone. This resulted in fewer small trees being detected and reduced the overall sensitivity of 57.2 %. However, the precision of positive tree identifications was considerably higher for the lidar derived DSM, with 97.2 % of positive tree identifications likely to be correct compared to 88.9 % for drone-based analysis (table 3)

Table 3. *Accuracy metrics for the QGIS Tree Density Calculator method for processing drone and LIDAR derived input DSM's.*

Classification metric	Method	Drone DSM (%)	LIDAR DSM (%)
False Negative Rate	FN/(FN+TP)	30.8	42.8
True Positive Rate (sensitivity)	TP/(TP+FN)	69.2	57.2
Positive Predictive Value (precision)	TP/(TP+FP)	88.9	97.2

As with the drone based DSM, the false negative rate for LiDAR based analysis was much higher (60.9 %) in the higher elevation plot where trees are generally smaller, compared to the two lower elevations plots (39.6 & 40.9 %).

4.4 Comparisons to other monitoring data

The whole area of slope containing our three areas of interest was classified in the NatureScot regeneration survey as 'saplings on open ground', with a spacing between trees of 4-10 m (100-600 trees/ha). This fitted well for our upper two areas (L2, L3) which had overall densities of 553 and 250 stems/ha (table 1), whilst the upper limit of the range was only half of what we recorded within the lower more densely covered plot (1124 trees/ha).

Breaking down our 10 m wide ground-truthing transects into multiple complete 0.01 ha plots (figure 6), as used in the NatureScot survey, we found that the variability (standard deviation) of tree density was much higher in the two plots with most trees (L1 (n = 5): 1140 trees/ha ± 365 SD; L2 (n = 7): 643 trees/ha ± 382 SD), compared with the higher elevation plot which had a much lower variability in tree density (L3 (n = 4): 200 ± 141 SD).

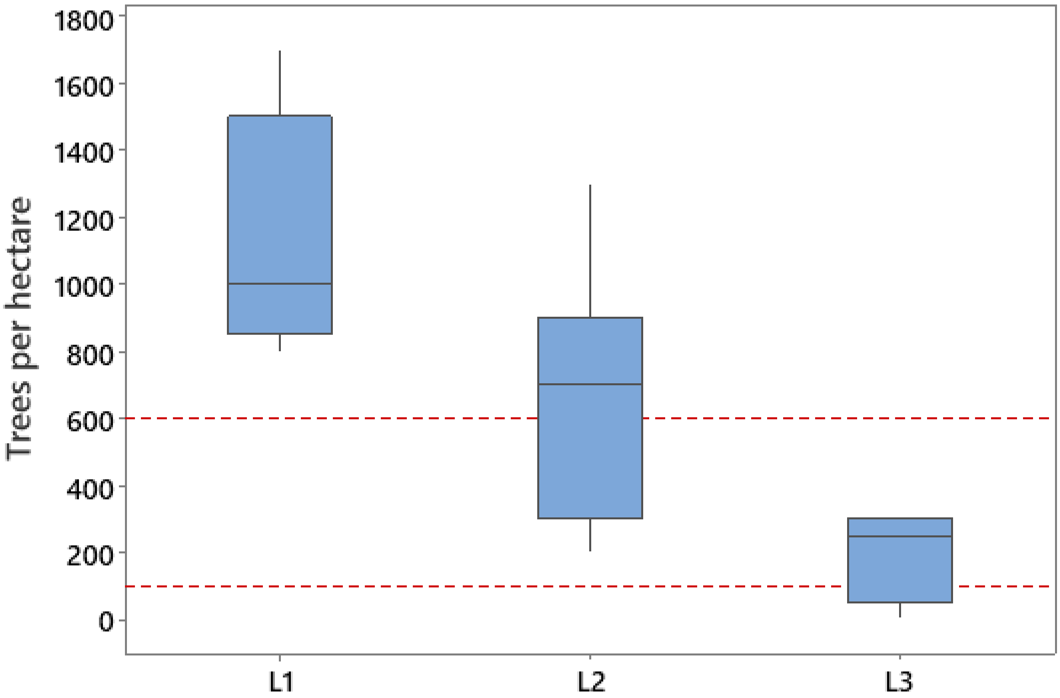


Figure 6. *Boxplot showing the variation in the number of trees (trees per hectare) identified using the tree density calculator method for 10 x 10 m (0.01 ha) sub-plots of the ground-truthing transects. Red dotted line shows the 100-600 trees/ha range reported by the NatureScot survey covering all three sites.*

Assuming there are no issues with GPS alignment, then the 0.01 ha plot tree densities reported in the NatureScot survey were identical to our TDC tree count for L1 (700 trees/ha) and L3 (200 trees/ha). However, our TDC tree count for L2 was half (300 stems/ha) of that reported by the NatureScot survey (600 trees/ha). Given the small plot size (0.01 ha) the number of trees counted is actually very small (3 and 6 respectively; 1/100th of the trees/ha value), and we found 3 additional trees matching the size ranges provided within 2 m of the given plot location. Given the error margin on a consumer Garmin GPS is between 5 and 10 m, then it is possible that these trees may have been included in the NatureScot survey and would account for the difference between the methods.

The variability in tree density between 0.01 ha plots within our survey highlights a challenge in assigning wider areas to a tree density category, based of plot derived data. Natural regeneration is very patchy in its distribution due to the numerous biotic and abiotic factors that determine germination and survivability of young trees. Capturing this variability and determining an applicable plot density for future surveys should be an important consideration to any future long-term monitoring of regeneration.

5. Potential use for future surveys

Results from this pilot study suggests the method has potential for mapping and quantifying regeneration, but that further refinements will be required to increase the sensitivity, particularly in relation to the detection of smaller trees. The open-source availability of the tools used to process and generate the data, and the use of DSMs derived from optical photogrammetry, rather than specialist tools such as LiDAR, means it could potentially be a cost-effective method for surveying in remote areas.

However, the practicability of utilising such a method depends on improvements in how smaller trees (below 75 cm in height) are identified by this process. Although Buters et al (2019) proposed a feasible alternative method for monitoring seedlings using consumer grade drones, their study utilised a colour (greenness) based methodology in a largely unvegetated and flat study area. In our region, where seedlings are growing through variable green shrub layers, often on steep slopes, the method they proposed is unlikely to be suitable. Initial explorations in R of several greenness-based methods proved very unreliable for our site.

To increase the detection of smaller trees in our method, improving the elevational accuracy of the generated DSM will be crucial. In our pilot study, we used a straightforward single-grid flight path with an overlap of 61 % and sidelap of 80%. The number of point-cloud feature detections between images, and resulting 3D model, could be significantly improved by changing the flightpath to a double-grid format, as well as increasing the overlap and sidelap of images to 85 %. Although not important for our pilot study, the use of several ground control points (GCP) would significantly improve XYZ accuracy and could have prevented or reduced the alignment issues we found when plotting against the LiDAR derived DSM/DTM. Instigating such changes, however, comes with several disadvantages, such as increased flight times and increasing the total number of images captured during the image acquisition stage. Processing more images results in longer image processing time, and the need for increased computational power during model generation.

Although using the available LiDAR derived DSM improved the accuracy for tree detection, it was limited by its resolution and resulted in fewer tree detections overall. It is likely a higher resolution LiDAR dataset would work very well for tree detection and has several advantages over the optical photogrammetry method. The most important of these are the increased accuracy in vertical (Z) data, and the ability to accurately detect ground from vegetation. Together this means individual tree heights can be extracted from the dataset and provide more detailed information on tree regeneration. The downside is that LiDAR surveys are typically more expensive than optical photogrammetry and require specialist equipment during image acquisition phase. Greater computational power, and specialist software is also usually required to process the resulting point cloud into a useable DSM/DTM.

Our plot sizes varied between 0.2 and 0.41 hectares. These were manageable plot size computationally, but doing larger areas would demand high processing power. It would therefore need to be considered whether whole areas need to be mapped, or whether sub-sampling a number of fixed-sized plots, could provide accurate measure of tree density at wider landscape scales. The variability of regeneration density, even over small areas, suggests this should be done with care. One option might be to use pre-existing satellite or aerial imagery to visually identify areas of tree density classes, and then sub-sample these with drone surveys, or simply to identify and survey a specific plot size on a regular grid pattern. In both cases, to determine the minimum number of plots required to be representative of wider scales, a range of plots and areas would need to be mapped, and a power-analysis undertaken. Alternatively the TDC method could be used for whole area surveys, after which an accurate gridded map of density could be produced for future change comparisons.

Given further time and funding, we would have measured all trees marked during the ground-truthing survey, rather than just the additional false negatives that were missed by the TDC method. This would have allowed us to have examine the sensitivity of the TDC method for each height class of tree, and better understand where improvements in the method are required. If we had had prior knowledge of the regeneration survey undertaken a month or two prior to our own, we could also have surveyed a number of these plots as an in-depth ground-truthed survey.

In future analyses it is also desirable to improve the efficiency of this mostly manual method, which could be achieved using an R or Python workflow. This would considerably improve manual processing time where there are larger or a greater number of plots, whilst also removing the possibility of user-error within the processing steps.

6. Acknowledgements

This report could not have been completed without Transnational Access funding for the drone team via the EU H2020 funded eLTER project. Further thanks goes to NatureScot for supporting UK Environmental Change Network long-term monitoring at Inshriach, providing NNR consent to the research, and specifically to Ian Sargent for providing data and information regarding ongoing regeneration surveys. We also thank Professor David Coomes and his team at the NERC Centre for Landscape Regeneration (NE/W00495X/1 and Tarides) for providing additional data products used in this report.

7. References

Beck, A. & Singh, J. (2024). Woodland and regeneration survey of Inshriach. NatureScot Commissioned Report, 27pp.

Buters, T., Belton, D., Cross, A. (2019). Seed and Seedling Detection Using Unmanned Aerial Vehicles and Automated Image Classification in the Monitoring of Ecological Recovery. Drones, 3(3): 53. https://doi.org/10.3390/drones3030053

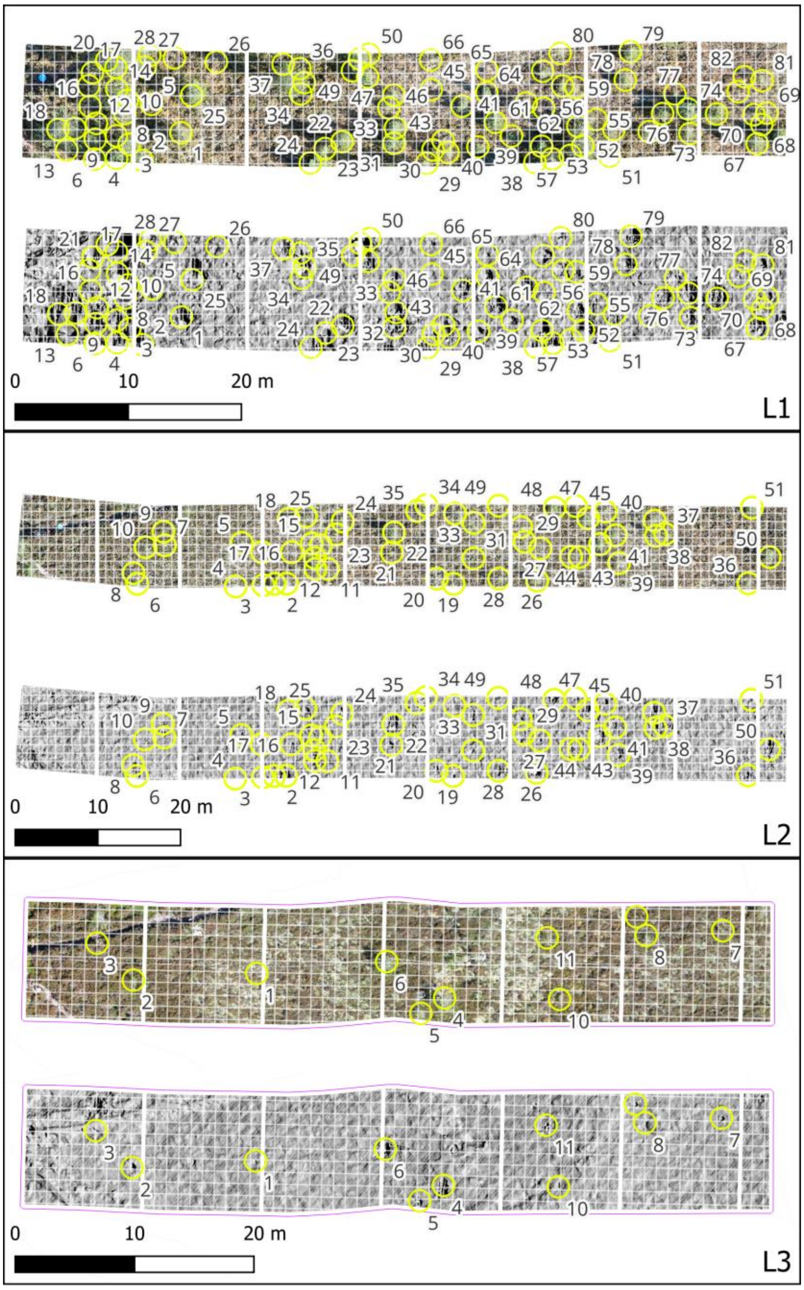
Crabbé, A. H., Cahy, T., Somers, B., Verbeke, L.P., Van Coillie, F. (2020). Tree Density Calculator Software (Version 1.5.7) [Software]. Available from https://bitbucket.org/kul-reseco/localmaxfilter.

Mohsan, S.A.H., Othman, N.Q.H., Li, Y. et al. Unmanned aerial vehicles (UAVs): practical aspects, applications, open challenges, security issues, and future trends. Intel Serv Robotics 16, 109–137 (2023). https://doi.org/10.1007/s11370-022-00452-4

Wortley, L., Hero, J.-M., Howes, M. (2013). Evaluating Ecological Restoration Success: A Review of the Literature. Restoration Ecology, 21: 537-543. https://doi.org/10.1111/rec.12028

8. Appendices

8.1.1 **Appendix 1.** 10m wide transects with digitally identified trees for three survey areas (L1, L2, L3) which were used as field maps for identifying and ground truthing output in the field. A 1 m x 1 m grid and 10 m intervals were superimposed to aid tree identification in the field.



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