A practical application of airborne LiDAR for forestry management in Scotland

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Abstract

This paper presents an assessment of the risk of windthrow for an area of ancient woodland of high environmental importance in Scotland, UK. ForestGALES (Geographical Analysis of the Losses and Effects of Storms in Forestry) is a process-based model, which identifies wind vulnerability. The collection of plot-level field data has previously permitted this model to be run for stand-level analysis. In this study, airborne LiDAR data were used to produce a normalised canopy height model (CHM). An algorithm was designed within Definiens Developer 7.0 object oriented analysis software in order to delineate individual tree crowns from the CHM. The results of this delineation were used to develop regression equations using individual tree height and crown width to estimate diameter at breast height. This aims to allow structural vegetation properties to be related to the spatial distribution of individuals. The spatial arrangement of individual tree heights and diameters at breast height were used to generate tree lists and use them as inputs to ForestGALES. This allowed the stability of individual trees to be mapped by modelling the critical wind speed at which they are predicted to be overturned. This offers a substantial improvement on previous model outputs and provides important data, which can inform forest management decisions.

Keywords: Airborne LiDAR; high point density; canopy delineation; windthrow

1. Introduction

Topographic exposure, the degree of exposure to Atlantic storms, shielding from adjacent vegetation together with individual tree dimensions are factors that need to be considered when modelling susceptibility to wind. Understanding these processes and site-specific risk will not only allow appropriate management of wind risk but also permit the optimum felling age of stands to be identified. Airborne LiDAR data enables the locations, heights and canopy dimensions of individual trees to be mapped and therefore addresses many of the data requirements for assessing vulnerability to wind (Suárez *et al* 2008).

Glen Affric consists of an area of lochs, moorland and mountains in the Scottish Highlands. It contains one of the largest ancient Caledonian pinewoods in Scotland, consisting of species such as Scots pine, junipers, birches, willows and aspen. This diverse landscape provides habitats for a wide range of plant, animal and bird species. As a result, it has been designated a Caledonian Forest Reserve, National Scenic Area and National Nature Reserve. Since the 1960s, the core area of Glen Affric has been under conservation management by the Forestry Commission of Great Britain in recognition of its high environmental value (Forestry Commission 2008a, 2008b).

2. Aims

Forest management plans contemplate a progressive transition from a traditional planting and clear-felling to a natural system characterised by a permanent presence of trees, selective cuttings and natural regeneration. The ultimate goal is the progressive substitution of non-native species for those ones that define a Caledonia forest.

However, this area is regularly subjected to storm events coming from the North Atlantic added to permanent waterlogged conditions, which makes it vulnerable to wind damage during those storm events. This study was conducted as part of the EU-funded Interreg project StormRISK. The aim was to test the capabilities of LiDAR analysis to provide more accurate information than that routinely gathered in the field by the forest district. In particular, this work looked at mapping structural differences within the forest stands such as the spatial distribution of individual trees, distance between neighbours, individual tree heights and stem diameters. All this information has been used to generate tree lists that were subsequently input into the ForestGALES model (Geographical Analysis of the Losses and Effects of Storms in Forestry) to make predictions of the Critical Wind Speed required to overturn each tree.

ForestGALES is a process-based model which enables risk of wind damage to be assessed for different management scenarios and with changing conditions due to stand growth (Gardiner *et al* 2004, Forestry Commission 2008b, Suárez *et al* 2008). Given local site characteristics, the model therefore identifies the wind speed at which windthrow will occur. Risk is expressed as the reoccurrence period of the critical wind speed calculated to overturn an average tree within a stand. These return times have been mapped for Britain using wind strength scores called DAMS (Detailed Aspect Method of Scoring).

3. Data

Airborne LiDAR data were acquired for an area of 58 km^2 on 9th, 11th and 13th June 2007 by The Environment Agency Science Enterprise Centre on behalf of Forest Research. The Optech ALTM 3100 LiDAR system was used recording up to four return echoes per laser shot at approximately 0.25m resolution. This resulted in an average pre-processed point density of approximately 12-16 points/ m^2 producing good energy penetration throughout the canopy (Figure 1).

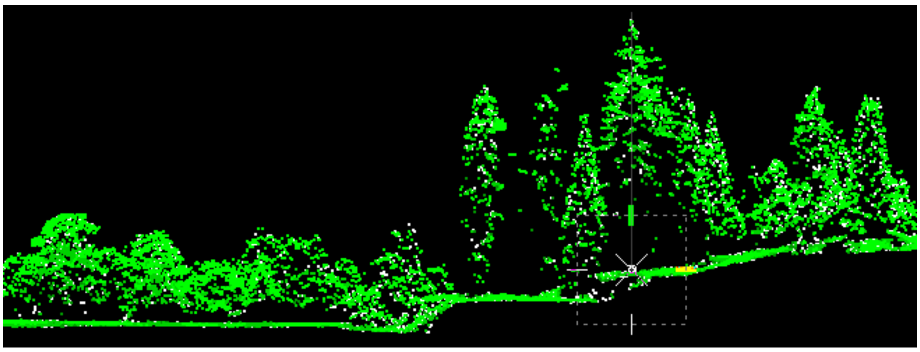

Figure 1. LiDAR point cloud cross section of Glen Affric, Scotland. Image produced with Terrascan.

4. Methods

A subset of airborne LiDAR data was used for a 1km x 2km area representing the range of surface and vegetative characteristics present within Glen Affric (Figure 2). This study area comprises stands of Scots Pine (*Pinus sylvestris*), Birch (*Betula spp.*), European Larch (*Larix decidua*), Douglas Fir (*Pseudotsuga menziesii*), mixed conifers, Sitka Spruce (*Picea sitchensis*), Norway Spruce (*Picea abies*) and Lodgepole Pine (*Pinus contorta*) in order of occurrence.

Scots Pine formed the oldest and youngest stands of 208 and 8 years old respectively. For the purposes of this study, field measurements and models for stands of Scots Pine (*Pinus sylvestris*) are to be used for validation. The LiDAR data were processed as outlined below.

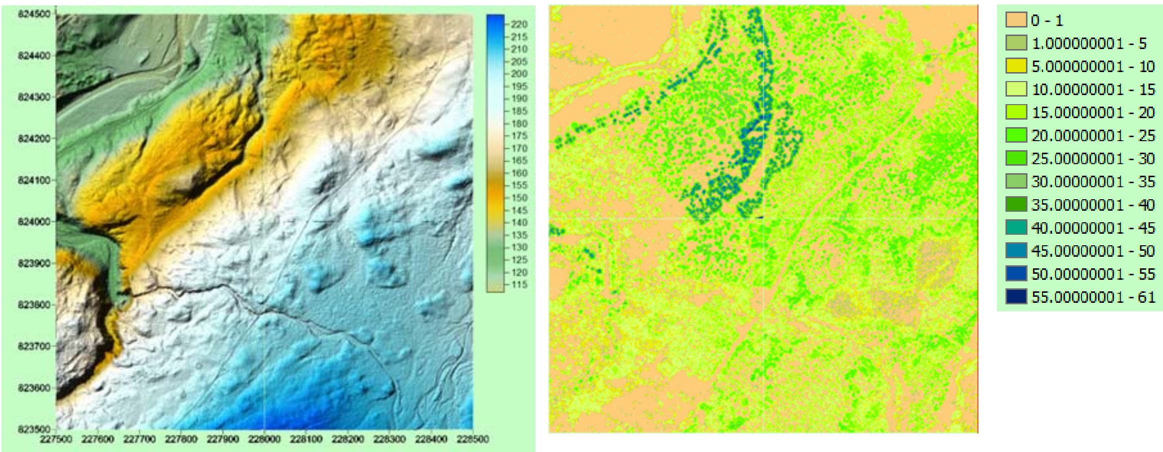

Figure 2. (left) 0.5m resolution digital terrain model of a 1km x 1km area produced with Golden Software Surfer 8. (right) Canopy height model of the same area using ArcGIS 9.1

A ground return class was determined from last return echoes using Terrascan 007.008 Software an extension application for Bentley Microstation V8 2004. This ground class and all first return data were subsequently exported and converted into regular 0.5m resolution raster geotiffs using Delaunay triangulation with linear interpolation. A canopy height model (CHM) was calculated as the difference between the digital terrain model (DTM) created from the ground class and the digital surface model (DSM) from the first return data using ArcGIS 9.1.

An algorithm was designed within Definiens Developer 7.0 to delineate individual tree canopies solely from the LiDAR-derived 0.5m resolution canopy height model. Firstly the CHM was smoothed with a kernel of 3x3 and local maxima were located and classified as tree tops. Areas of ground or understorey vegetation, plus canopy 'edges' were identified and used as boundaries to prevent further canopy growth. Tree tops were subsequently extended radially until either meeting an adjacent canopy or designated boundaries and a mask was applied to limit irregularly shaped polygons. Tree top locations were then saved as point shapefiles and polygons representing individual canopies were also exported with associated maximum canopy height, area, maximum and minimum radii, width and polygon centroid co-ordinates.

An allometric relationship between canopy width and height with diameter at breast height (DBH) was developed using the Forest Research Environmental Database (FRED) containing field measurements for more than 15,000 trees over the entire country. This model allowed the estimation of stem diameters for each individual tree.

Thus, stand information obtained form the FC sub-compartment database was used to generate mean wind conditions inside the forest canopy for each stand in ForestGALES. Tree lists generated from LiDAR were used to calculate resistive factors at tree level. Finally, edge effects were estimated from the distance between each individual to its neighbours (Figures 3-5).

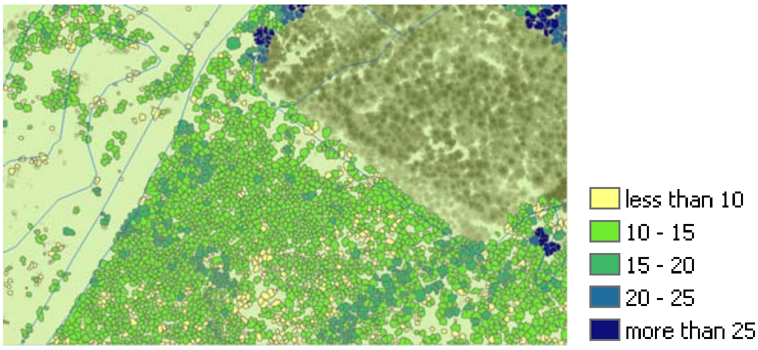

Figure 3. Estimation of individual tree heights (in m).

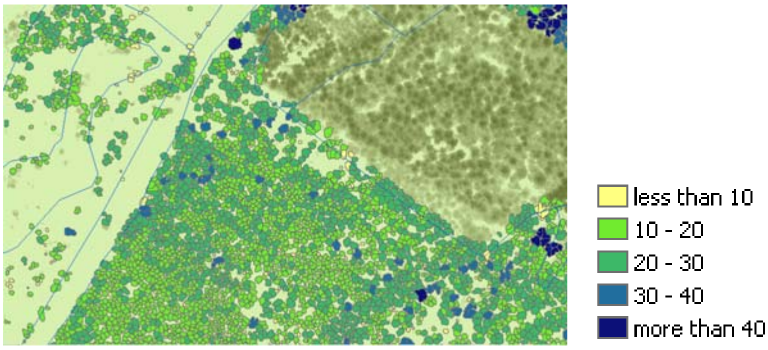

Figure 4. Estimation of individual DBH (in cm).

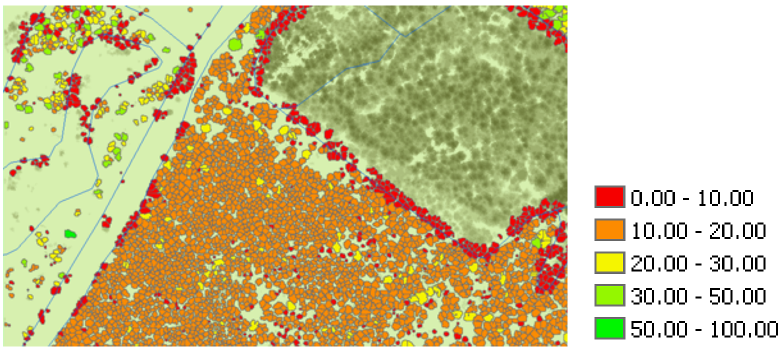

Figure 5. Critical wind speed for overturning each tree (in ms^{-1}). The most stable trees are depicted in green.

5. Results and Discussion

The canopy delineation method produced a better description of the influence of stand structure on the risk of wind damage. This is a substantial improvement compared to the normal way of operating ForestGALES, with just mean stand parameters, because it allows the most vulnerable parts of the stand to be located. This is true for those individuals that are not properly sheltered by neighbours or present lower taper values. In Figure 5, the most vulnerable trees, depicted in red, are around the edges of the stand or inside the forest canopy if their taper relationships are below 80. On the contrary larger canopy dimensions, high taper values and sheltered trees are more stable and require higher critical wind speed values for overturning. Most of those trees, depicted in orange, require wind speeds between 10 and 20 ms^{-1}.

The practical consequences for future management plans will contemplate the choice of thinning practices (normally ruling out thinning), the degree of exposure to certain parts of the stand when clearfelling neighbouring stands, the location of forest roads (normally avoiding the sudden exposure of vulnerable individuals), etc.

The limitations of the ForestGALES method come from the modelling of the adaptation of trees to changing exposure conditions. In this case, most of the trees around the edges of the stands or those trees growing in open stands or in total isolation are already very well adapted to wind conditions. In particular, those individuals that form part of the remnants of the ancient Caledonian pinewood have been growing in isolation for more than 100 years without being affected by windthrow (top left of Figure 5). Therefore, this method seems to be more useful for new plantations (like the one than occupies most of the image) than for isolated individuals. More research will be required in the future for parameterising this adaptation to wind.

Acknowledgements

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