Predictive Modelling of Eucalyptus Tree Metrics Using Stump Measurements

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SUMMARY

Estimating diameter at breast height (DBH) from stump measurements can be used for calculating tree diameter distributions and predicting tree height (H) and other tree metrics. Stump data in terms of stump diameter (SD) and stump height (SH) often provides a foundation for reconstructing pre-harvest stand conditions, particularly in cases of unplanned or unauthorised tree removals.

To enable these estimations, two regression equations were developed, the first to predict DBH from outside-bark stump measurements. These DBH estimates were subsequently used in a second equation tailored to determine tree H. This approach could support applications in carbon stock assessments, habitat quality evaluations, and biodiversity monitoring where rapid yet accurate tree dimension data is needed.

The equations were derived from data collected from 35 mature Eucalyptus tereticornis (Forest Red Gum) urban trees, with heights ranging between 23 to 42 meters. This eucalyptus species, widespread in Southeast Queensland, Australia, offers sustainable, resilient timber that is both cost-effective and ecologically advantageous due to its fast growth and carbon-sequestering properties.

Trees H was measured using a surveying total station. Stump diameters were recorded at heights above ground level ranging from 0.20 m to 1.30 m, capturing likely SH below the DBH, which was conventionally measured at 1.30 m. Data collection included capturing scaled images of the tree trunks at close range, delineating sections, and processing them with open-source image software. The resulting equations, based on SH and SD, provided DBH estimates with an RMSE of ±0.027 m, corresponding to an average discrepancy of 2.14% relative to measured DBH values. Furthermore, the equation estimating tree H, derived from these DBH values, exhibited an RMSE of ±1.85 m, equating to a 3.62% discrepancy from the average tree heights observed in this study.

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1. INTRODUCTION

Eucalyptus timber is a sustainable, cost-effective, and durable building material. With its rapid growth and natural regenerative ability, eucalyptus contributes valuable ecological benefits, such as carbon sequestration and waste reduction. It boasts a high strength-to-weight ratio and is naturally resistant to pests, decay, and fire, making it suitable for both indoor and outdoor construction (Nogueira et al. 2020). Pressure-treating eucalyptus can further enhance its durability, offering a long-lasting and affordable alternative to traditional hardwoods. Its versatility allows eucalyptus wood to be used across various applications, from structural supports to decorative finishes, making it an ideal choice for eco-conscious construction projects seeking both environmental and economic advantages (Australian Government, 2018).

Accurately measuring eucalyptus stump dimensions or DBH is essential in forestry and environmental studies to support sustainable resource management and conservation efforts (Jurjević et al., 2020). These metrics serve as fundamental indicators of tree growth, health, and biomass, providing a basis for assessing carbon sequestration potential, evaluating timber yield, and estimating ecological contributions of forested areas. In addition, precise tree measurements enable the monitoring of forest dynamics, such as tree mortality, recruitment, and growth rates, which are critical for understanding forest ecosystems over time.

These data are not only crucial for practical forestry applications, such as optimizing harvest plans and maintaining forest productivity, but they also play a pivotal role in scientific research. For example, they contribute to the development of predictive models for forest growth and carbon cycling, facilitates biodiversity assessments, and informs restoration projects in degraded landscapes (Pace et al., 2022). Furthermore, reliable tree metrics are vital for policy-making and climate change mitigation strategies, enabling evidence-based decisions that balance economic, environmental, and social goals. In this context, the accurate measurement of stump dimensions and DBH offers a foundation for advancing sustainable forestry practices while addressing global challenges in conservation and resource management.

2. MEASURING THE DBH

Assessment of tree health and growth can be achieved through regular measurement of DBH, allowing foresters to monitor tree growth rates over time (Elzinga et al., 2005). This practice helps in evaluating the overall health and vigour of individual trees and entire forest stands (Sumida et al., 2013). Healthy growth patterns suggest effective forest management, while stagnation or decline indicates the need for intervention (Ordonez et al. 2023).

Estimating tree biomass often depends on DBH, which can also be a primary predictor of tree volume. Accurate biomass estimation is frequently needed for evaluating available timber resources, often achieved through allometric equations that use DBH as a core variable. As mentioned, DBH measurements play a role in assessing and understanding carbon storage and sequestration within forests, an important factor in climate change mitigation (Magarik, 2021).

While DBH alone does not directly measure tree H, it can be used alongside other data to estimate it. Many tree growth models include both DBH and tree H to provide more accurate predictions of tree size and wood volume. Measurements of DBH also assist in determining the structure and composition of forest stands. They aid in classifying trees into size and age classes, which is important for biodiversity studies, habitat assessments, and wildlife management (Corral-Rivas, 2007)

Tree weight can also be derived from DBH measurements, which is crucial for practical applications such as the transportation and processing of timber and for calculating load-bearing requirements in engineering applications (Bai, 2023; Chukwu, 2020). Accurate DBH or stump dimensions measurements inform forest management practices, including thinning, clear-cutting and selective logging. These practices aim to optimize forest health, productivity, and regeneration, ensuring sustainable forest management (Di Cosmo, 2020).

3. APPLICATIONS OF SD AND SH MEASUREMENTS

After logging activities, SD and SH measurements help to reconstruct the original stand structure, which in turn assist with understanding the pre-harvest condition of the forest. This information is necessary for planning reforestation and assessing the impact of logging. When trees are harvested, stump measurements assist in estimating the residual volume of wood left in the forest, ensuring that logging practices are efficient and valuable timber resources are not wasted (Bylin, 1982).

Stump measurements are needed for assessing losses following natural disasters like forest fires. By analysing the stumps of damaged trees, foresters can estimate both the volume and economic value of the lost timber and plan for recovery and restoration efforts. In situations where DBH measurements are unavailable, such as when trees have been felled or damaged, stump metrics provide a means to estimate DBH, enabling the calculation of other tree attributes and helping maintain continuity in forest data records (Koren et al., 2024; Horvath and Popa, 2021). Accurate measurement of stumps can also be important for legal and regulatory compliance, ensuring that logging activities conform to forestry laws and sustainable practices. This helps in detecting illegal logging and unauthorized tree removals (Di Cosmo et al., 2020).

4. THE DATA

Measurements were obtained from 35 *Eucalyptus tereticornis* trees (Cronin, 2007), with the DBH conventionally measured at 1.30 meters from the ground. Additionally, tree diameters were recorded along the trunk of each tree to emulate possible SD dimensions, ranging from

0.20 m to 1.00 m at various intervals. All SD measurements were taken outside the bark. The histogram in Figure 1 illustrates a typical distribution of measured SD for a given SH of 1.00 m.

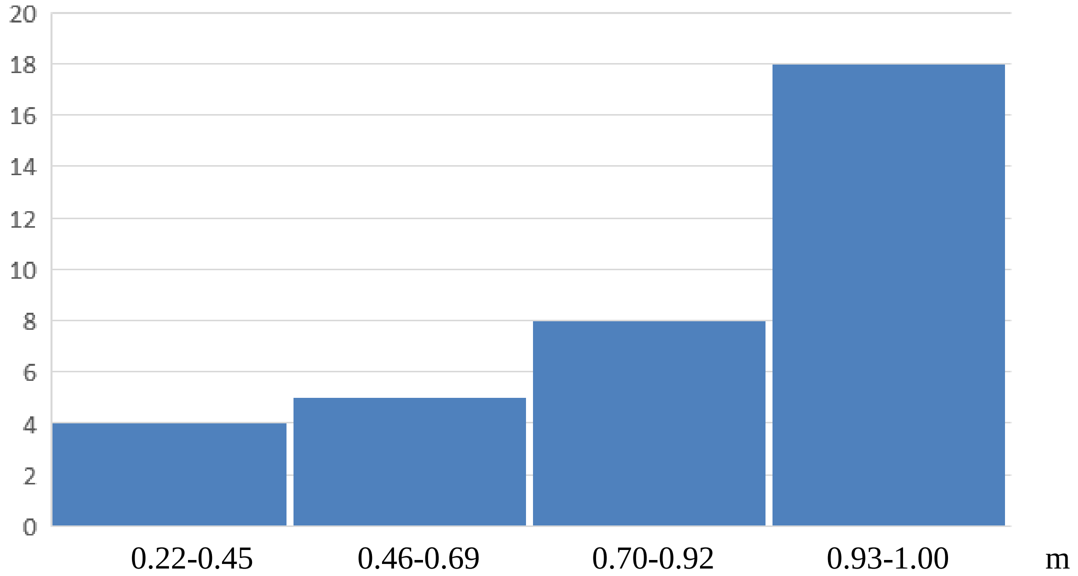

Figure 1 - Typical distribution of measured SD. The histogram corresponds to the distribution of SD (outside bark) up to a SH equal to 1.00 m above ground.

The field procedure involved selecting trees within the area of interest. For each individual tree, measurements were taken and recorded to the nearest 0.01 m at several heights above ground level, including SD at 0.20 m, 0.40 m, 0.80 m, 1.00 m, and 1.30 m (corresponding to the DBH). In cases where root swell at 0.20 m made measurement impractical, a small number of measurements at this height were omitted. By incorporating SD measurements at multiple heights from ground level, the proposed predictive equation accounts for variations along the trunk, thereby providing a reliable estimate of the DBH. This approach not only enhances the accuracy of predictions but also ensures that the equation can be adapted or modified for use across different tree species and forest conditions.

Tree metrics of interest (i.e., SD and SH) were obtained using an adaptation of a photographic method described in Fulkerson (2020). This method, originally conceived for measuring tee H, was considered here for measuring the DBH, the SD and the SH below the DBH. The photographic method used here involves using a cell phone camera to photograph the tree alongside an object of known dimensions. This method is effective when the camera is held vertically at a right angle to the tree trunk, thereby limiting or eliminating optical distortions. This approach was found to provide accurate estimates of the tree's diameters with less than 0.5% inaccuracy. To employ this method, the reference object with known dimensions is placed or held next to the tree where diameter measurements are desired. A photograph is then taken ensuring both the tree and the reference object are clearly visible. This is illustrated in Figure

2. Figure 2 also gives an indication of the kind of urban environment where all measurements were carried out.

Measurements are then extracted from the photograph using an open-source image processing software (ADI, Analysing-Digital-Images) which is a free to use program designed for educational use on either PCs or Macs. These measurements were then scaled based on the known dimensions of the reference object to calculate the actual diameters of the tree at the desired heights above the ground but below the DBH. Two images were taken for each tree at approximately 90^0 angles and the two diameters at each envisaged SH were averaged.

This photographic method is easy to use, economic, non-invasive, and accessible to both forestry professionals and the public without requiring specialized equipment. By following these steps, it was simple to obtain precise measurements of a tree's DBH and at various diameters below DBH, providing a practical alternative to current measurement methods (Koren et al., 2024; Howie and Di Stefano, 2024; Guenther et al., 2024; Weaver et al., 2015).

Figure 2 - Tree SD measurements taken from ground level at 0.20 m, 0.40 m, 0.80 m, 1.00 m, and 1.30 cm (the DBH). A graduated scaled object (0.19 m long) was placed/held next to the tree and a photo taken keeping the camera as much as possible perpendicular to the object photographed (the tree section of interest). A perspective view of the urban area where measurements and images were taken is also shown (right).

5. ANALYSIS

Least squares regression equations were fitted to the data from each tree, with the analysis performed separately for each stump SH at 0.20, 0.40, 0.60, 0.80, 1.00, and 1.30 m (the DBH). The relationship associating SD to SH for all measured trees is described by Equation 1 below, where $R^2 = 0.9958$:

$$SD = -0.0032*SH^2 - 0.2625*SH + 1.1957 \quad (1)$$

Both SD and SH are measured in meters.

This model was selected due to the slight curvature observed in the trunk sections of interest, as illustrated in Figure 2. Notably, Equation 1 implicitly determines the DBH when the value of SH is taken as 1.30 m. The DBH values predicted using this equation were compared against the actual DBH measurements obtained from field data for all 35 trees in the test sample. The results demonstrated a good correlation between the measured and predicted DBH values, with an RMSE of ±0.028 m and an average discrepancy of 1.71% relative to the nominal (measured) DBH average.

The observed discrepancy is attributed to the challenges associated with accurately identifying the precise SH from ground level and measuring the corresponding SD, which may introduce systematic errors. While the suitability of this correlation level may vary depending on specific application requirements, the RMSE and percentage error observed here are generally acceptable for most practical forestry and environmental applications.

6. TREE HEIGHT BASED ON STUMP MEASUREMENTS

An additional task was undertaken to estimate tree H based on values computed from Equation 2. Since the nominal tree H had been measured using a theodolite total station, it was possible to establish a relationship between SD, SH, and the H of each of the 35 trees.

To achieve this, an equation relating DBH to tree height was applied. The equation was derived from the conventional DBH measurements taken at 1.3 meters above ground. The regression analysis yielded the polynomial relationship in Equation 2. In this case the RMSE of the residuals between the nominal height values and those computed via Equation 2 was equal to ±1.42 meters, representing a discrepancy of 1.9% from the average tree heights.

$$H= 122.5*DBH^4 - 398.4*DBH^3 + 455.5*DBH^2 - 188.53*DBH + 51 \quad (2)$$

DBH units = metres

The next step involved using Equation 1 and Equation 2 in sequence so to obtain tree H as a function of stump measurements. This process begin with Equation 1, which estimates DBH based on SH and SD. This intermediate calculation provides the DBH necessary for the next step. The DBH values computed from Equation 1 were substituted into Equation 2, resulting in a process that relates tree H to both SH and SD, thus validating the accuracy and practical utility of combining Equations 1 and 2 for estimating tree H based on stump measurements.

7. CONCLUSIONS

Accurately predicting a tree's DBH is essential for numerous forestry applications, including estimating tree volume, biomass, and growth rates. In this study, DBH predictions were derived from SD measurements taken near the ground level up to the DBH height, providing the foundation for a method to eventually estimate tree H based on SD and SH.

In cases where trees have been removed due to timber theft or missing data from harvested stands tree volumes, heights, and related metrics can still be estimated from stump measurements. This underscores the importance of a reliable method to predict DBH from SD and SH measurements.

Predictive equations in this study were developed using observed and potential SD and SH data and were validated by comparing predicted DBH and H values to actual field measurements. Results demonstrated good correlations between predicted and actual values, indicating that the proposed method effectively predicts DBH and H and has promising applications in forestry practices.

While the reported R^2 values and error percentages suggest that the accuracy achieved here meets the requirements for most practical applications, higher precision may be necessary for specific scientific studies or precision forestry tasks. Nevertheless, the accuracy obtained in this study highlights the utility of stump measurements for estimating DBH and H.

Future research should focus on refining this approach to improve accuracy and evaluating its applicability across different forest types and tree species. Additionally, investigating environmental factors affecting the stump-to-DBH relationship and creating models that account for these variables would be beneficial. Another research avenue could involve integrating new technologies to enhance the efficiency and precision of SD and SH measurements, which would be particularly advantageous for large-scale forestry operations.

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