INSIGHTS INTO STANDARDS FOR NURSERY-GROWN TREE STOCK

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Abstract

Root to shoot balance in nursery tree stock is an important quality characteristic and contributing factor to tree form, growth and planting success in the landscape. Yet specifying root to shoot balance criteria and standards has been problematic owing to a lack of critical information on biological variation among species, nursery production practices and the role of climatic influences on shoot morphology and growth. Our research addressed this knowledge gap through a field-based survey of nursery tree production throughout Australia, capturing information on 159 species and varieties and nearly 14,000 trees. Our findings revealed large natural variation in root to shoot balance across the wide range of containerised trees sold in Australian nurseries. Species differences were well captured by a simple classification into winter deciduous and evergreen categorical types. This rich data set, specific to nursery grown trees in Australia, provides insights into potential improvements in quality assessment criteria and standards for nursery-grown tree stock for landscape use.

Introduction

The *'202020 Vision'* aims to increase Australian urban green space by 20% by the year 2020. This initiative has the potential to drive market growth in tree nursery production for landscape use. Challenges may include problems in establishment and survival of newly planted urban trees (Nowak et al., 2004; Miller et al., 2015) and meeting the rising demand for tree stock that can endure increasingly harsh environments expected with climate change. Thus, nursery tree stock quality and its assessment are likely to increase in importance in the industry.

In April of 2015 the "*Australian standard: Tree stock for landscape use*" (AS 2303) was adopted as the industry standard to enable assessment of the quality of tree stock across Australian nurseries (Standards Australia Limited, 2015). This standard was designed to assess aboveground and belowground characteristics of production tree stock. AS 2303 is increasingly called upon to ensure quality at the point of sale with the aim of minimizing risks of outplanting failure or poor form and growth. At the time of its adoption, it was recognized that provisions concerning root to shoot balance assessment in the standard required further research in the Australian context.

Proper balance between root and shoot systems is critical for establishment of outplanted trees as balance encompasses the initial structural stability of a tree. Root to shoot balance also serves as an index of plant water uptake capacity (root) to water loss (shoot) at the time of planting (Ritchie, 1984; Thompson, 1985; Grossnickle, 2000; Haase & Others, 2007). However, parameters used to evaluate tree stock balance are likely affected by nursery practices such as container style, root system management, irrigation, fertilization, root pruning and growing media, as well as climate and time since re-potting. However, to date few explicit tests have been conducted on the role of natural variation among species and the role of nursery practices or climate. Field-based surveys of nursery production stock would provide insight into these potential sources of variation.

In AS 2303, root to shoot balance is assessed based on tree size and container volume. An aboveground size parameter (Size Index) is calculated as the mathematical product of stem calliper (mm) at 300 mm and total tree height (m). Aboveground Size Index is then compared to the size of the container in which the tree is grown, where container volume (measured in liters, L) reasonably represents root system size, owing to complete occupancy of the root ball. Minimum and maximum acceptable values of Size Index, generalized for all species, are specified for the large range of container volumes used in Australian wholesale tree nurseries.

If use of Size Index and its relationship with rooting volume provides an accurate assessment of tree stock balance, it offers a tool for growers and buyers of landscape trees to assess product quality and uniformity and ensure or potentially enhance the performance of outplanted trees.

If large natural variation in Size Index occurs across species, climate regions or in response to nursery practices, the currently specified acceptable values in AS 2303 may not adequately capture natural variation tree stock balance. Likewise, if variation in height and calliper and thus Size index is quantifiable in terms of tree stock type (i.e. species groupings) or climate zone, then this information may be useful in revising or tailoring acceptable ranges in the standard to provide more refined guidelines.

Survey methodology

Measurements were completed at 23 wholesale tree production nurseries across all of Australia's major continental market regions centered on capital cities in six states. Multiple nurseries were visited in New South Wales, Queensland, Victoria, South Australia and Western Australia. A single nursery was visited in Darwin in the Northern Territory. The nurseries were visited over a 10-month period between April 2016 and February 2017. Batches of tree stock that were currently ready for sale were identified with nursery production managers at each site. Priority was given to tree species that were available in multiple container sizes. Further details of this Horticulture Innovation Australia research project are described elsewhere (Tjoelker, 2017).

Visual quality assessments and testing against the standard

A two-part above and belowground visual assessment of morphological quality was completed for each pre-selected batch of tree stock deemed ready to sell. The aboveground visual testing criteria were completed as specified by AS 2303 (see Clause 2.2, Standards Australia Limited, 2015). Briefly, the sample trees were required to be self-supporting, have a symmetrical crown, have healthy leaves and crown structure and be free of injury, pests and disease. If a sample tree passed all aboveground assessment criteria, then the belowground assessment of root ball occupancy and root form (absence of woody circling roots, j-rooting) was completed as specified in AS 2303 (see Appendix B, Standards Australia Limited, 2015).

The assessments were conducted independently by the project team and thus consistently across all 23 nurseries. Root to shoot balance measurements were completed only for production batches that passed all criteria for both the above and belowground assessments. This methodology ensured that data collection was representative of trees possessing all the morphological attributes required by AS 2303 at dispatch.

Tree stock root to shoot balance assessment

Tree height and trunk diameter at 300 mm were measured on a subset of trees for each selected batch of tree stock that passed all above and belowground tests. Up to 45 trees were measured for batches in containers ≤ 45 L and up to 20 trees were measured for batches in all larger-sized containers, if available. The Size Index parameter was calculated as the product of height (m) and trunk calliper at 300 mm (mm) for each measured tree. Tree slenderness index was calculated as the ratio of height and trunk calliper.

Differences in measured tree height, calliper and Size Index with container volume were analysed using mixed-effects statistical models. In the statistical models, tree species and nursery were classified as random effects, constituting a representative sample of both the species that were grown and of the nursery sites in Australia. The effects of climate, nursery, species origin (i.e. native or non-native), tree functional type (i.e. evergreen or deciduous) were treated as either continuous or categorical fixed effects.

Mixed model analyses were performed in the statistical analysis platform R (R Development Core Team, 2016), with the 'lme4' package (Bates et al., 2015). Explained variance (R^2) of mixed models was computed as in Nakagawa & Schielzeth (2013), in which the marginal R^2 represents variance explained by fixed factors and the conditional R^2 by both fixed and random factors. All tests of statistical significance were conducted at an alpha level of 0.05.

Evaluation and Discussion

Across all nurseries, root to shoot balance of 13,820 trees was measured according to AS 2303 assessment criteria. Size Index and other data were collected for 650 ready to sell batches of containerized tree stock ranging from 18 L to 3000 L. There are 159 tree varieties represented in the database, including 113 unique tree species. Of the 650 measured batches of tree stock, 393 were classified as evergreen and 257 were classified as winter deciduous trees. Similarly, 373 batches were native Australian tree species and 277 batches were non-native tree species.

In AS 2303, tree stock balance is assessed by comparing the Size Index parameter with the nominal container volume in which the tree is grown. Specifically, minimum and maximum values of Size Index are specified for different container volumes. In this study, only 31% of all measured individual trees were within the specified Size Index range (Figure 1). Of the trees that fell outside the specified range, 45% were below the minimum range and 23% were above the maximum range. Likewise, following aggregation of measurements to batch-level means of Size Index, 62% of the measured batches of tree stock fell outside of their specified range. Measured Size Index of large container trees (> 500 L) was generally smaller than the range specified in AS 2303 (Figure 1), largely due to the reduced height growth of trees with increasing container size.

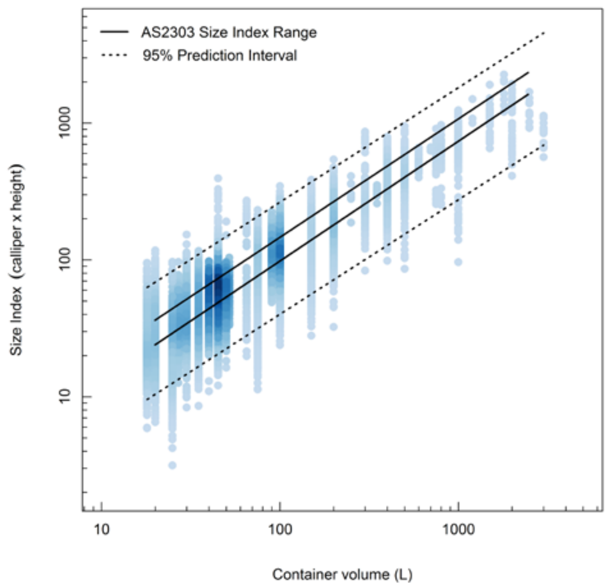

Figure 1. Aboveground Size Index in relation to a range of container sizes for trees measured across 23 Australian wholesale nurseries. Circles represent each of the 13,820 trees measured. Colors indicate local density (and overlap) of measurements (darker colours indicate more data). Solid lines represent the minimum and maximum acceptable range as specified in AS 2303. Dotted lines represent the 95% prediction interval based on the measured trees, which effectively include 95% of the data at a given container volume. Size index is calculated as calliper (mm) multiplied by tree height (m). Note that the axis scaling is logarithmic.

These measurements indicate that tree stock with otherwise standard-conforming morphological quality have a much greater variation in Size Index than specified in the current guidelines for tree stock balance. Consequently, this may indicate that the current guidelines are perhaps too general and thus overly restrictive in the context of observed variation in real-world tree production, potentially leading to buyer rejection of suitable tree stock. Alternatively, the observed variation may arise from quantifiable sources, such as species or production differences, that if taken into account may inform refined guidelines.

With this extensive database, we quantified sources of variation in tree Size Index. Overall, variation attributed to species, nursery site, climate, species origin (native vs. non-native) and tree functional type (evergreen vs. deciduous) combined to explain 43% of observed variation in standardized tree Size Index. Though variation attributed to species identity was large, species-specific differences in Size Index were also dependent on the nursery in which they were measured. Nursery effects could arise from differences in batch production history (e.g. age, irrigation, fertilization or container style) or other factors. Consequently, there is no robust way to create species-specific acceptable ranges of tree Size Index.

Aggregation of species into tree functional types of either evergreen or deciduous provided a useful categorization. Overall, Size Index values were higher in deciduous trees than evergreen trees (Figure 2). This effect was most pronounced in small to medium sized containers and less so in large container sizes. Importantly, both tree height and calliper were greater, on average, in deciduous trees than evergreen trees and this effect was consistent across all container volumes. Tree origin (native vs. non-native) had similar patterns as the tree type (evergreen vs. deciduous) classification as most measured Australian native trees were evergreen, and most deciduous species were non-native.

Thus, categorization of tree stock assessment criteria into deciduous and evergreen tree types may serve as a promising way forward to allocate the large inherent variation that is not accounted for in the current single guideline format of AS 2303. We speculate that growth rate differences could account for higher Size Index values in deciduous than evergreen species. For instance, faster height and diameter growth of deciduous than evergreen species could result in a higher Size Index values at a given container volume.

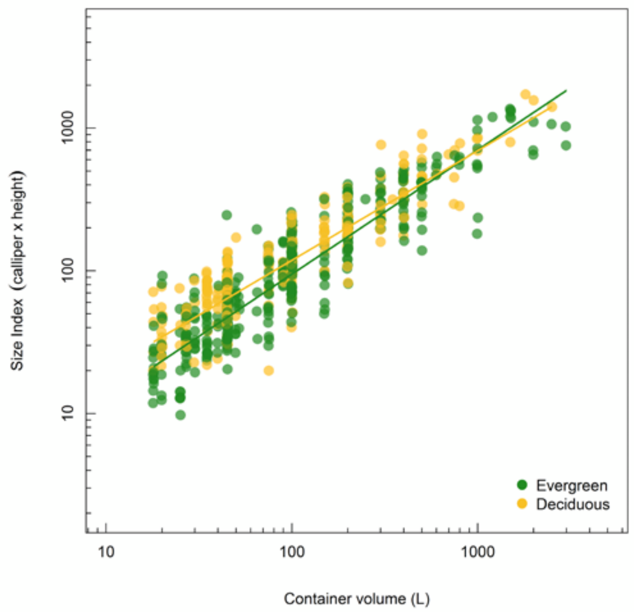

Figure 2. Differences between evergreen and deciduous tree types in measured aboveground Size Index across the range of container volumes. In contrast to Figure 1, data were averaged by tree stock batches (n = 650) for all 23 nurseries. Colored lines represent the log linear model fit for each tree type. Winter deciduous trees had higher Size Index values than evergreen trees, particularly over the lower range of container sizes.

Surprisingly, regional climate differences played only a minor role in the amount of measured variation in Size Index values. The effect of climate was assessed by both the region (i.e. state) in which tree stock was grown as well as mean annual temperature and precipitation for each specific nursery site. Neither mean annual precipitation nor mean annual temperature significantly affected measured Size Index values, despite large differences in these climatic variables among nursery sites.

AS 2303 suggests that nursery grown trees can be separated into simple stem form categories of tall-slender, general or thick stemmed (Appendix D in AS 2303). We tested whether or not slenderness categories varied depending on climate region or species and likewise determine where individual trees fit in the range of allowable Size Index values. In this study, tree slenderness was similar among climate regions and did not differ between evergreen and deciduous tree species groups. Our results suggest that use of tree stem slenderness to determine the acceptable range of Size Index has limited utility for Australian grown containerized trees.

Summary and Conclusions

As currently specified in AS 2303, the comparison of aboveground Size Index to container volume as the criterion for tree stock balance does not adequately describe existing natural variation in root to shoot balance of otherwise conforming Australian nursery tree stock ready for dispatch. A larger proportion of tree stock (45% of all measured trees), with sound above and belowground morphological quality, were below specified Size Index limits than were above (23% of all measured trees).

Specification of appropriate Size Index range values for large trees is of particular importance, owing to their comparatively high commercial value. Risk of failure is likely mitigated as a result of well-developed root systems in large container volumes. Given evidence of reduced height growth in large containers, a tailored Size Index range for large trees warrants further consideration.

In order to ensure that tree stock has not outgrown its container size, it is recommended that a maximum range of Size Index values be specified. If the specified range in the current version of AS 2303 is to be revised, the available database could be used to determine the upper range of Size Index values to include as a single generalised specification for all species or separation by species type into evergreen and deciduous (e.g. 75% prediction interval).

As expected, variation in Size Index values attributed to tree species was very large. As species-specific differences were also dependent on the nursery, it is recommended that either a broad categorization (e.g. evergreen or deciduous) or a single generalised specification for all species be used for assessing tree stock balance. Differences in evergreen and deciduous tree stock were widely detected in the height and calliper components used to calculate Size Index as well as canopy structural parameters. This suggests that different patterns in growth rates likely occur between these two broad categories in containerized Australian tree stock. This provides a viable alternative to redefine acceptable ranges of Size Index, using the available database, according to either an evergreen or deciduous category to better encompass variation across a large range of tree species.

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