Quantifying Structural Response in a Through-fall Drought Experiment Using Terrestrial Laser Scanning

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1. Introduction

Terrestrial ecosystems provide a very wide range of essential ecosystem services, but these services are under increased levels of stress due to climate change. An increase in global temperature is leading to more extreme events, such as forest fires and droughts. Drought is one of the most important potential threats to tropical forests, and can result in forest die-back, i.e catastrophic losses of forest cover and biomass. This illustrates the growing concern that terrestrial ecosystems (and tropical forests in particular) might not be able to maintain uptake of anthropogenic emissions at the current rate (Huntingford et al., 2013; Verbesselt et al., 2016).

Ecosystem structure and climate are closely-linked: changes in climate lead directly to physical changes in ecosystem structure and vice versa (Grimm et al., 2013). Different global change factors, such as fire, nutrient deposition and drought, could have an impact on forest structure. Feedbacks between canopy structure and seasonal droughts, for example, suggests that tree phenological and hydrological strategies are linked in tropical forests, which could determine which tree species will survive under shifting precipitation regimes (Smith et al., 2019). To improve our understanding of these mechanisms and ecosystem resilience, we require information of the fine-scale structural heterogeneity between individual trees, as well as forest structural differences at larger spatial scales. This will be key for effective forest management and to support climate mitigation actions appropriately (Houghton et al., 2009; Pan et al., 2011).

Drought experiments simulate drought conditions by excluding rainfall from a given zone, and local consequences on soil, tree or ecosystem functioning are monitored. These drought experiments bring highly valuable information on the mechanisms involved in the response of ecosystems to drought (Bonal et al., 2016). Inducing plot-level droughts is logistically and financially difficult, but it is important to operate at a relatively large scale because many adult trees have laterally extensive root systems (Laurance 2015).

Novel techniques using 3D laser scanning (LiDAR – Light Detection and Ranging) can provide us with a new way to estimate the structure of individual trees (Calders et al., 2015; Raumonen et al., 2013; Hackenberg et al., 2015). Terrestrial laser scanning (TLS) can measure the canopy structure in 3D with high detail, and several algorithms have recently been developed to produce full 3D models of trees down to fine (cm) scale. Terryn et al. (2020) calculated 17 different structural tree metrics in the context of tree species identification.

Within this study we explore the same structural metrics to determine if induced drought affects tropical tree structure on a time-span of 3 years using TLS.

2. Data and Methods

2.1 Study site

The Daintree drought experiment is a through-fall drought experiment which has been maintained continuously since 2015 in a lowland rainforest at the Daintree Rainforest Observatory near Cape Tribulation, in north Queensland, Australia (detailed in Laurance, 2015, Tng et al., 2018). The experiment comprises one 0.6 ha control plot with no drought infrastructure and a 0.4 ha drought plot. The site is characterised by a mean annual rainfall of 5143 mm/year and a mean temperature of 24.4°C.

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2.2 Laser scanning data collection

TLS data were collected in August 2018 (during the dry season) from the Daintree drought experiment plot (Figure 1). TLS was collected using a RIEGL VZ-400 terrestrial laser scanner (RIEGL LaserMeasurement Systems, Horn, Austria), which provides multiple returns for a single outgoing laser pulse. The control part of the plot was scanned in a 10 m by 10 m regular grid and at each scan location an additional scan was acquired with the instrument tilted at 90° from the vertical to sample a full hemisphere. The drought experiment part of the plot was scanned under the drought panels as well as a few scans in the gutters between the panels (Figure 1). Reflective targets were used to co-register all the scan locations to a single point cloud using RIEGL's RiSCAN PRO software package. The co-registration of the scan positions was further optimized with the Multi-Station Adjustment (MSA) algorithm, within the RiSCAN PRO software package. The MSA algorithm modifies the orientation and position of each scan in several iterations to calculate the best overall fit.

Figure 1 Illustration of the drought experiment and the RIEGL VZ-400 terrestrial laser scanner.

2.3 Expected tree structure quantification

Individual trees from the control as well as the experiment will be automatically extracted from TLS using a novel individual tree segmentation routine based on shortest-path calculations (Raumonen et al., 2021). Next, tree structure will be modelled through Quantitative Structural Models (QSM) built with *TreeQSM* (Raumonen et al., 2013). From these QSMs different structural tree metrics relating to branching structure and, crown and tree dimensions will be obtained (Terryn et al., 2020). The process from TLS point cloud to individual tree structural features is illustrated in Figure 2.

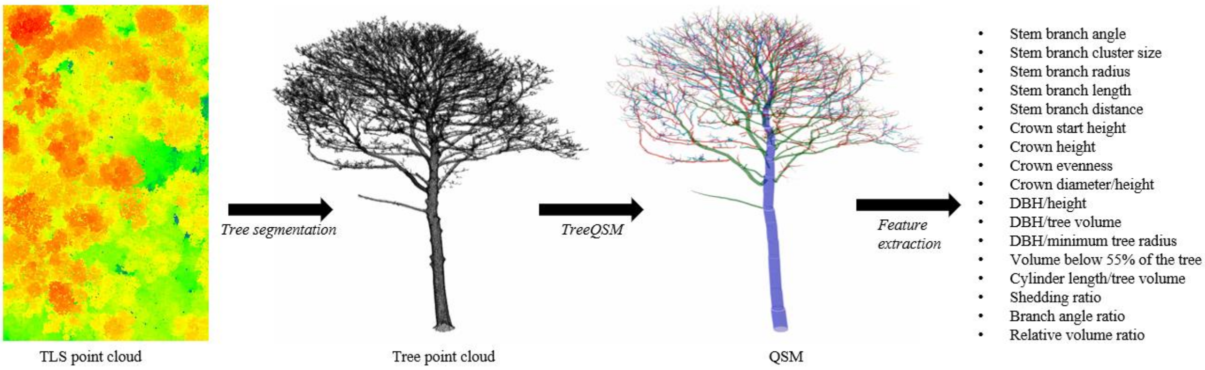

Figure 2 Illustration of the feature extraction process.

3. Expected outcomes

Tng et al. (2018) showed that species-specific systematic variation in hydraulic-related wood anatomy and leaf traits was a response to 24 months of drought stress in the Daintree drought experiment. They showed that relative to controls, drought-affected individuals variously exhibited trait measures consistent with increasing hydraulic safety (e.g. narrower or less vessels, reduced vessel groupings, lower theoretical water conductivities, less water storage tissue and more abundant fiber in their wood, and more occluded vessels) (Tng et al., 2018). These responses could in their turn result in changes in the 3D structure of the drought-affected trees. We expect that some structural traits might take longer to respond to stress, and some others (e.g. leaf and branching angles) to show responses.

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