Utilising airborne scanning laser (LiDAR) to improve the assessment of Australian native forest structure

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River Red Gum (E. *camaldulensis*) located on an island in the Murray river, NE Victoria.

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LIST OF ABBREVIATIONS

AIRSAR	Airborne Synthetic Aperture Radar
AGO	Australian Greenhouse Office
API	Aerial Photographic Interpretation
BA	Basal Area
CASI	Compact Airborne Spectral Imager
CC	Crown Cover
CFMF	Continental Forest Monitoring Framework
CHM	Canopy Height Model
CRCGA	Cooperative Research Centre for Greenhouse Accounting
D_{130}	Diameter of tree stem at 130 cm height above ground
DEM	Digital Elevation Model
DNRE	Department of Natural Resources and Environment (Victoria)
DPI	Department of Primary Industries (Queensland)
DSTO	Defence Science and Technology Organisation
DTM	Digital Terrain Model
EMC	Ecological Maturity Classification
FBC	Foliage-Branch Cover
FPC	Foliage Projective Cover
GIS	Geographic Information Systems
GPS	Global Positioning System
HSCOI	Height Scaled Crown Openness Index
ICESat	Ice, Cloud, and land Elevation Satellite
IBRA	Interim Biogeographical Regionalisation for Australia
JERS	Japanese Earth Resources Satellite
LiDAR	Light Detection And Ranging
MAUP	Modifiable Areal Unit Problem

MODIS______________MODerate-resolution Imaging Spectroradiometer

NFI _________________National Forest Inventory

NFPS________________National Forest Policy Statement

NLWRA_____________National Land and Water Resources Audit

NVIS________________National Vegetation Information System

PSU_________________Primary Sampling Unit

QDNRM_____________Queensland Department of Natural Resources and Mines

RSE ________________Residual Standard Error

RWG2 ______________Research Working Group 2

δ____________________Standard Deviation

SAR_________________Synthetic Aperture Radar

SFRI________________Statewide Forest Resource Inventory (Victoria)

SLATS______________Statewide Landcover And Trees Study (Queensland)

SLR ________________Single Lens Reflex (camera)

SPOT________________Satellite Pour l'Observation de la Terre

SOFR________________State of the Forests Report

SSU_________________Secondary Sampling Unit

TIN _________________Triangulated Irregular Network

TM / ETM___________Thematic Mapper / Enhanced Thematic Mapper

UTM________________Universal Transverse Mercator

CERTIFICATE OF AUTHORSHIP

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent was accepted for the award of any other degree or diploma at the Australian National University or any other educational institution, except where due acknowledgement is made in the thesis. Any contribution made to the research by colleagues with whom I have worked at the Australian National University or elsewhere during my candidature is fully acknowledged.

Alex Lee Date:

PREFACE

Parts of the description of the Injune study area in Chapter 3 of this thesis was published in:

Tickle, P. K., Lee, A., Lucas, R. M., Austin, J. and Witte, C. (2006) Quantifying Australian forest floristics and structure using small footprint LiDAR and large scale aerial photography. *Forest Ecology and Management,* 223, 379-394.

Description of the Height Scaled Crown Openness Index (HSCOI) in Chapter 3, 4, and 5 was published in:

Lee, A. C. and Lucas, R. M. (2007) A LiDAR-derived Canopy Density Model for Tree Stem and Crown Mapping in Australian Forests. *Remote Sensing of Environment*, 111, 493-518.

Description and discussion of the LiDAR modelling for stand reconstruction for SAR simulation was published in:

Lucas, R. M., Lee, A. C. and Williams, M. L. (2006) Enhancing SAR simulations using LiDAR for understanding the relations between forest structure and SAR imagery. *IEEE Transactions on Geoscience and Remote Sensing*, 44, 2736-2754.

In Tickle *et al.,* (2006) and Lucas *et al.,* (2006) all LiDAR related processing and discussion was undertaken by me.

Appendix 3 provides a more detailed description of author contributions to the above papers.

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ABSTRACT

Enhanced understanding of forest stocks and dynamics can be gained through improved forest measurement, which is required to assist with sustainable forest management decisions, meet Australian and international reporting needs, and improve research efforts to better respond to a changing climate. Integrated sampling schemes that utilise a multi-scale approach, with a range of data sourced from both field and remote sensing, have been identified as a way to generate the required forest information. Given the multi-scale approach proposed by these schemes, it is important to understand how scale potentially affects the interpretation and reporting of forest from a range of data.

To provide improved forest assessment at a range of scales, this research has developed a strategy for facilitating tree and stand level retrieval of structural attributes within an integrated multi-scale analysis framework. The research investigated the use of fine-scale (~1m) airborne Light Detection and Ranging (LiDAR) data (1,125 ha in central Queensland, and 60,000 ha in NE Victoria) to calibrate other remotely sensed data at the two study sites. The strategy refines forest structure mapping through three-dimensional (3D) modelling combined with empirical relationships, allowing improved estimation of maximum and predominant height, as well as foliage and crown cover at multiple scales. Tree stems (including those in the sub-canopy) were located using a height scaled crown openness index (HSCOI), which integrated the 3D density of canopy elements within the vertical profile into a two-dimensional spatial layer. The HSCOI modelling also facilitated the reconstruction of the 3D distribution of foliage and branches (of varying size and orientation) within the forest volume.

Comparisons between forests at the Queensland and NE Victorian study sites indicated that accurate and consistent retrieval of cover and height metrics could be achieved at multiple scales, with the algorithms applicable for semi-automated use in other forests with similar structure. This information has facilitated interpretation and evaluation of Landsat imagery and ICESat satellite laser data for forest height and canopy cover retrieval. The development of a

forest cover translation matrix allows a range of data and metrics to be compared at the plot scale, and has initiated the development of continuous transfer functions between the metrics and datasets. These data have been used subsequently to support interpretation of SAR data, by providing valuable input to 2D and 3D radar simulation models. Scale effects have been identified as being significant enough to influence national forest class reporting in more heterogeneous forests, thus allowing the most appropriate use and integration of remote sensed data at a range of scales. An empirically based forest minimum mapping area of 1 ha for reporting is suggested. The research has concluded that LiDAR can provide calibration information just as detailed and possibly more accurately than field measurements for many required forest attributes. Therefore the use of LiDAR data offers a unique opportunity to bridge the gap between accurate field plot structural information and stand to landscape scale sampling, to provide enhanced forest assessment in Australia.