bnhcrc.com.au

bushfire&natural HAZARDSCRC

A LIDAR-DERIVED FUEL MAP FOR THE ACT

Non-peer reviewed research proceedings from the Bushfire and Natural Hazards CRC & AFAC conference
Perth, 5 – 8 September 2018

Adam Leavesley[1,2], Albert Van Dijk[2,3] and Marta Yebra[2,3]
[1] Parks and Conservation Service of the Australian Capital Territory
[2] Bushfire and Natural Hazards CRC
[3] Fenner School of Environment and Society, Australian National University
Corresponding author: Adam.Leavesley@act.gov.au

Version	Release history	Date
1.0	Initial release of document	05/09/2018

Publisher:
Bushfire and Natural Hazards CRC

September 2018

TABLE OF CONTENTS

ABSTRACT

A LIDAR-DERIVED FUEL MAP FOR THE WHOLE ACT

Many Australian fire managers rely on fuel maps derived from vegetation classifications and time-since-fire via an accumulation curve (e.g. Phoenix Rapidfire). However fuel maps derived using this method lack potentially critical information about pockets of high and low fuel loads. This is important because a poor understanding of fuels was found to be a critical factor in investigations of both the Margaret River and Lancefield prescribed burn escapes. A potential solution for this problem is the use of LiDAR to create spatially-explicit fuel information.

A LiDAR dataset covering the whole of the ACT was flown over a number of months in 2015-16 using the LAS 1.4 format. The density of returns was 8ppm over the urban area and 4ppm over the remainder of the territory including a large alpine national park that covers 45 percent of the ACT. Bushfire & Natural Hazards Cooperative Research Centre (BNHCRC) research partners arranged for the dataset to be included in feasibility analyses conducted by the Terrestrial Ecology Research Network (TERN) AusCover Landscape Observatory project. A number of fuel-related layers were created based on the Overall Fuel Hazard Assessment (OFHA) and inputs to Project Vesta.

The fuel layers were created at resolutions of 1m, 2m, 5m and 25m in the NetCDF file format. The 25m data were selected for initial assessment because these were the only whole-of-territory datasets easily manipulated in ArcGIS 10. Qualitative assessments indicate: 1) a discernible pattern of fuel variation related to topography; 2) good agreement between LiDAR-derived elevated and near-surface fuel layers and OFHA data collected during the LiDAR acquisition; and 3) good agreement between the LiDAR and fire severity assessments made on burns that were conducted a short time before the acquisition. The next step is to conduct quantitative assessments.

GLOSSARY

ANU	Australian National University
ANZLIC	Australia and New Zealand Land Information Council
DEM	Digital Elevation Model; a representation of the earth's surface.
FIREMON	A fire severity method based on the Normalised Burn Ratio (NBR) developed by the United States Forest Service.
ICSM	Intergovernmental Committee on Surveying and Mapping; ICSM levels are defined as: 0) = undefined, unclassified; 1) = Automated or semi-automated classification; 2) = ground surface improvement; 3) = ground correction; 4) = detailed classification and correction.
LAS	Laser file format; a public file format for exchange of 3-dimensional point cloud data. Version 1.4 was released in November 2011.
LiDAR	Light Detection and Ranging; an active remote sensing method which uses light from a pulsed laser to measure distance to the earth.
NBR	Normalised Burn Ratio: a method for estimating fire severity using a combination of near-infrared (NIR) and shortwave infrared (SWIR) wavelengths.
NEDF	National Elevation Data Framework; an Australian cross-sectoral initiative to advance the availability of digital elevation data
NetCDF	Network Common Data Form; a set of software libraries and self-describing, machine-independent data formats that support the creation, access, and sharing of array-oriented scientific data
TERN	Terrestrial Ecology Research Network; Australia's land ecosystem observatory tasked with producing standardized, integrated, model-ready data for detecting and interpreting land ecosystem change
ppm	pulses per metre^2

INTRODUCTION

The Australian bushfire sector predominantly characterises forest fuel for operational purposes in terms of vegetation type and time-since-fire (eg Phoenix RapidFire). This reflects what is usually known about Australian forests and woodlands - the dominant tree species, what is known about how fuel load and structure varies with time-since-fire and the historical necessity for data to be collected by humans at a human scale and extrapolated to larger scales. Fuel information derived in this way does not provide spatially explicit information about pockets of high or low fuel. Instead the variation is encompassed in a statistical format (eg standard deviation) which is not spatially explicit and hence less useful for operations.

The advent of remote sensing removes the need to collect data at a human scale and can deliver spatially-explicit information. However early investigation of the utilisation potential of remote sensing for assessing forest fuels in Australia identified shortcomings compared to the information that was collected at a human scale and the models that used that information. For example, the FIREMON Normalised Burn Ratio (NBR) procedure for estimating fire effects (Key and Benson, 2006) varies depending on the amount of unburnt overstorey vegetation, so that the same numeric value can represent a range of fire effects depending on the ratio of burnt to unburnt vegetation (De Santis and Chivieco, 2009). Similarly, LiDAR cannot easily assess the surface litter or bark components of the fuel array nor separately identify the dead component of the near-surface, elevated and canopy fuels. Bushfire managers appear to have focused on the shortcomings of the technology and as a result there has been relatively little uptake of remote-sensing for gathering fuel information, but see Lhuede et al. (2017).

Improved knowledge of fuels is important for at least two reasons. Poor spatial information of fuels was found to be a critical factor in investigations of both the Margaret River (Keelty, 2012) and Lancefield (Carter et al. 2015) prescribed burn escapes. Improved knowledge of fuels also has the potential to reduce the amount of unpredictable fire behavior especially during elevated fire danger, to which variation in spatial arrangement of fuel may have contributed.

In this paper we present some experimental forest fuel mapping of the Australian Capital Territory derived from LiDAR. We summarise the specifications of the data acquisition and processing methods and provide a qualitative accuracy assessment. We also describe the findings of an operational trial.

METHODS

DATA CAPTURE AND PREPROCESSING

A project to capture LiDAR over the whole of the ACT, Queanbeyan and Googong Dam, a project area of 3272km^2 was implemented under contract by the ACT Government during 2015 and 2016 (RPS – MAPPING, 2016; Figure 1). Most of the data were acquired between 18 May and 29 July 2015. But completion of the full dataset was delayed to 2016 due to airspace restriction over the Canberra Deep Space Communication Complex.

The data were captured using a Trimble AX60 system which coupled a Riegl LMS-Q780 scanning instrument with a Trimble AP50 GPS. The nominal density was four outgoing laser pulses per square metre across the greater ACT region and eight pulses per square meter over Canberra's urban area (Figure 2). The average pulse density across the project area was 7.9ppm and estimated vertical accuracy was 0.20m.

Processing by the contractor included production of classified LAS 2km x 2km tiles to ICSM (see Glossary) specifications. Metadata were produced to comply with Australian standards (ANZLIC and NEDF specifications; see Glossary). The point cloud was used to create a ground classification to ICSM level 3. Automated algorithms were then used to classify the remaining points to: 1) low vegetation; 2) medium vegetation; 3) high vegetation; 4) buildings; and 5) water. Further processing improved the buildings classification to ICSM level 3. The other products remained ICSM level 1.

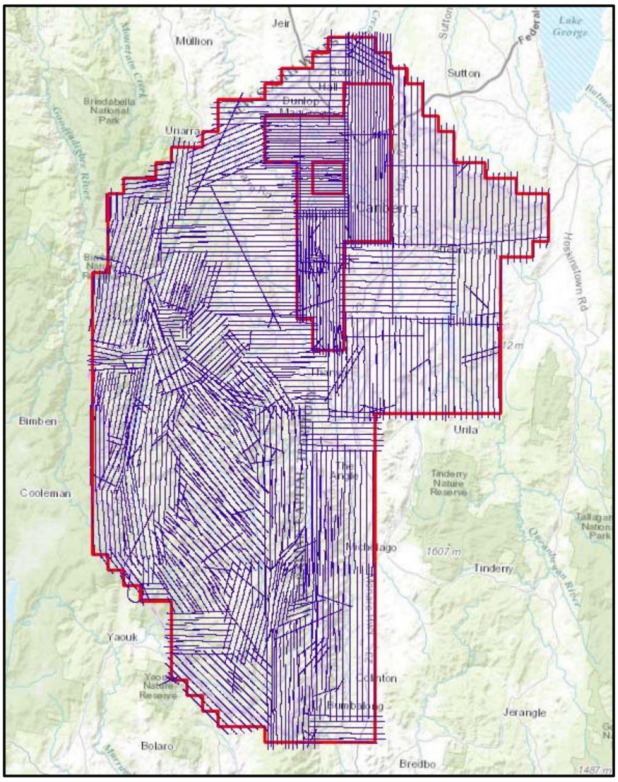

Figure 1. Flight trajectories for LiDAR acquisition.

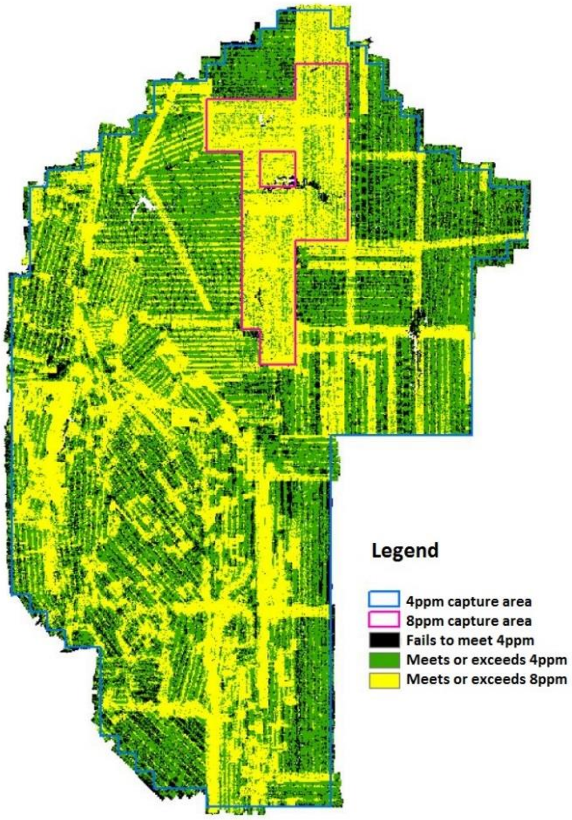

Figure 2. Density assessment of first return pulses.

PROCESSING FOR VEGETATION STRUCTURE

The TERN AusCover facility engaged the Australian National University (ANU) to conduct a feasibility analysis and production of some LiDAR-derived products from preprocessed airborne LiDAR (Van Dijk, 2017). The contract was executed in collaboration with the University of Queensland, Royal Melbourne Institute of Technology and CSIRO. The aim of the project was to: 1) develop products that could be used relatively easily by ecosystem managers, researchers and other stakeholders; and 2) develop a prototype data specification and processing methodology for consultation and review. ACT Parks bushfire managers requested evaluation of inputs to the Overall Fuel Hazard Assessment (Hines, 2010) and to this were added inputs to Project Vesta (Gould et al. 2007).

The ANU project produced 14 experimental LiDAR products. Three products, the digital elevation model, fraction building footprint and fraction water surface were essentially unchanged from the work conducted by the ACT Government contractor. To this were added six products analogous to inputs to the Overall Fuel Hazard Assessment version 4 (Table 1) and Project Vesta. A further five products were developed that characterise vegetation structure in other ways. All products were delivered at four resolutions: 1m (in the 8ppm capture area), 2m (in the 4ppm capture area), 5m and 25m in the NetCDF format. The 1m and 2m data were stored as tiles, while the 5m and 25m data were stored as single territory-wide files.

A key bushfire behavior input that was not feasible from LiDAR was an analog of the surface litter fuel hazard. In principle, this could be obtained from the intensity and spread of ground and near-surface LiDAR returns. In practice, the vertical error

(0.20m) was too great to reliably perform this analysis. It was also noted that information about vegetation on the ground was more easily obtained from optical imagery. Other products relevant to bushfire management that could not be easily derived from LiDAR were: 1) standing volume or biomass which could be useful for determining fuel load; 2) species mapping which could assist with prediction of bark hazard; 3) coarse woody debris which could not be reliably distinguished from the near-surface fuels. These products are likely to be possible in principle but require considerably more research and are unlikely to work satisfactorily in all conditions.

Table 1. Products derived from LiDAR for a variety of fire management, land management and ecological research purposes.

Product description	Use	Notes
Canopy top height	Overall fuel hazard assessment	Height of vegetation >2m.
Canopy base height	Overall fuel hazard assessment	The 10% quantile of returns from height >2m.
Leaf cover fraction – elevated fuel	Overall fuel hazard assessment/Vesta	An estimate of the cover fraction from height 0.5m – 2m
Leaf cover fraction – near surface fuel	Overall fuel hazard assessment/Vesta	An estimate of the cover fraction from height 0.05m – 0.5m
Leaf cover fraction – overstorey	Vesta	An estimate of the cover fraction of the top canopy
Leaf cover fraction – understorey	Vesta	An estimate of the cover fraction of the intermediate canopy
Canopy layer index	Experimental surrogate for leaf area index	
Leaf cover fraction – canopy fuel	Vegetation structure, habitat assessment, carbon accounting	An estimate of the cover fraction >2m in height
Leaf cover fraction – herbaceous layer	Vegetation structure, habitat assessment, carbon accounting	An estimate of the cover fraction from height 0.05m – 1m
Vegetation cover fraction	Vegetation structure, habitat assessment, carbon accounting	An estimate of the cover fraction derived from first returns not originating from the ground
Vegetation height	Vegetation structure, habitat assessment, carbon accounting	Height of vegetation

RESULTS

The experimental LiDAR-derived bushfire products were reviewed by ACT Parks and trialed during the 2018 autumn burn program.

DATA MANAGEMENT

Territory-wide NetCDF files at 5m resolution had file sizes in the order of 300MB (extent ~3,300km^2). The equivalent information at 25m resolution was in the order of 15MB. The 25m resolution was easier to use in ArcGIS 10 and was therefore selected for further review and trial.

QUALITATIVE ACCURACY ASSESSMENT

The LiDAR capture commenced within a month of the Cotter River burn which was ignited on 30 March 2015 and escaped containment on 1 April generating a broad range of fire severity effects from unburnt, to full canopy consumption. A detailed fire severity analysis was conducted following the FIREMON Normalised Burn Ratio (NBR; Key and Benson, 2006) procedure using data from Landsat 8 (Leavesley et al. 2015). Ground-truthing of the NBR returned an overall accuracy of 81 percent and showed strong effects of fire on vegetation structure (Figure 3). For a more detailed account of the fire severity assessment of the Cotter River burn see Leavesley et al. (2015). Careful comparison of the fire severity map and the LiDAR-derived elevated fuel cover map, showed good agreement (Figure 4).

PRESCRIBED BURN PLANNING AND EXECUTION

An important use for spatially explicit fuel maps is prescribed burn planning and execution. Delivery of the experimental LiDAR-derived fuel maps was too late for burn planning for the autumn 2018 season, however it was available to the Incident Management Team to assist with operations. The fuel maps showed considerable variation in near-surface and elevated fuels that was not explained by vegetation type or time-since-fire (Figure 5). This supported the conclusions of previous work in the ACT which compared Overall Fuel Hazard Assessments with modelled estimates (Leavesley et al. 2016). The burn could not be contained along the planned soft containment line on the western edge but was kept within the contingency containment lines (Figure 6). The final extent coincided with the extent of dense elevated fuels (Figures 6-7).

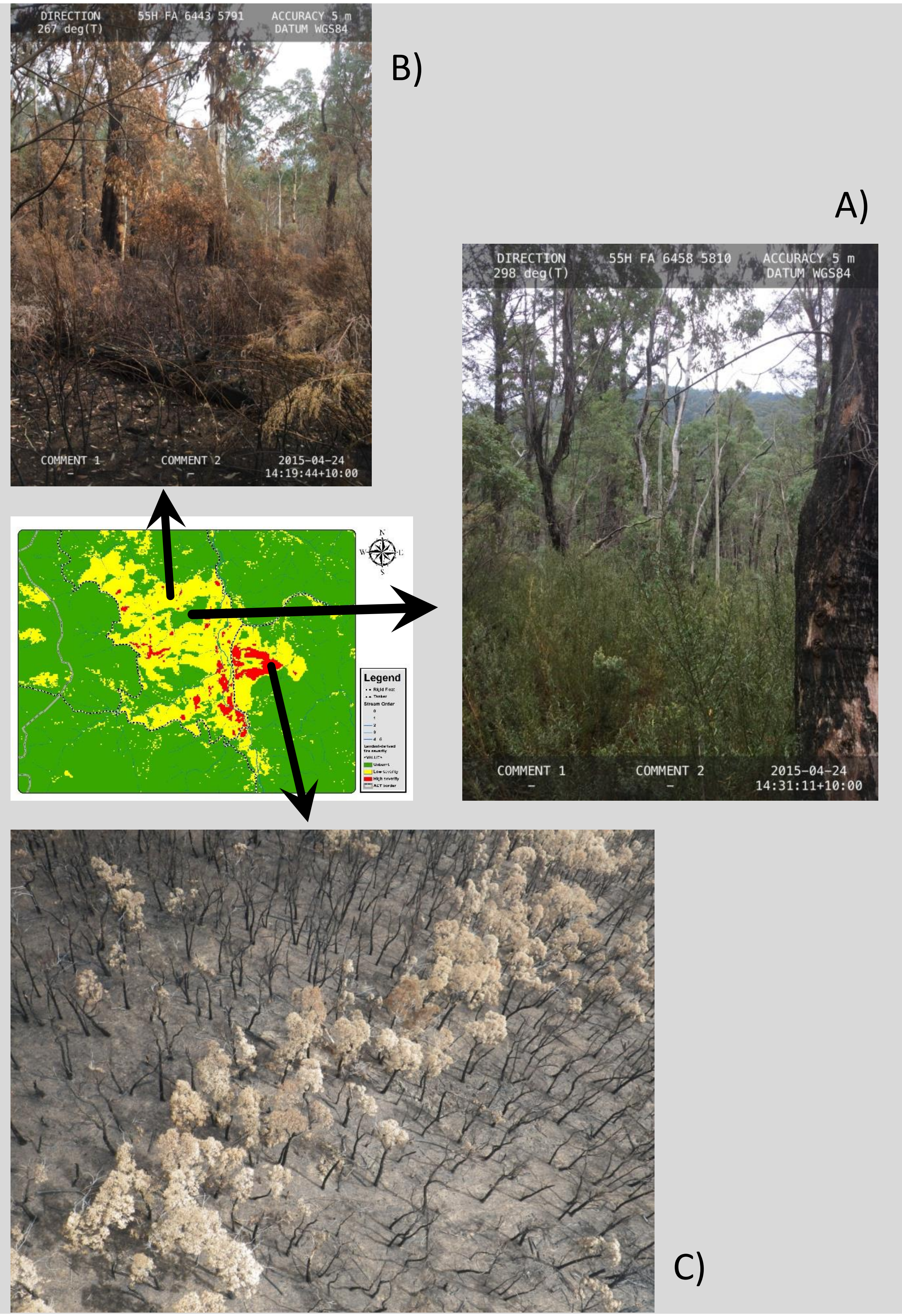

Figure 3. Photographs representing the fire severity classes identified in the NBR; A) = unburnt, B) = low severity and C) = high severity.

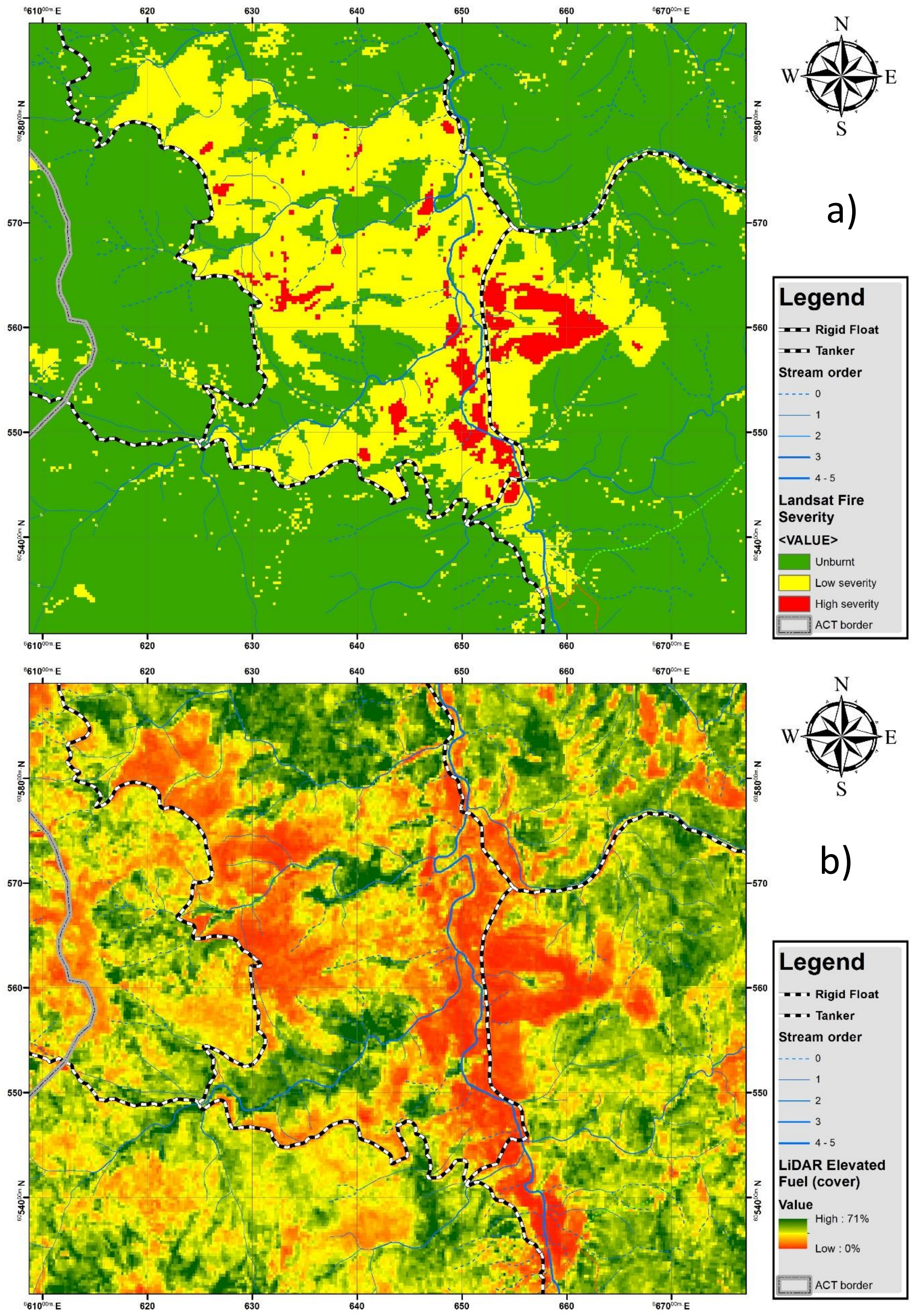

Figure 4. Comparison of the fire severity analysis (a) and LiDAR-derived elevated fuel map (b) showed good agreement.

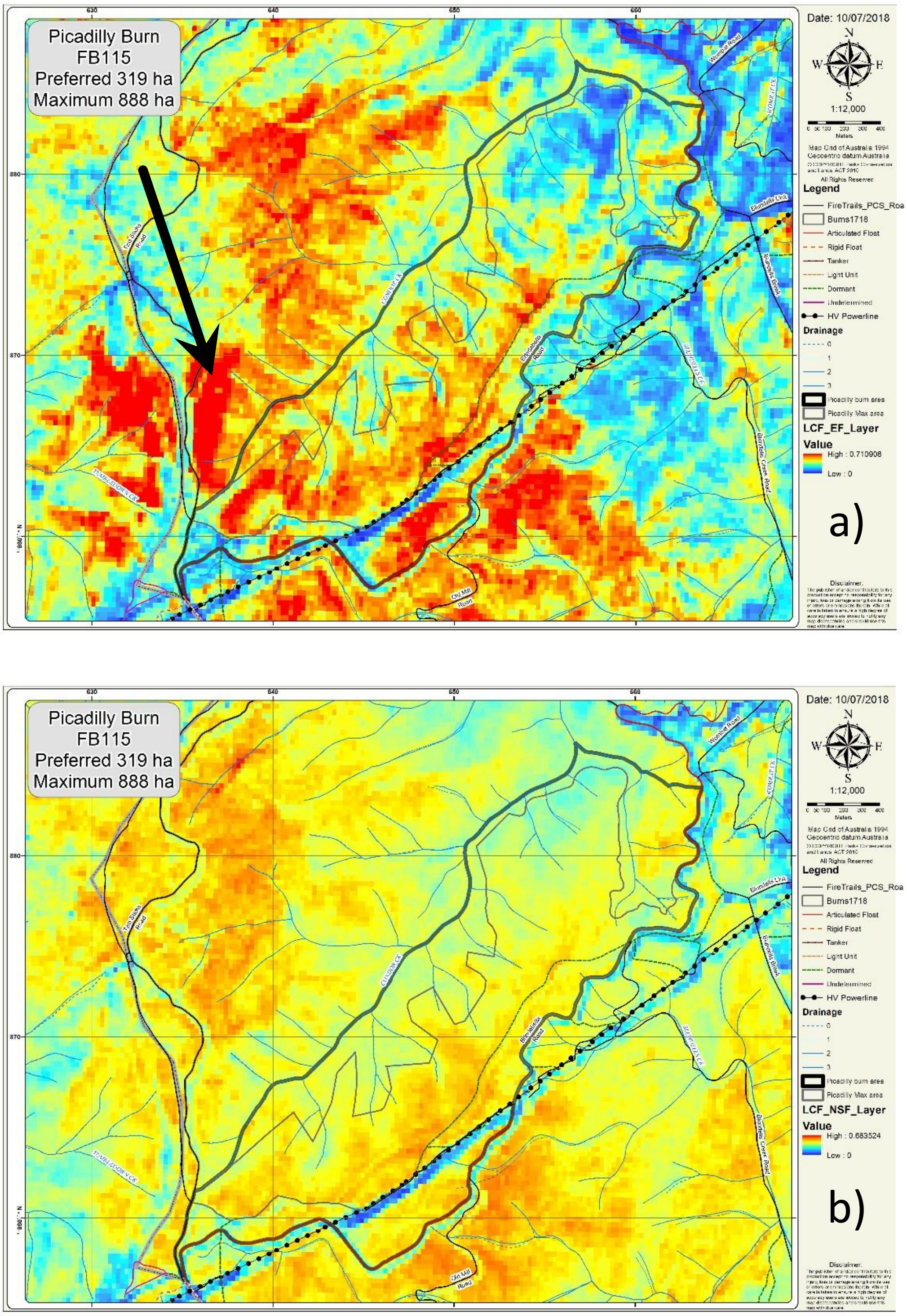

Figure 5. Experimental LiDAR-derived fuel maps for the Piccadilly burn: a = elevated fuel; b = near-surface fuel. The distribution of fuel varied considerably across the fire ground, particularly the elevated fuel. Note the dense patch of elevated fuels adjacent to the soft containment line on the western end; indicated by arrow.

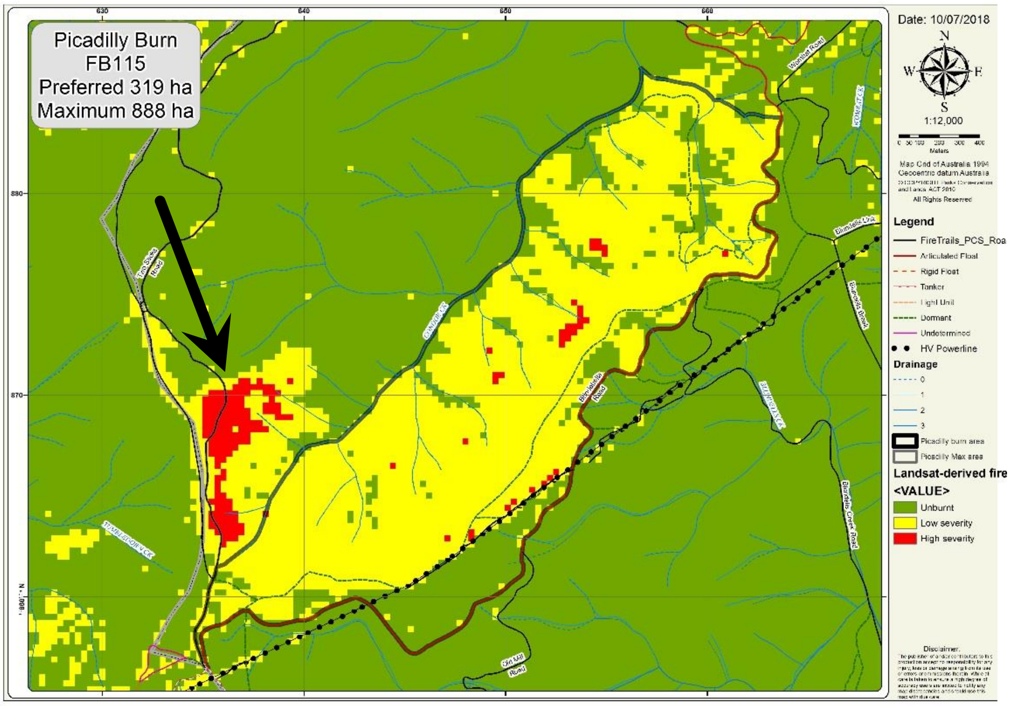

Figure 6. Fire severity analysis of the Piccadilly burn inserted into a template of the Piccadilly burn maps to aid comparison with figure 5. The burn could not be contained along the planned soft containment line at the south-western end. The final extent coincided with the extent of dense elevated fuels, indicated by arrow.

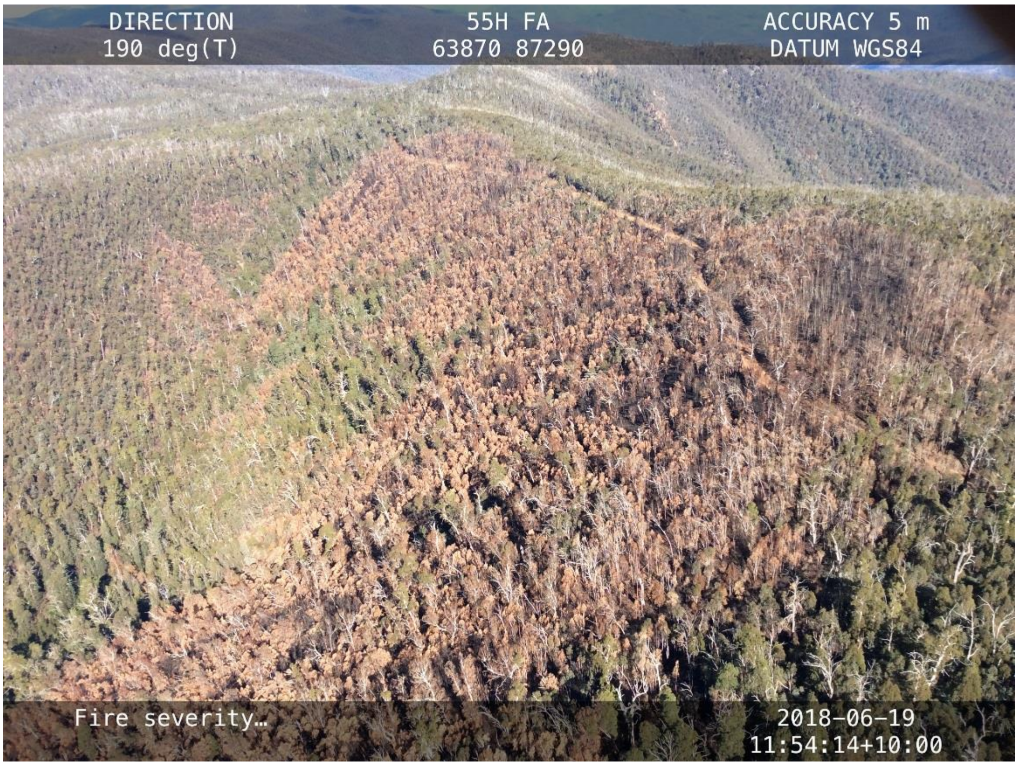

Figure 7. Looking south along the western edge of the Piccadilly burn at a large patch of high fire severity burning coincidental with dense elevated fuels (see figure 5). The burn was contained on the obvious fire trail and a dormant trail on the spur top.

DISCUSSION

The use of LiDAR collected at 8ppm and 4ppm for fuel mapping was found to be feasible for all the strata of forest and woodland except for the surface litter (Van Dijk, 2017). In principle it is possible to derive some of this information from LiDAR but it requires a greater vertical accuracy than achieved during LiDAR data acquisition. Excluding the surface litter layer, the height classes for which vegetation cover can be estimated are easily varied.

A qualitative accuracy assessment of the LiDAR-derived fuel maps of elevated and near-surface fuels delivered promising results. The LiDAR appeared to agree well with a coinciding fire severity assessment that achieved an overall accuracy of 81 percent (Leavesley et al. 2015). The next step in this project is to conduct a quantitative accuracy assessment. Datasets that can be applied are: 1) the ground-truth data from the Cotter River burn; and 2) the annual fuel monitoring OFHA data (Hines et al. 2010.

An operational trial of the LiDAR-derived fuel maps for command of prescribed burning operations met with excellent feedback from Divisional Commanders and Incident Management Team staff. Fuel maps assisted understanding of unexpected fire behavior at the Piccadilly burn and allowed field commanders to focus resources at points where the maps showed fuel density was greater. Burn planning staff were unable to use the maps for their role in operations, but the feedback was that it could potentially lead to operational changes at the planning level.

The fuel maps used during the 2018 autumn burning season were derived from LiDAR which was acquired in 2015. Nonetheless, the pattern of elevated fuel across the landscape appeared to reflect reality. This raises the possibility that a LiDAR forest fuel map can be confidently used for prescribed burn planning without major adjustment for years after acquisition. This is important because if correct, it would reduce the rate of depreciation of the investment considerably.

An intermediate step in the transition to spatially-explicit fuel maps is the production of hybrid, fuel curve-derived maps combined with LiDAR-derived maps to deliver the best possible representation of fuel at any given point in the landscape. For example, if Phoenix Rapidfire could accept raster data, then it could potentially be run with surface litter and bark fuel maps derived from a fuel curve and with near-surface and elevated fuel derived from LiDAR.

The present focus with remote-sensing data is to produce analogues of inputs for existing fire models that were developed for inputs that were readily available from human-scale visual field assessment. In our opinions this is only an intermediate step necessitated by existing systems and understanding. We are essentially retrofitting a method designed for visual field assessment to work with a more modern data acquisition method that has different strengths (eg spatially explicit) and weaknesses (eg cannot estimate surface litter or bark fuels). As remote-sensing expertise improves and if confidence in the technology within the bushfire sector is achieved, a more logical approach is to develop robust fire behavior models using parameters easily derived from remote sensing. The irony here is that the task of retrofitting LiDAR data to MacArthur or Project Vesta, is an endeavor potentially more difficult and ultimately of less use than developing a new remote-sensing enabled technique. We pose the question: "What is holding back development of remote-sensing enabled bushfire behaviour techniques?"

CONCLUSION

1) LiDAR data are generally suitable for bushfire fuel mapping except for: a) the surface litter which to achieve requires a level of vertical accuracy which is challenging; and b) bark.
2) Ground vegetation is more easily characterised using optical imagery than LiDAR.
3) The height classes for which vegetation cover is estimated can be easily varied.
4) Low frequency collection of LiDAR data is useful for bushfire management for pin-pointing areas of high and low fuel loads. This is likely to be especially useful to prescribed burn planners.
5) If LiDAR becomes cost effective at higher frequency, it has good potential for chararacterising changes in fuel load, carbon stocks and post-burn changes to water quality and quantity.
6) A number of other uses for LiDAR were investigated such as delineation of tree crowns, estimation of standing volume or biomass, species identification and detection of coarse fuels (woody debris) but these uses require development of specific models or more detailed understanding of the study site.
7) The development of remote-sensing methods to collect parameters developed for human-scale data collection methods may ultimately be a dead-end in the transition to remote-sensing enabled techniques. Such systems could be designed to use parameters easily derived from remote sensing to drive robust fire behavior models.

ACKNOWLEDGEMENTS

Andreia Siqueira, John Lee, Bethany Dunne, Norman Mueller, Ryan Lawrey, Mick Ivill, Mark Beech and Matt O'Brien provided valuable input to the ACT Parks fire severity program. ACT Parks fire crews skillfully implemented the Cotter River burn and collected the ground-truthing data. Kristy Van Putten supervised the acquisition of LiDAR for the ACT Government and RPS Mapping conducted the collection. The Terrestrial Ecology Research Network funded processing of the data which was undertaken by CSIRO Centre for Earth Observation. Jen Smits provided advice on the use of LiDAR products in ArcGIS.

REFERENCES

Carter, M., Howard, T., Haylock, K., Philpotts, V. and Richards, J. 2015b, *Lancefield-Cobaw Fire Investigation: Issues not within the terms of reference*, Department of Environment, Land, Water and Planning, Melbourne.

De Santis and Chuvieco (2009) GeoCBI: A modified version of the Composite Burn Index. Remote Sensing of Environment 113: 554-562.

Gould, J. S., W. McCaw, N. Cheney, P. Ellis & S. Matthews. 2007. *Field guide: fuel assessment and fire behaviour* 743 *prediction in dry eucalypt forest*. Commonwealth Scientific and Industrial Research Organization (CSIRO).

Hines F, Tolhurst KG, Wilson, AAG, McCarthy, GJ. 2010 Overall fuel hazard assessment guide, 4th edition. Fire and adaptive management, report no. 82. Department of Sustainability and Environment, Melbourne.

Keelty, M.J. 2012, *Appreciating the Risk: Report of the Special Inquiry into the November 2011 Margaret River Bushfire*, Government of Western Australia, Perth.

Key and Benson (2006) FIREMON: Fire effects monitoring and inventory system. General Technical Report RMRS-GTR-164-CD. Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station.

Leavesley AJ, Siqueira, A, Lee, JW, Dunne, B, Mueller, N. 2015 Assessing planned burn severity in forest and woodland using Landsat 8 Operational Land Imager (OLI). Proceedings of the AFAC/BNHCRC conference, Adelaide, 1-3 September.

Leavesley AJ, Kenny B, Dunne, B, Cooper, N. 2016. A comparison of observed and modelled estimates of bushfire fuel hazard in the ACT. Proceedings of the AFAC/BNHCRC conference, Brisbane, 30 August - 1 September.

Lhuede, N. Sandin, E. Willis, N. (2017) Applying location based analytics and LiDAR to model Bushfire Attack levels. Proceedings of the BNHCRC/AFAC Conference, Sydney, 4-7 September.

RPS – Mapping 2016 Final report: Acquisition of LiDAR and Imagery for the Australian Capital Territory. Brisbane, Queensland.

Van Dijk A. 2017 Feasibility analysis: Deriving products for TERN AusCover sites from preprocessed airborne and ground data, TERN AusCover. Consultation Report – Not for Publication.