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USING PRE- AND POST-FIRE LIDAR ASSESS THE SEVERITY OF THE 2019 TASMANIAN BUSHFIRES

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Cover: Field work in progress. Source: James Furlaud

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ABSTRACT

In January 2019, over 64,000 ha of bushland burned in the Riveaux Road fire in Tasmania's southern forests. Most of area burned occurred in tall wet eucalypt forest. These forests are considered to be highly flammable in dry conditions, but fires are infrequent due to the generally cool, wet climate in which they grow. As a result, limited data exists on the behaviour and effects of wildfire in these forests. Prior to these fires, extensive areas of these southern forests have been studied in-depth. In 2014, a large area of the forests that burned were mapped with aerial LiDAR, a remote-sensing technology that can characterise three-dimensional forest structure. Further, in 2016, detailed field-based measurements of fuel load, structure, and hazard were taken at 12 permanent plots which subsequently burned in 2019. Hence, the 2019 fires in Tasmania represent a globally-rare opportunity to characterise the severity of a large wildfire using pre-fire and post-fire data. In October 2019, the Department of Primary Industries, Parks, Water and Environment (DPIPWE) in Tasmania, along with five other BNHCRC end-users and the University of Tasmania, launched a project to use remote-sensing and field-based data to create a detailed case study of the 2019 Riveaux Rd. Fire, and to untangle the drivers of fire severity in tall wet eucalypt forests. To do this we (i) remeasured plots to assess tree mortality and changes in fuel loads post fire; (ii) acquired LiDAR data from a transect across a burned buttongrass-forest boundary on the Weld River enabling comparison with pre-fire LiDAR data; (iii) established baseline postfire LiDAR buttongrass-forest boundary transect on the Huon River at Blakes Opening. Here we describe the data sets and report some preliminary analyses.

END-USER STATEMENT

Steve Leonard, *Department of Primary Industries, Parks, Water and Environment, TAS*

Improved understanding of fire severity and ecosystem recovery is fundamental for assessing fire impacts and planning post-fire environmental management and recovery works. The use of LiDAR to assess fire severity is potentially a major advance on current severity mapping techniques, as LiDAR can 'see' below the forest canopy. In addition, the high resolution, landscape scale data on fire induced changes to vegetation structure and recovery, which is logistically unfeasible using traditional survey techniques. The fact that the Riveaux Road fire occurred over an area for which we have a rich array of long-term ecological data presented a rare opportunity to examine fire effects in eucalypt forest. This project has generated new insights including demonstrating the potential of LiDAR to provide detailed data on fire impacts and post-fire vegetation recovery and fuel accumulation. These insights will inform future fire management in eucalypt forest and related ecosystems.

BACKGROUND

THE RIVEAUX ROAD FIRE

The Riveaux Road Fire in started on 15 January 2019 and burned 63,769 ha over the course of roughly one month. In the lead up to this fire, Tasmania had experienced its driest January since 1939, and parts of southern Tasmania experienced their driest January on record. The fire burned through forest dominated by *Eucalyptus regnans* and *E. obliqua* with both rainforest and broadleaf understoreys. The area burnt included a number of important research sites, described below. The period in the second half of January, during which most of these research areas burned, was marked by extremely variable fire weather, with daily maximum FFDI varying between 10 and 40. The fire itself was marked by a high level of variation in fire severity, with patchy crown fires and extensive areas of only surface fires.

These fires presented us with an excellent opportunity to obtain pre- and post-fire LiDAR estimates of fuel load and structure both directly before and after a mixed-severity fire. Not only would such measurements provide an estimate of how much fuel is consumed in planned burns, but such fuels data could be used to validate fire behaviour models, whose utility in these forests is poorly understood. Further, we can link fine-scale measurements of fire severity (which are regularly collected post-fire) to precise estimates of foliar damage, allowing for wider-scale assessments of fire severity. This information, when associated with fuels data from directly before the fire will allow us to untangle the effect of fuels on fire severity in a forest type where flammability is poorly understood.

Lastly, it will provide baseline fuel loads directly after a fire. This is valuable as fire behaviour models predict fuel accumulation as a function of time since previous fire, therefore knowing the starting point for fuel accumulation is incredibly important.

RESEARCH SITES

Warra Long Term Ecological Research Site

The Warra Long Term Ecological Research Site (LTER) was established in 1995 in 15,900 ha of tall wet *Euclayptus* forest in southern Tasmania. Its goal was to encourage long-term ecological research in the world's most carbon-dense forests. The area is also embedded with small patches of temperate rainforest and buttongrass moorland. In 2014, the area was subject to an aerial LiDAR survey, measuring the heights and foliar densities of the different forest strata. Within and just outside the Warra LTER area a number of sites were set up that are relevant for measuring fuel loads and fire hazard in tall wet forests: the TERN Ausplots, the Warra Chronosequence Plot Network, and the Weld River drone-based LiDAR demonstration site.

TERN Ausplots

The Terrestrial Ecosystem Research Network (TERN) Ausplot Forests network is a long-term ecological monitoring network of 48 1-hectare plots in mature, tall, wet eucalypt forest. It was established between 2012 and 2015 with the goal of setting up a network of permanent forest plots on a continental scale across a large climactic gradient.Error! Bookmark not defined. The climates in which these plots are located ranges from that of the cool temperate forests of Tasmania to the warm tropics of far north Queensland. The original objective was to set up the first Australia-wide network of plots in highly productive forests to monitor the effect of climate change on carbon stocks. However, consistent with the overarching goal of TERN, these plots were also intended to contribute to a continental-scale infrastructure for scientific study. In keeping with this concept, researchers from the University of Tasmania visited all 48 plots in the summer of 2014-15 to measure the fuel loads with intention to understand fuel dynamics across a macro-ecological gradient. Four of the Ausplots then burned in the Riveaux Road fire.

Tasmanian Fuel Chronosequence plots

The Tasmanian Fuel Chronosequence project was set up in 2016 to measure fuel load, structure, and hazard specifically in Tasmanian tall wet eucalypt forests with varying times since previous fire (hereafter referred to as stand-development stages). For the chronosequence plots, 23 permanent plots were set up in forests in four different stand-development stages: sapling, spar, early-mature, and late-mature. This contrasted with the Ausplots, which only focused on forests in the early-mature stand-development stage but covered the entire continent. Forests were measured in the sapling stage regenerating following clearfell, burn, and sowing operations, rather than a high-severity fire, as there have been no high-severity fires in Tasmania's southern tall wet forests since 1967. The purpose of these permanent plots was to understand fuel dynamics in Tasmanian tall wet eucalypt forests as a function of time since previous disturbance and to develop a fuel model that could be used in fire behaviour models. 12 of these plots burned in the Riveaux Road fire, all under relatively mild fire weather conditions.

Blake's Opening and Huon River buttongrass-forest interface

Due to weather conditions and COVID impacts, the full-size aircraft LiDAR mission over the complete Warra region could not be flown. The airborne LiDAR element of this project was therefore replaced with UAS-based LiDAR acquisition. In the project, LiDAR data was collected at the Weld River site (see previous section) and four new sites were established at Blake's Opening in the southwest forests (approximately 10 km west of the Tahune Airwalk and 3 km west of the TERN Warra flux tower). Blake's Opening is a buttongrass plain with peri-glacial landforms. The buttongrass-forest interface shows different fire intensity impacts from the Riveaux Road fire. UAS LiDAR data was collected in August and September 2020 to capture the variability in 3D forest structure at four sites that showed clear differences in fire behaviour and impact.

OBJECTIVES

The main goal of this study is to obtain empirical measurements of fuel load, structure and hazard within the first year after a fire to complement the measurements of fuel loads taken directly before the fires. This will not only allow us to precisely quantify the fuels consumed by these relatively low-severity fires, but it will also give us a baseline measurement of fuel loads. We can use this baseline to anchor measurements of fire severity and fuel accumulation in wet eucalypt forests related to other BNHCRC studies attempting to measure both fuel accumulation and the drivers of fire severity in wet forests.

CURRENT STATE OF KNOWLEDGE

The flammability of tall wet eucalypt forests is poorly understood. A globally unique forest type, these forests consist of a highly-flammable *Eucalyptus* overstorey and a moist, low-flammability understorey consisting of rainforest and broadleaf trees and shrubs. As a result, these forests are rarely available to burn, and almost no data exists on flammability and fire behaviour. While current fire behaviour models assume that fuel load and hence flammability increase asymptotically as a function of time since previous fire, there is much debate over whether this is the true trajectory of flammability in these forests. Understanding how fire severity is influenced by fuels and time since fire is a critical question in these forests.

As the rate of spread and intensity of a fire is a function of fuels, fire weather and topography, and as only the latter can be physically manipulated, the effect of fire on fuel loads is extremely important to understand. Low-severity fires are known to reduce surface fine fuels loads across a landscape in certain forest types, so intentionally lighting low-severity fires (i.e. planned burns), will increase the encounter rate of wildfires with low fuel load areas.[7] However the effect of low-severity fires in wetter forests is mostly unstudied. While reducing fuel ages has been shown to reduce both the extent and incidence of unplanned fires, the effect of low severity fires on actual fuel loads has not been explicitly quantified. While the period of effectiveness of a planned burn has been generally reported to be 5-6 years, these studies have looked at the empirical probability or size of unplanned fires as a function of fuel age, no studies that we could find in Australia measured fuel loads directly after a low-severity fire.

The project also targeted buttongrass-forest boundaries. There is an unresolved debate about the relative importance of fire and edaphic factors in controlling these boundaries. We were able to resurvey a prefire LiDAR survey of a buttongrass plain on the Weld River that was burnt in the 2019 fires. We also established buttongrass- forest transect at Blakes Opening that will serve as postfire baseline data. LiDAR surveys (both in aircraft and on drones) have revolutionised landscape ecology providing detailed data on variation in surface terrain and vegetation structure. Globally there are very few studies that have used LiDAR to resolve the effects of fire on vegetation structure. Our studies present a potentially cutting edge, highly effective method to assess both fire severity and fuel loads.

This study is one of the first studies to utilise UAS/drone LiDAR data to study the impacts of fire on forest structure. The main benefit of UAS LiDAR over full-size aircraft LiDAR is the much higher 3D point density that can be achieved with UAS LiDAR. The superior point density allows mapping and quantification of structural changes at the scale level of individual trees. This technology has the potential to assess fire severity across relatively large landscape gradients (compared to what could be measured through field surveys). This project has leveraged a unique pre- and post-fire UAS LiDAR dataset to assess detailed structural forest changes across a vegetation gradient at the Weld River. In addition, valuable baseline data has been collected at four sites at Blake's Opening that will facilitate future monitoring of structural changes and recovery, in addition to a better understanding of the impacts of fire on forest composition.

RELATED PROJECTS

This study is will also add valuable data to a recently-completed BNHCRC funded PhD project at the University of Tasmania with the Tasmania Fire Service serving as the lead end-user. The project characterised flammability in tall wet *Euclayptus* forest to better represent their fuels in fire behaviour models. This project relies heavily on data from both the Ausplots and Chronosequence plots to describe, using a modelling approach, the fire regime of these forests. This data will provide critical validation of this description. More specifically, this study will add a valuable validation section to a forthcoming peer-reviewed paper providing a first-ever explicit description of the fire regime of mature wet *Eucalyptus* forests across Australia. Additionally, an internal grant from the University of Tasmania has allowed for the purchase of 31 dataloggers to measure temperature and humidity in the understorey of burnt forests. This, combined with the fuel load data and LiDAR data will allow us to see how changes in forest structure and fuel load after a fire affect the understorey microclimate and hence the vulnerability of these forests to successive fires.

More broadly, this project will contribute to a growing database of pre- and post-fire permanent plot data, now spanning the continent, from Queensland to Western Australia to Tasmania. This will provide valuable research tools, both in the form of pre- and post-fire fuels datasets, and an opportunity to validate different fire behaviour models and fire severity metrics.

RESEARCH QUESTIONS

This study plans to focus on three major research questions:

- How effective is pre and post fire LiDAR data in creating high resolution maps of fire severity?
- How useful is LiDAR mapping for monitoring post fire recovery?
- How does fuel age, structure, and load affect fire severity in wet forests?

METHODOLOGY

LIDAR DATA ACQUISITION

UAS LiDAR data was collected on the following dates:

- Weld River transect 5 Sep 2018 and 29 June 2020
- Blake's Opening 11 Aug 2020 (site #1, #2, #4) and 10 Sep 2020 (site #3 and #5)

The UAS LiDAR system is a DJI Matrice 600 drone airframe with a custom-built LiDAR payload developed by the TerraLuma Team at the University of Tasmania (Figure 1). The laser scanner is a Velodyne VLP-16 'Puck' scanning ~80,000 pulses per second within -40 to +40 degrees field of view (across-track) and -15 to +15 degrees forward and backward of the scanner. The UAS flight trajectory and orientation was recorded with a tightly coupled GNSS/IMU Spatial Dual from Advanced Navigation. The position was processed against a local GNSS base station, resulting in an absolute accuracy of 5 – 10 cm for each laser point. The UAS can fly for 12 minutes per flight. Each flight covers approximately five flights strips that are 400 – 600 m long. The point density in a single flight strip was 110 pts/m2 with a combined point density of 530 pts/m2 and a point spacing of 4 cm.

Raw GNSS/IMU data and laser scanner data is processed in-house through GNSS processing software and Python code to produce georeferenced 3D point clouds as las files.

An example of the las file for the Weld River site (Figure 2), covering 13 hectares (from three UAS flights) is shown in Figure 3. The study sites acquired at Blake's Opening are shown in Figure 4. Access to Blake's Opening was via helicopter. All drone and surveying equipment was flown into the site (Figure 5).

FIGURE 1. UAS LIDAR COLLECTING DATA OVER WELD RIVER TRANSITION ZONE.

FIGURE 1. AERIAL PHOTO MOSAIC OF WELD RIVER BUTTONGRASS-FOREST TRANSITION ZONE (BEFORE FIRE) ACQUIRED BY UAS PHOTOGRAPHY.

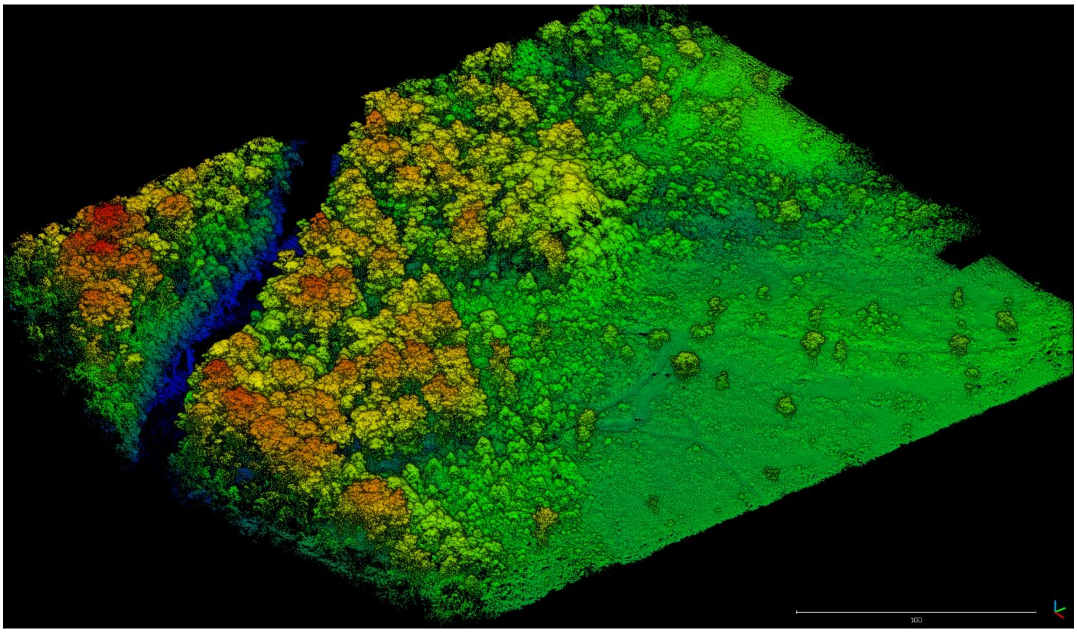


FIGURE 2. UAS LIDAR 3D POINT CLOUD FOR WELD RIVER SITE (5 SEP 2018).

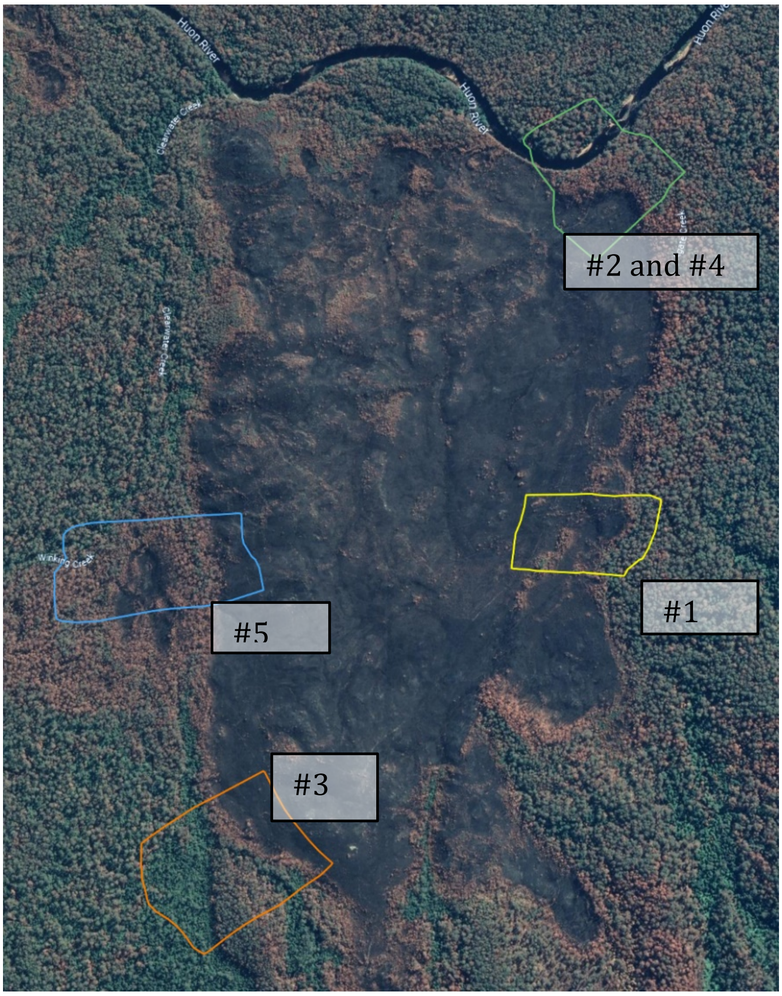


FIGURE 3. UAS LIDAR SURVEY SITES AT BLAKE'S OPENING.

FIGURE 4. ACCESS TO BLAKE'S OPENING VIA HELICOPTER WITH UAS AND SURVEYING EQUIPMENT FLOWN IN.

FIELD METHODS

Background

In order to validate airborne and satellite-derived measurements assessing the severity of the 2019 Riveaux Road Fire in Southwest Tasmania, we conducted a field-based fire-severity assessment during a 3-month period from November 2019- January 2020 in the Huon Valley, centred around the Warra research site. Then, in September 2020, we made field-based fire-severity assessments using fuel transects on a buttongrass-forest boundary in the lower Weld River region to validate the UAV LiDAR imagery. Blakes Opening UAV LiDAR ground-truthing surveys will occur in February 2021 as part of a current ARC Discovery project.

Weld River buttongrass-forest transects

Before setting up fuel transects at the Weld River site the site was stratified into 5 vegetation classes based on dominant plant species and height based on the LiDAR imagery as follows:

1. Tall- Forest dominated by *Eucalyptus obliqua* and *Euclayptus globulus* with a *Pomederris apetella* understorey and a canopy of >40 m
2. Medium- Forest dominated by *Eucalyptus obliqua* with a *Monotoca glauca* understorey and a canopy of 20-40 m
3. Low- Forest dominated by *Eucalyptus nitida* with a *Melaleuca* and *Leptospermum* understorey and a canopy between 10-20 m
4. Shrubby- Forest dominated by *Melaleuca* and *Leptospermum*
5. Buttongrass- dominated by *Gymnoschoenus sphaerocephalus*

In each of the five classes, three 30 metre transects were assessed for fire-severity, ground validation of LiDAR data and fire recovery as outlined in the methodology below. The location of each of these transects are shown in Figure 6.

Blakes Opening buttongrass-forest transects

Prior to establishing transects at Blakes opening the four flight paths were classified into 3 broad vegetation types based on dominant vegetation. These vegetation types were:

1. Buttongrass: near treeless communities dominated by *Gymnoschoenus sphaerocephalus* with occasional *Eucalyptus ntida* trees present.
2. Scrub: transitional community between the buttongrass and forest dominated by one, or a combination, of *Melaleuca, Leptospermum* species or *Eucalyptus ntida*.
3. Forest: the surrounding wet Eucalyptus forests dominated by *Eucalyptus obliqua* with an understory consisting a mixture of rainforest and wet sclerophyll species.

In each flight path three 30 metre transects for each vegetation of the three vegetation types. A further 15 transects undertaken across the button grass plain to further understand fire impact in this community type. Each transect was divided into five metre subsections in order to better understand fire impact at a smaller scale. Fire severity, mortality and recovery rates were assessed by adapting the Weld River methodology as outlined below.

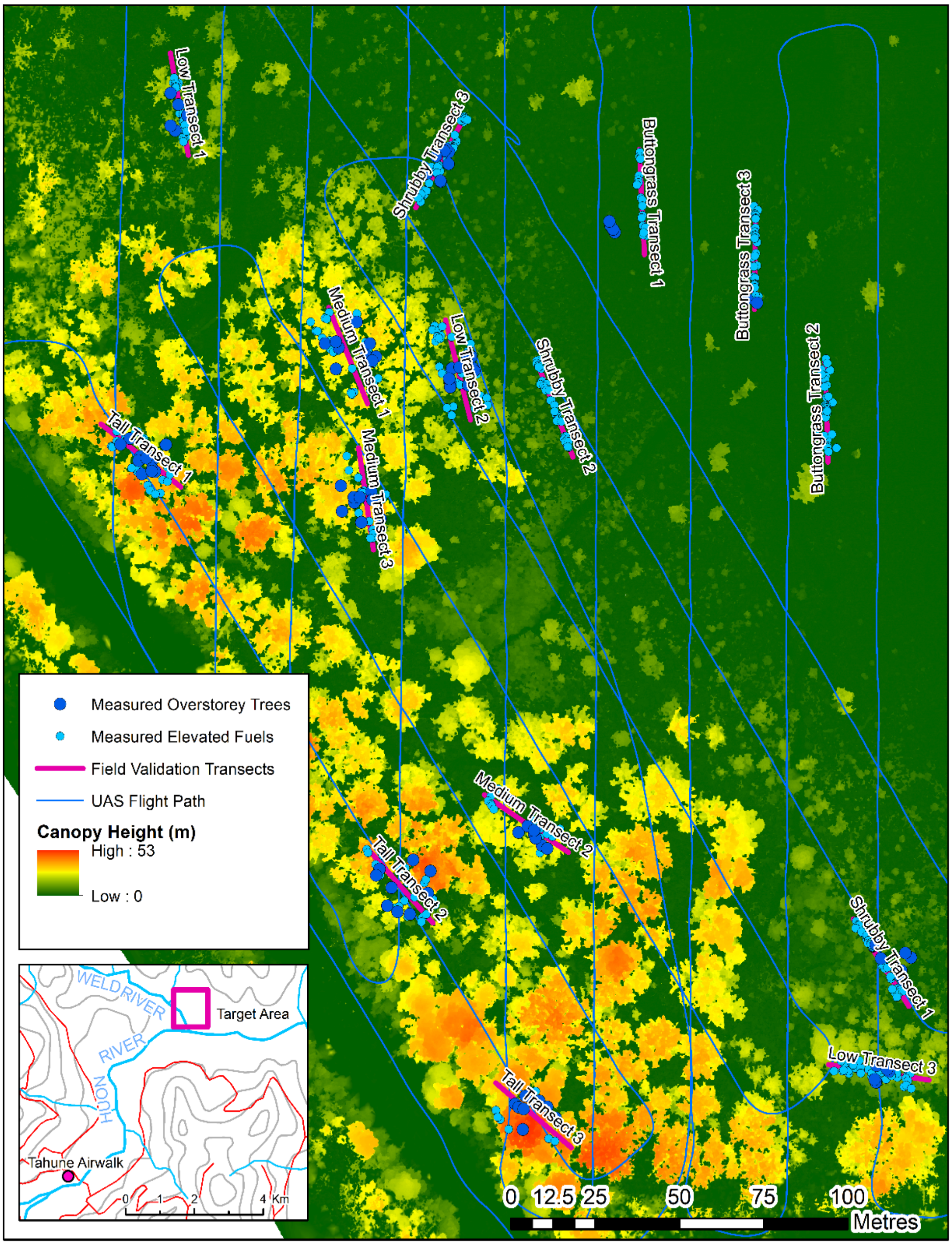


FIGURE 5. THE LOCATION OF 15 TRANSECTS TO VALIDATE UAS-BASED LIDAR MEASUREMENTS. THE EXACT LOCATION OF EACH PLANT MEASURED IN THE ELEVATED AND CANOPY LAYERS, ALONG WITH THE OUTPUT OF A LIDAR-DERIVED 20 CM RESOLUTION CANOPY HEIGHT MODEL POST-FIRE, IS ALSO GIVEN.

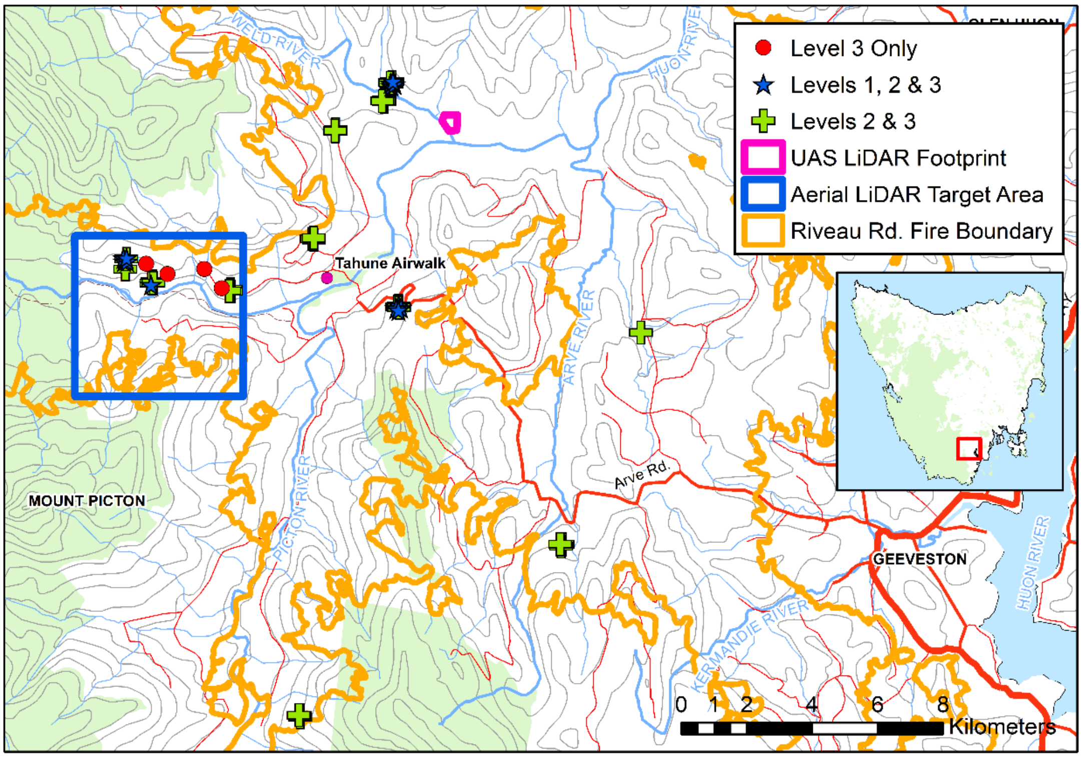


FIGURE 6. LOCATION OF LIDAR TARGET AREAS WITHIN THE STUDY AREA AND OF FIELD VALIDATION SITES.

A map of the locations of the Level 1, 2, and 3 assessments, along with the locations of the aerial and UAS-based LiDAR target areas, is presented in Figure 7. As is described in the Methodology, each of these assessments involved different methodologies and data.

We used three different methodologies to obtain field-based fire severity estimates at three different levels of detail. We refer to these three different methodologies as follows:

1. Level 1 methods focused on overstorey (>10cm DBH) tree mortality and species survival across the entirety of four 1ha Tasmanian Tall Forest Southern Ausplots sites that burned in the fire
2. Level 2 methods involved measuring 3-4 30 m transects to assess post-fire fuel, fire hazard, and fire severity, focusing on the elevated, near-surface, and surface fuels. This was done across 12 chronosequence plots and the 4 Ausplots;
3. Level 3 methods involve point severity assessments of fire impact across the wider fire landscape.

Level 1

For our Level 1 methodology, we performed a high-resolution assessment of fire severity in the overstorey by measuring the mortality of all trees >10cm DBH in the four Ausplots Tall Forest sites. At these sites all woody stems >10cm DBH have been given an aluminium tag with a unique id number with their location recorded on a 100x100m grid, we defined these trees as the overstorey trees.Error! Bookmark not defined. Tree maps have then been created with species, unique id, and location of each tree for all the Ausplots.

Using the aforementioned tree map at each site, the tagged trees were assessed for fire severity and tree mortality as follows:

1. Tree level mortality was assessed as dead or alive. This was assessed on the presence of any green leaves. This means a tree with no canopy leaves, but epicormic or basal resprouting was considered live. A tree with no canopy leaves or no resprouting was considered dead. If a tree was likely to have been dead before the fire, then this was also noted in the data.
2. Fire severity was assessed in 2 ways. First canopy scorching was assessed visually with a percentage given for canopy scorched. Scorching was considered as visible charring or browning of leaves or, given the 10-11-month time frame since the fire, defoliation of the leaves. An understorey tree with a few dead charred leaves remaining and the rest missing was recorded as 100% scorched. Where the fire severity is more difficult to ascertain then a note was made about whether the canopy has been scorched or just defoliated due to fire stress.

   Secondly, trees were also assessed for epicormic or basal resprouting with the occurrence of these recorded. These are considered stress responses to fire and therefore an indicator of the impact of the fire on an individual tree.
3. Finally, notes were also made if a tagged tree had fallen, and the cause of this, if it could be discerned, was noted. This is important as without such notes trees that have fallen post fire should not be included in the fire tree mortality count.

In keeping with the Ausplot methodology any previous untagged trees >10cm DBH were also assessed for fire severity and their status also recorded. The species, and DBH, of any new tree was recorded and noted and each occurrence given the identifier NEW. Trees were marked with spray paint once assessed to limit double counting and ease data collection.

Level 2

The Level 2 methodology was developed to provide a detailed assessment of post-fire fuel loads, especially in the surface, near-surface, and elevated layers. All Level 2 assessment occurred at sites in which fuel loads were measured using the same methodology 3-5 years prior to the fire. Comparison of live and dead fuel loads before and after the fire will allow for a thorough assessment of fuel consumption and fire severity. We also measured standard fire-severity metrics in the elevated layer such as scorch height and burnt-tip diameter. All assessments and measurements were made using three or four 30m fuel transects at each plot.

Surface and Near-surface Fuels

We set up 1x1 m quadrats between the 7-8m and 21-22m marks along the transect tape. Along the inside edge of each quadrat we measured the litter depth and grass height at 10cm intervals between 7.0 and 7.8 m, and 21.2 and 22.0 m on the transect tape. We then collected all woody and vegetative plants <0.5m in height, live grasses, fine fuels (all detached dead material, including twigs <6mm in diameter), and coarse fuels (twigs between 0.6 and 2.5 cm diameter) from each quadrat. We dried these samples to a constant weight at 70°C, weighed them to obtain dry weights, and estimated the tonnes per hectare (t/ha) fuel load directly. Lastly, we measured the depth of the topmost organic layer in the soil.

Downed Woody Fuels

We measured downed woody fuels along each transect to estimate the biomass of this fuel type. Downed woody fuels were defined as any detached (not rooted in the ground) woody material. We divided downed woody fuels into 2 categories, based on 10, and 100-hour moisture time-lag classes:

(a) 2.5-7.6cm diameter, and

(b) >7.6cm diameter.

For category b, we measured the diameter of every log or fragment that intercepted the transect tape in this size class. The diameter was measured perpendicularly to the direction of the log at the point of intersection. For category a, we counted the number of woody intersects between the 5-7m and 19-23m marks on the transect tape. A full diagram of the locations of the quadrats and woody fuel counts along the transect tape is presented in Figure 8. We then used a standard technique for converting the diameter of downed logs into t/ha, assuming a relative density of 0.4.

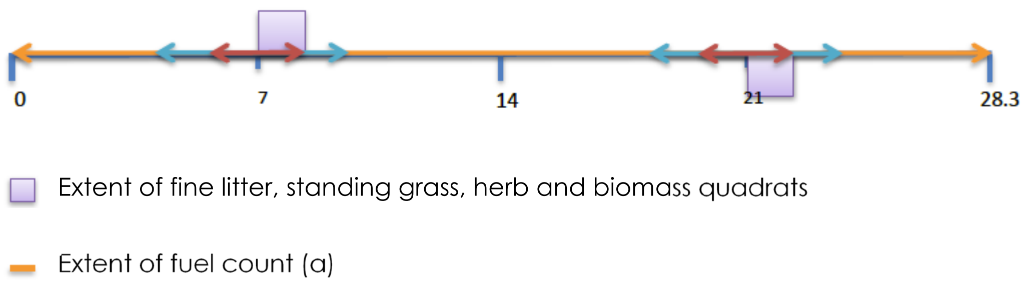


FIGURE 7. EXTENT OF WOODY FUEL COUNTS AND SURFACE FUEL QUADRATS.

Elevated Fuels

To measure live and dead standing plants in the elevated fuel layer (hereafter referred to as "shrubs"), we split the transect tape into four 7m long subsections. In each of these subsections we measured the five live shrubs and the five standing dead shrubs that were perpendicularly closest to the tape (see Figure 9). We did not measure any shrubs more than 5m away from the transect tape. We considered any plant that was greater than 0.5 m in height and less than 10cm in DBH to be a shrub. We also considered all tree ferns as "shrubs". In each subsection, we measured the height, DBH (where applicable), and basal diameter of each shrub. We also estimated the canopy length and width of each shrub to measure canopy cover. For each tree fern we recorded the length of the stem. We also measured the length and width of a rectangle bounding the group of five shrubs so we could estimate density (Figure 9). These measurements gave us estimates of the density and height of the elevated fuels layer. Using the diameter and height measurements we will be able to accurately predict the biomass of each live and dead plants and obtain t/ha elevated fuel load estimates. Lastly, we measured char height and burnt tip diameter on each live and dead plant for which this was applicable.

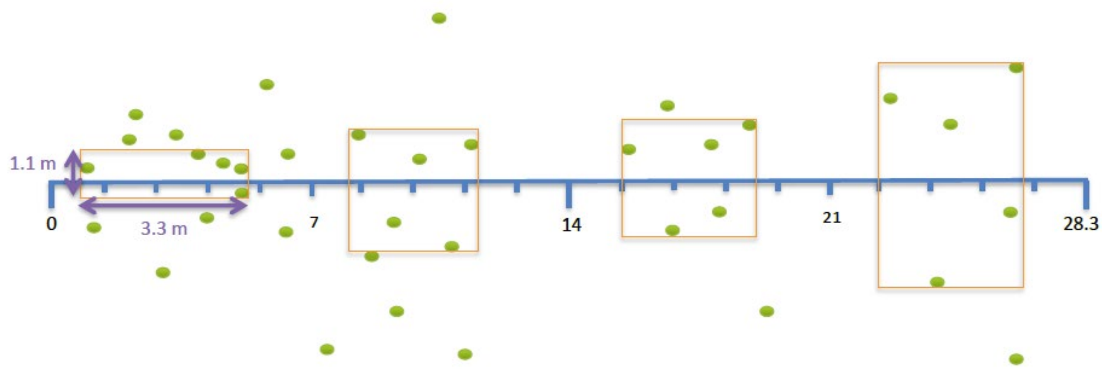


FIGURE 8. DIAGRAM OF CHOICE OF SHRUBS AND MEASUREMENT OF SURROUNDING RECTANGLE.

Further Measurements

Lastly, we took a number of additional measurements. We measured char heights of overstorey (>10cm DBH) non-stringy bark trees adjacent to each transect. In the case of the Ausplots, measured all applicable trees within the subplot the transect bisected. In the case of the chronosequence plots we measured all applicable trees within 3-7 m of the transect, varying this width with the goal of measuring 10-20 char heights per transect. Lastly, we performed qualitative hazard score assessments, using the mid-point of each transect as an assessment point, according to the methodology of Hines et al., to compare these to pre-fire hazard scores.

Level 3

The purpose of the Level 3 methodology was to perform quick ground truthings of fire severity to validate measurements derived from LiDAR and aerial photos. These methods were deigned to obtain numerous on ground post-fire severity data. As such it was designed to be a quick assessment taking around 10-15 minutes for each point.

Initially, level 3 surveys were performed on existing permanent plots in which the level 2 and/or level 1 methodologies were employed. This provided an assessment of the validity of these rapid assessment methods using the more detailed level 1 & 2 data. Four additional roadside points were sampled to further refine the methodology. All points were a minimum of 50m away from any road. Within similar vegetation and disturbance histories, all points were at least 500m away from one another.

At each point the following data was recorded:

1. Plot Location

2. Date

3. Vegetation type – Both overstorey and understorey species assemblage

4 . Logging/Disturbance- If the pre-fire disturbance history of site was known.

5. Crown Scorching (%) – Percent of crown that was scorched by fire (assessed for the understorey and overstorey strata)

6. Burnt surface (%) - Visual assessment of burnt ground litter and surface at a 5m radius centred on the point.

7. Rock cover (%) - Rock within a 5m radius of the point.

8. Slope (°) - This was taken with a vertex hypsometer. If a vertex is unavailable this can also be achieved with a clinometer.

9. Aspect (°) - taken with a compass facing the direction the slope is running. This can be taken at the same time as slope to ensure there is a point to reference to.

10. Status of the 5 nearest woody stems

Methodology for selecting five nearest woody stems

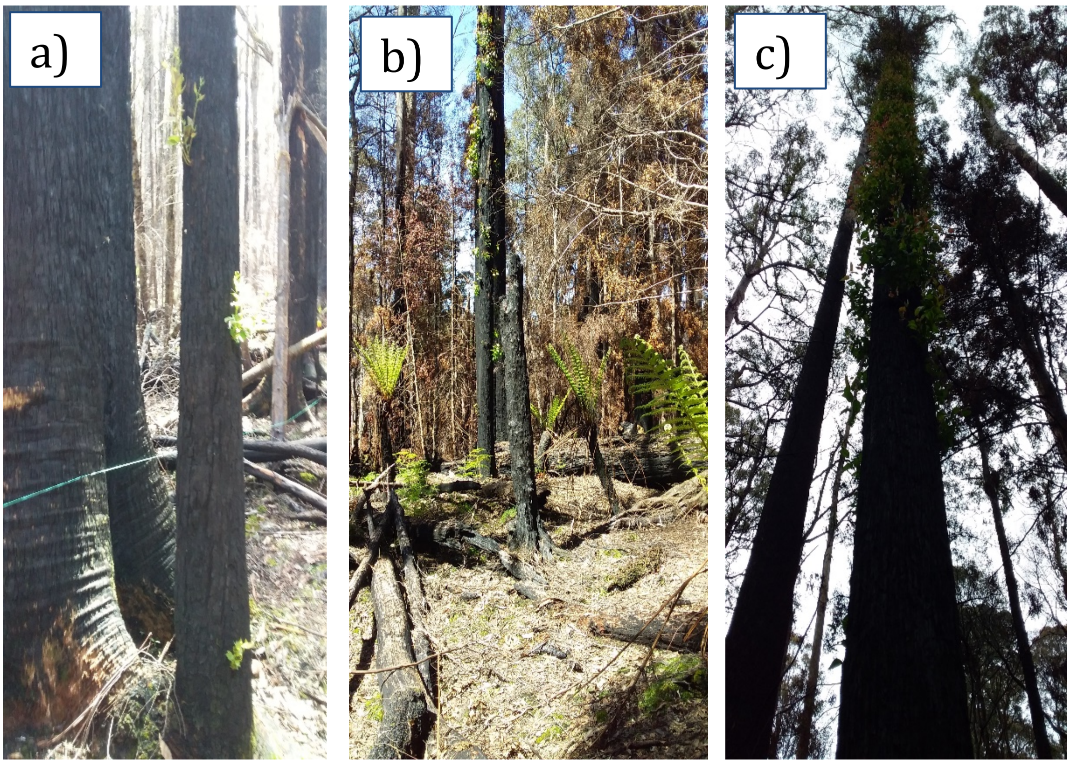


FIGURE 9. EPICORMIC RESPROUTING SCALE ASSESSMENT EXAMPLES WITH A) BEING A SCORE OF 1, B) A SCORE OF 2 AND C) A SCORE OF 3.

Woody stems were selected by holding a pencil, at the pointy end, 30cm in front of nose in the manner of a basal sweep. The five closest trees/ larger than the end of the pencils were then assessed for their post-fire status according to following categories: dead, basal resprouting, epicormic and alive undamaged. The species name and percent canopy scorch for each woody stem was also noted. If trees were smaller than the end of a pencil the same process was used with the pencil held with the point in front of the eyes and this was used as the basal sweep.

Trees in which epicormic resprouting occurred were given a score on a scale from 0-5 based on the following criteria:

0. No epicormic resprouts
1. One or two epicormic sprouts (Figure 10 a).
2. More than 3 epicormic resprouts along the trunk (Figure 10b).
3. Vigorous epicormic sprouting from base of tree to lower canopy branches (Figure 10c).
4. Epicormic sprouting along tree trunk and lower canopy branches.
5. Crown totally consumed, epicormic sprouting along trunk and entirety of the canopy, including upper canopy.

UAS-BASED LIDAR VALIDATION TRANSECTS

Weld Fire Severity

Fire severity assessment was undertaking using the Level 2 methodology for the chronosequence and Ausplot sites. Additional near surface fuels, fuel hazards and buttongrass specific changes are detailed below.

Surface and near surface fuels

In each of the transect quadrats live seedlings and bracken were counted and measured with both the total number and averaged height taken. Seedling species was also noted with average height and total number taken for each species. Material was also bagged and collected with seedlings separated into eucalyptus and non-eucalyptus with bracken collected as dead or alive.

Elevated fuels

For all classes, except buttongrass, a shrub was assessed as having a height >1.3m. In the three buttongrass transects an elevated shrub was assessed as having a height of 0.5m.

Overstorey fuels

At the 15m mark of each transect the 5-7 closest trees > 10cm DBH were tagged and assessed for severity. Assessment was performed recording each tree as live or dead, and recording DBH, height and resprouting type for each tree. Height was measured in three ways: height to the base of crown, height to top of crown and height to resprout. Resprouting was assessed as Yes or No for Basal and percentage for Epicormic and Canopy resprouting. For each transect we measured the distance between the 15m mark of the transect and the farthest tree. This distance served as the radius of a circular plot centered on the transect that enclosed all the measured trees.

Buttongrass fire severity

Additional surface and near surface fuel quadrats were collected in the three buttongrass transects at 12-13m and 17-18m. Additional fuel for live and dead buttongrass and live non-eucalyptus seedlings were collected. The average height and total number for seedlings was also collected in each quadrat. The height of buttongrass in the quadrats was also collected. Along the length of transect the height, location, and status (live or dead) of all buttongrass tussocks that intersected the measuring tape was collected.

Flight ground validation

Ground validation of the UAV LiDAR flights were undertaken as follows.

Transect names and droppers

To permanently mark transect locations, four steel droppers were placed along the length of transect. Two droppers were used for the start (0m) and end (30m) with the other two droppers being place as closer to 10m and 20m as possible depending on overhead canopy. Each dropper had a round yellow dropper cap placed on which the distance along transect and name of transect was written.

Elevated shrubs and overstorey trees

To assess the fire-severity of elevated fuels transect is divided into seven metre subsections with the five nearest live and standing dead shrubs assessed. In order to validate the LiDAR each of these elevated shrubs was tagged and numbered in accordance to their status and subsection location. Shrubs were numbered as following 1-5 (0-7m), 6-10 (7-15m), 11-15 (14-21m), 16-20 (21-28m) with live shrubs tagged and numbered in orange and dead shrubs tagged and numbered in blue and green. For each tagged shrub the location along transect and distance from transect (left or right) were also collected.

Likewise all overstorey trees that had been assessed for fire-severity were also tagged with individually number aluminum tags hammered into the trunk.

High-accuracy geocalculation

The steel droppers and tagged shrubs and overstorey trees were located via high-accuracy survey-grade global navigation satellite systems (GNSS) measurements (accurate to 2 – 4 cm). For each transect the transect name and shrub number was recorded with tagged shrub given a prefix of L (live) or D (dead) and a 3 digit number. Surveying took place using a ground station with their GPS and error margin recorded for each dropper, shrub and tagged overstorey trees.

Fire recovery

Fire recovery was assessed in each transect as follows.

Quadrat seedlings

In quadrats total number of seedlings and average height were collected for each species.

Transect seedlings

Along the length of transect all seedlings that intersected the measuring tape were measured for height, species and location.

Transect dominant vegetation type

Dominant vegetation type was collected along the length of each transect.

Buttongrass specific fire recovery

Alongside each of the above the status (live or dead), height and location of each buttongrass tussock that intersected the measuring tape was also collected.

Blakes Opening fire severity

Fire severity at Blakes Opening was measured using five metre subsection. Fuel type specific changes based on the smaller subsection and different questions are outlined below.

Surface and near surface fuel

No surface or near surface fuel was collected or assessed at Blakes Opening.

Burnt tips

Within each 5 metre subsection the 5 nearest burnt tips (if present) were measured instead of across the whole transect.

Elevated fuels

For forest and scrub communities shrubs were assessed as having a height of >1.3m whilst for all buttongrass transects an elevated shrub were assessed as having a height of >.5m. Within each 5-metre subsection the scorch heights of the 5 nearest shrubs (if present) were recorded. Each shrub was assessed for status, char height, resprout height and the overall height. Shrub width and length for each subsection were also recorded to calculate shrub density.

Overstorey fuels

Within each 5 –metre subsection the 5 nearest trees were assessed using categories of live or dead, DBH, height and resprouting type. Height was measured in two ways: height to the base of crown, height to top of crown, height to resprout and whether the tree was dominant or understorey tree.

Resprouting was assessed as Yes or No for Basal and percentage for Epicormic and Canopy resprouting. Tree width and length for each subsection were also recorded to calculate tree density. Where burnt tips and shrubs were absent char height of on Eucalyptus trees were also recorded.

Buttongrass and Ghania fire severity

Within each 5-metre subsection the nearest Buttongrass tussock was assessed for status (live or dead), char height, resprout height. In Scrub and Forest transects, where *Gymnoschoenus sphaerocephalus* was absent, the nearest *Ghania spp* tussock was assessed instead for the same criteria. No buttongrass specific fuel sampling occurred at Blakes Opening.

Fire recovery

Fire recovery was assessed at Blakes Opening via transect characteristics, seedlings and buttongrass/ghania recovery.

Seedling density

Seedling density for each five metre subsection was recorded using a variable width based on the density of seedlings. Density width varied from 0.1m to 4m. In each subsection seedling height and species were recorded with seedlings defined as being between 0.1-1.5m in height.

Saplings

When one of the closest shrubs saplings (seedlings >1.5m in height) were treated as a shrubs and recorded for status, resprout height and height.

Transect characteristics

In each subsection the following surface and near surface details were recorded for percentage cover: litter, monocots, bare ground, rock, moss, bracken, seedling, buttongrass, fern and fern allies, logs/slash, resprout, liverworts and rocks. For standing fuels (bracken, seedlings, buttongrass and resprout) average height was also recorded. Subsection percentage coverage was recorded using a two metre strip (one metre either side).

Buttongrass and Ghania specific fire recovery

Recovery for buttongrass and ghania was recorded through resprout height and percentage dead.

DATA ANALYSIS

LiDAR post processing and analysis

From the raw UAS LiDAR data all noise points were manually removed from individual flight strips (point floating below and above the main surface). The flights strips were merged with lastools, and the merged las file was edited in CloudCompare software. Ground points were automatically extracted with the

Cloth Simulation Filter algorithm (cloth resolution = 0.2, maximum iterations = 500; classification threshold = 0.1). With the ground point layer, the remaining LiDAR points were normalised resulting in a point cloud with normalised vegetation height (height of vegetation in relation to the ground).

The lastools las2dem was used to produce GIS grid layers containing a digital terrain model (DTM or bare ground model), a digital surface model (DSM), and a canopy height model (CHM).

Lastools lascanopy was used to produce a range of grid derivatives from the normalised point clouds. These derivatives were produced at 4 m spatial resolution. The format of the command is included below. Detailed documentation on lascanopy can be found here: http://lastools.org/download/lascanopy_README.txt In summary (and in order of alphabetical appearance of grid layers):

a. Avg = average height of point in canopy
b. b30, b50, b80 bincentiles at 30%, 50%, and 80%. For example, the 30% bincentile shows the fraction of points between the height cut-off (which is set to 30 cm to limit the impact of noise around the ground layer) and 30% of the maximum height.
c. c0, c01, c02, c03, c04 = count of points in the following height intervals: [1.0 – 2.0], [2.0 – 5.0], [5.0 – 10.0], [10.0 – 20.0], [20.0 – 50.0]
d. cov = canopy cover (number of points above the height cut-off (1.0 m) divided by all points)
e. d0, d01, d02, d03, d04 = density of points (as a %) in the following intervals: [1.0 – 2.0], [2.0 – 5.0], [5.0 – 10.0], [10.0 – 20.0], [20.0 – 50.0]
f. dns = canopy density (same as cov, but expressed as %)
g. kur = kurtosis of the vertical distribution in grid cell
h. max = max height in grid cell
i. p25,p50,p75,p95 = height percentiles, e.g. p95 is commonly used as the 95^{th} height percentile
j. std = standard deviation of point in grid cell
k. vc1, vc2, vc3, vc4, vc5 = vertical complexity index for vertical bin sizes of 2, 10, 20, 30, 40, and 50 m.

We suggest that the following grid layers are the most important derivatives: d0, d01, d02, d03, d04 (density of points in each of the height strata), dns (horizontal canopy density), p95, and vc1 (indicator of vertical complexity, e.g. parts of the forest with an overstory and understory within a 4x4 m cell will show high vertical complexity).

Fire severity analyses

Fire severity among vegetation classes

To investigate the applicability of pre- and post-fire UAS-based LiDAR at assessing fire severity, we compared the LiDAR data to the data collected from the UAS LiDAR validation transects. We first extracted the LiDAR canopy derivatives associated with each transect, by extracting all the raster values within 10 m (horizontally) of each transect. The canopy derivates we analysed were point densities within the 5 canopy strata (d_0, d_1, d_2, d_3 and d_4) and a vertical complexity index with a 2 m bin size (vc_1). An example of the extraction process for these derivatives is given in Figure 11. We first compared the variation in these derivatives both among and within the 5 vegetation classes in which we set up transects with box and whisker plots, using the value of each 4 m x 4 m raster cell within 10 m of a given transect as a data point.

Relationship between field- and LiDAR-based fire severity metrics

We then compared the standard fire severity metrics we measured in the field with canopy loss (as measured by the LiDAR data). We calculated the percentage of foliage lost in the fire in each strata using the average percent change between pre- and post-fire measures for each of the d_0 – d_4 values associated with a given transect as described in the previous paragraph. We used burnt tip diameter, char height, and a basal area per hectare of both live and dead plants in the elevated and canopy layers. Basal area per hectare was calculated as $BA = \frac{\sum \pi \, (basal\ diameter/2)^2}{subsection\ area}$ for elevated fuels, and $BA = \frac{\sum \pi \, (DBH/2)^2}{\pi \ plot\ radius^2}$ for trees in the canopy. We also calculated a dead:live basal area ratio (defined as basal area per hectare of dead plants divided by overall basal area per hectare) in both the understorey and canopy. This allowed us to evaluate the utility of different severity metrics in determining the level of damage in different forest strata and among different forest types.

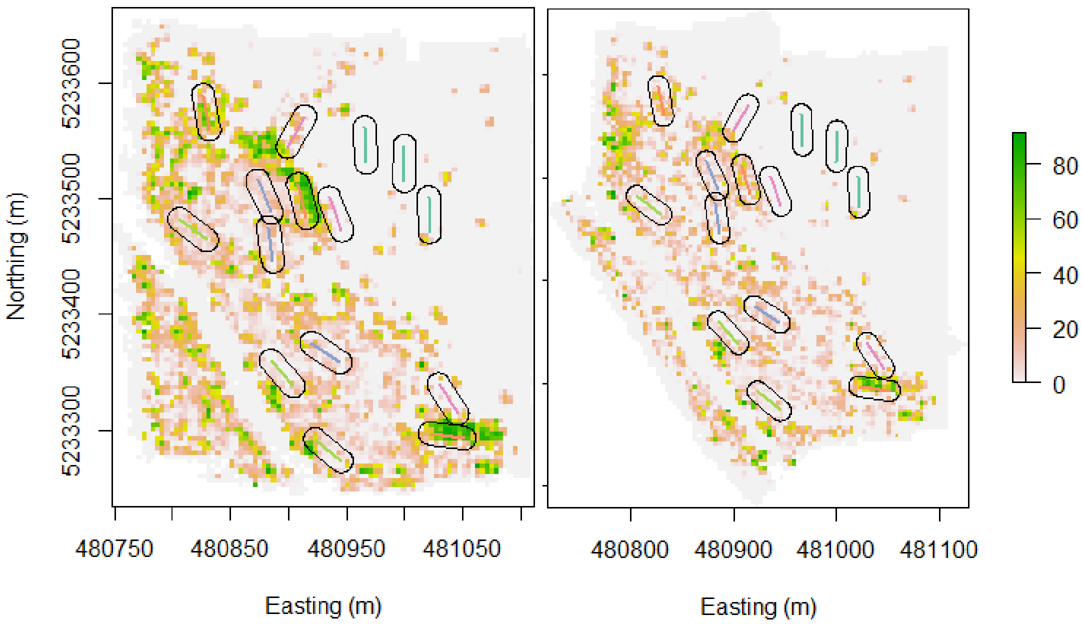


FIGURE 11. EXAMPLE OF CANOPY DERIVATIVE OUTPUTS AND SUBSEQUENT COMPARISON TO TRANSECT DATA. THE MAPS SHOW DENSITY OF POINTS CAPTURED IN THE CANOPY STRATUM OF 10-20 M ABOVEGROUND (D4) ACROSS THE STUDY AREA PRE-FIRE (LEFT) AND POST-FIRE (RIGHT). COLOURED LINES REPRESENT THE LOCATION OF TRANSECTS AND THE BLACK LINES REPRESENT A 10M BUFFER AROUND EACH TRANSECT. FOR EACH TRANSECT ALL VALUES WITHIN THE BUFFER WERE AVERAGED TOGETHER TO CALCULATE THE PRECENT CHANGE IN POINT DENSITY SURROUNDING EACH TRANSUCT FOR THE GIVEN STRATUM.

Capability of LiDAR to detect fuel loads and regeneration

We also investigated the correlation between fuel loads in different layers and the LiDAR canopy derivatives. We calculated the surface fuel load and near-surface fuel load (all standing, non-woody fuels, and all woody fuels < 1.3 m tall) directly from their masses in the quadrats. Surface fuel loads can be inversely correlated with fire severity, as high-severity fires will consume most of the fine fuels, whereas low-severity fires will kill or scorch smaller trees causing them to drop leaf litter. Near surface fuel loads provide an estimate of recovery as they indicate the amount of regeneration of bracken, grasses, and *Eucalyptus* and non-*Eucalyptus* seedlings. We investigated the correlation between surface fuel load and the percent foliar loss in each stratum to see how surface fuel load correlated with fire severity. Then we investigated the correlation between post-fire point density in the 1-2 m stratum and near-surface fuel loads to evaluate the potential for UAS-based LiDAR to detect regeneration and hence evaluate ecosystem recovery. Lastly, we investigated the ability of the LiDAR data to detect live and dead burnt plants in the elevated layer. To do this we investigated the correlation between post-fire point density in the 5-10 m and 10-20 m strata and the post-fire basal area of dead and live fuels in the elevated layer.

PRELIMINARY RESULTS

LEVEL 1 FIELD VALIDATION

Across the four TERN Ausplot sites 2365 stems (DBH >10cm) were assessed for mortality and fire response. There was an overall mortality of around 71% with 1679 stems dead and 686 alive (Table 1. LEVEL 1 validation). DBH ranged from 10cm to 380cm with only three species- *Acacia melanoxylon, Eucalyptus obliqua* and *Eucalyptus regnans*- having a DBH > 45cm. Mortality rates varied across species and size with mortality highest in the wet sclerophyll and rainforest species (5% and ~6% respectively, Figure 12) and lowest for the Eucalyptus species.

For all species mortality was highest in stems with DBH < 40cm and lowest in stems between 40 and 100 cm DBH (Table 1. LEVEL 1 validation results. *Eucalyptus obliqua* where the vast majority of stems had resprouted (Figure 13). Aside from the two Eucalypts the only other species that had survival rates greater than 10% was *Acacia melanoxylon* with survival rates also higher in DBH >40cm than stems < 40cm DBH.

DBH	***Count***	**Alive**	**Dead**	**Epicormic**	**Basal**	**Basal and Epicormic**	**Dead resprout**
0 To 20	1226	71	1155	24	20	11	0
20 To 40	624	207	417	97	28	18	9
40 To 60	260	183	77	92	22	19	4
60 To 80	133	118	15	56	9	7	2
80 To 100	72	67	5	40	3	3	0
100 To 120	22	20	2	16	2	2	0
120 To 140	7	6	1	3	2	1	1
140 To 160	4	4	0	1	1	1	0
160 To 180	5	3	2	3	0	0	0
180 To 200	1	0	1	1	0	0	1
200 To 220	2	1	1	1	1	1	0
220 To 240	2	1	1	1	0	0	0
240 To 260	4	3	1	1	0	0	0
260 To 280	2	1	1	1	1	1	0
360 To 380	1	1	0	1	0	0	0
Total	2365	686	1679	338	89	64	17

TABLE 1. LEVEL 1 VALIDATION RESULTS.

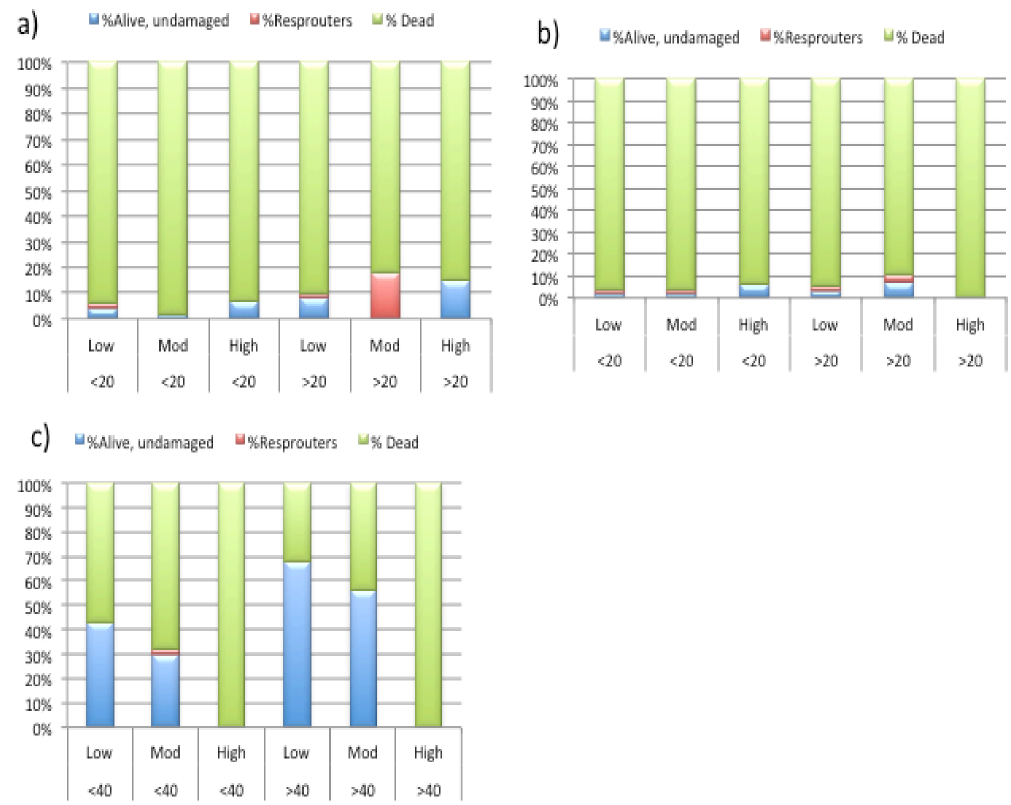


FIGURE 12. PERCENTAGE MORTALITY AND FIRE RESPONSE FOR RAINFOREST (A), WET SCLEROPHYLL (B) AND BLACKWOOD (C) FOR FOUR TERN AUSPLOTS. DUE TO NUMBERS DBH FOR BOTH RAINFOREST AND WET SPECIES ARE SEPARATED INTO DBH < AND > 20CM WHILST FOR ACACIA MELANOXYLON DBH IS SEPARATED INTO DBH < AND > 40CM DBH.FIRE SEVERITY IS BASED ON AVERAGE CHAR HEIGHT FOR ¼ HECTARE PLOTS WITH <2M (LOW), 2-5M (MODERATE) AND >5M HIGH.

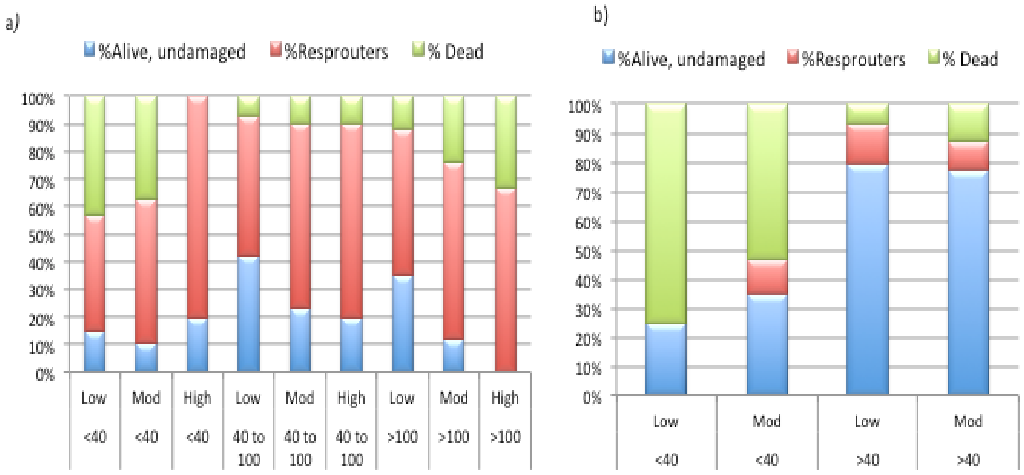


FIGURE 13. SIZE FREQUENCY PERCENTAGE MORTALITY AND RESPONSE TO DIFFERENT FIRE SEVERITY FOR EUCALYPTUS OBLIQUA (A) AND EUCALYPTUS REGNANS (B). FIRE SEVERITY IS BASED ON AVERAGE CHAR HEIGHTS IN ¼ HA PLOTS WITH <2M (LOW), 2-5 (MODERATE) AND >5M (HIGH). RESPROUTERS INCLUDES BOTH EPICORMIC AND BASAL RESPROUTERS.

LEVEL 2 FIELD VALIDATION

While the aerial LiDAR (for which the level 2 plots will provide validation) has yet to be flown, some interesting insights on fire severity can be derived from the fuels data at the level 2 plots.

Surface fuels

Among the most interesting results in this study is that the surface fine fuel loads quickly re-accumulated after the fire. All Ausplots and Chronosequence plots had accumulated roughly 5 t/ha of surface fine fuels within the first year after a fire (Figure 14). Given the primary importance of fine fuels in driving fire behaviour, this is potentially an important result regarding the effectiveness of low-severity fires at reducing fire hazard in different climates and stand development stages in wet *Eucalyptus* forests.

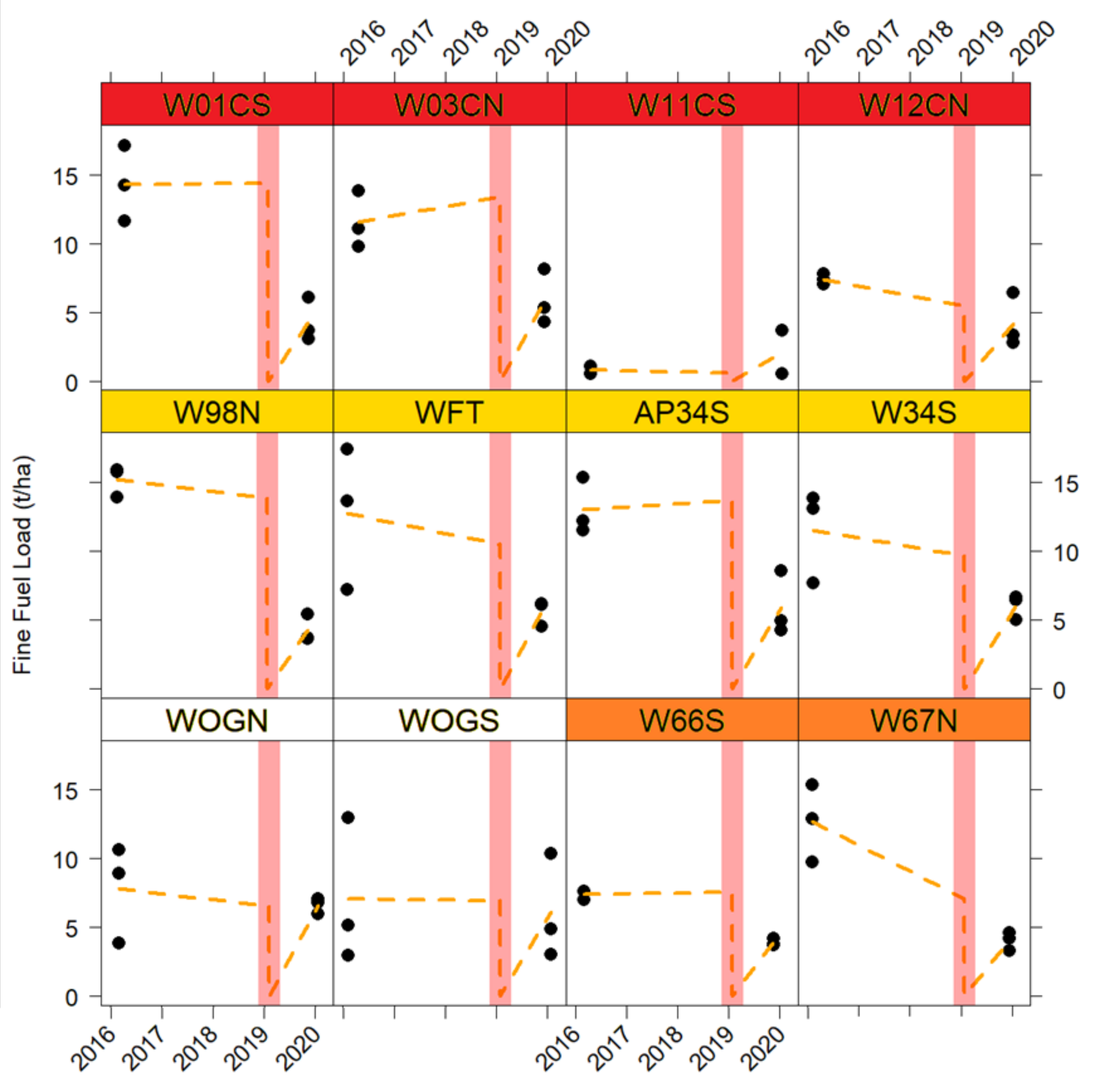


FIGURE 14. TIMELINE OF SURFACE FINE FUEL LOADS (IN TONNES PER HECTARE) AT THE CHRONOSEQUENCE PLOTS. THE BLACK DOTS REPRESENT INDIVIDUAL QUADRATS, AND THE ORANGE DOTTEDD LINE REPRTESENTS THE ESTIMATED FUEL ACCUMULATION PATTERN. FUEL ACCUMULATION WAS INFERRED FROM PREVIOUSLY MEASURED RATES (SEE METHODS) AND ASSUMED COMPLETE CONSUMPTION THE THREE FUEL TYPES DURING THE BURN. SHADED RED BOXES REPRESENT THE ESTIMATED TIME OF THE FIRE. PANEL COLOUR REPRESENTS STAND DEVELOPMENT STAGE: LATE-MATURE (WHITE), EARLY-MATURE (YELLOW), SPAR (ORANGE), AND SAPLING (RED).

Elevated fuels

Perhaps the most consistent effect of the low-moderate severity fires across all plots was the death, but not combustion, of most plants in the fire-sensitive understorey. The exception to this were tree ferns, all of which paradoxically combusted yet survived. This is apparent through the amount of dead basal area (Figure 16a) and the hazard assessment of the elevated layer (Figure 16b), which revealed a decrease in estimated percent cover and an increase in estimated percent dead fuels to above 50% in nine plots. This would explain the quick re-accumulations of fine fuels after the fires, as all the dead plants that were not consumed by the fire would quickly drop their leaves. Further, analysis of basal area of dead standing fuels revealed a large amount of standing dead fuels in most plots (Figure 16a), suggesting that a large deposition of coarse fuels onto the surface is yet to come. The prevalence of dead fuels in the elevated layer seems to be especially high in the sapling and early-mature stand development stage.

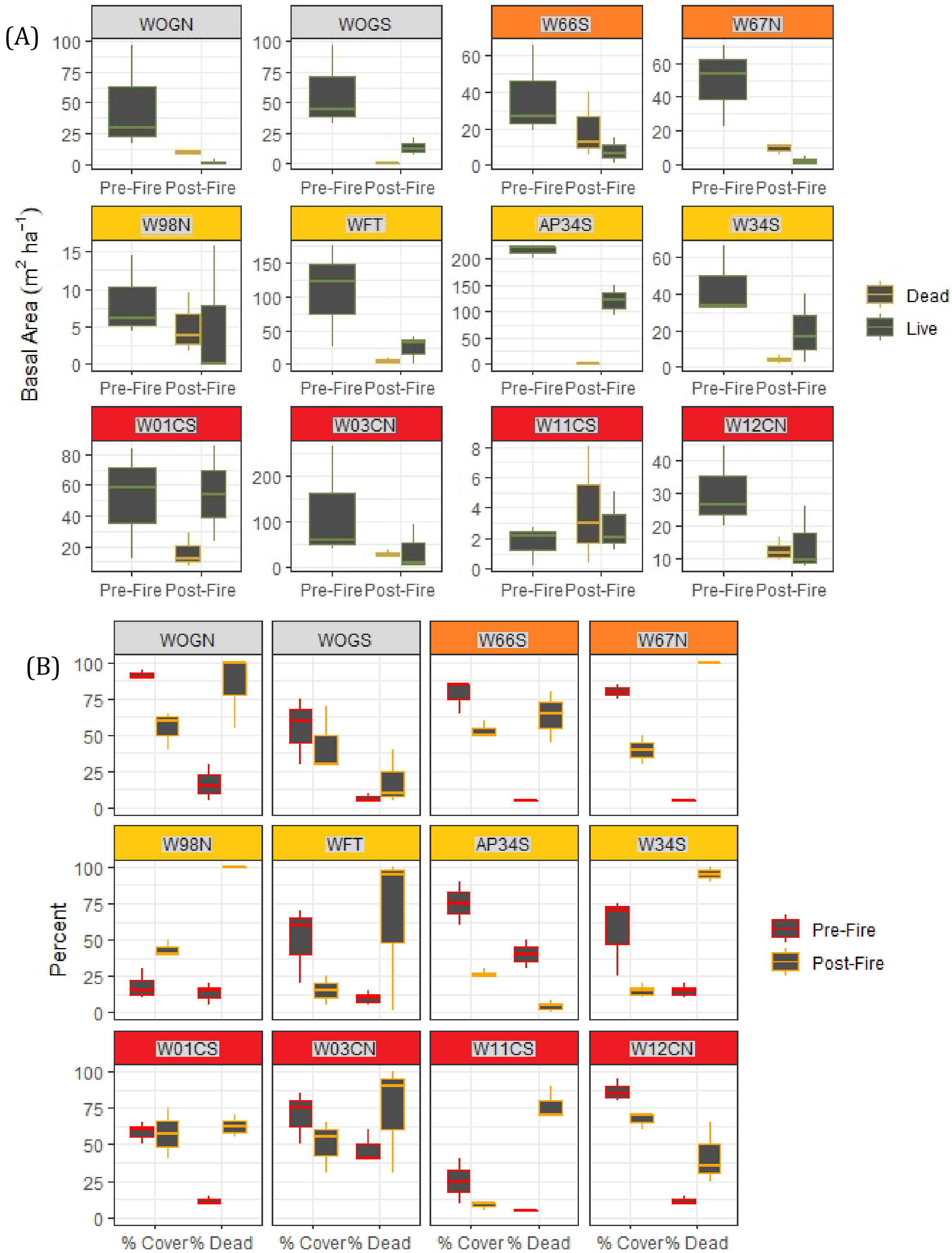


FIGURE 15 (A) BASAL AREA PER HECTARE OF LIVE (ORANGE BOXES) AND DEAD (RED BOXES) STANDING PLANTS IN THE ELEVATED LAYER BEFORE AND AFTER THE FIRE IN THE CHRONOSEQUENCE PLOTS. PANEL COLOUR REPRESENTS STAND DEVELOPMENT STAGE: LATE-MATURE (GREY), EARLY-MATURE (YELLOW), SPAR (ORANGE), AND SAPLING (RED). (B) ESTIMATED PERCENT DEAD FUELS AND PERCENT COVER IN THE ELEVATED LAYER BEFORE AND AFTER THE FIRE IN THE CHRONOSEQUENCE PLOTS. PANEL COLOUR REPRESENTS STAND DEVELOPMENT STAGE: LATE-MATURE (GREY), EARLY-MATURE (YELLOW), SPAR (ORANGE), AND SAPLING (RED).

The effect of low-severity fires on fire hazard

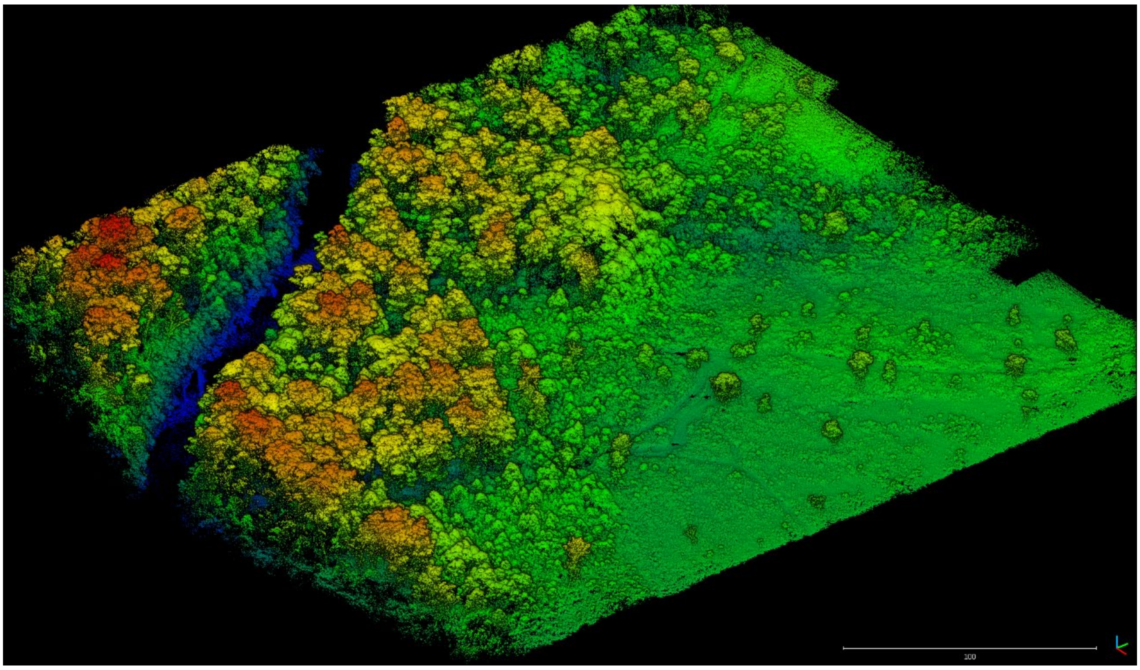
Given the quick re-accumulation of leaf litter resulting from the deposition that is suggested by this data, and given the fuel-rich nature of tall wet *Eucalyptus* forests, these forests are likely to have adequate fuel loads to sustain a fire relatively quickly after a low-severity burn. Further, the reduction in the percent cover and bulk density of understorey plants indicates a likely removal of the understorey microclimate effect characteristic of these forests., This dried-out understorey and adequate fuel load could indicate that these forests are vulnerable to a second fire in quick succession, especially given an increasing dryness of the Tasmanian landscape due to climate change. Such fires in quick succession have been shown to be catastrophic in obligate-seeder dominated wet forests, especially those in the sapling stage, and could be problematic in resprouter dominated forests as well. However, these results are preliminary and more analysis needs to be conducted before any strong conclusions can be drawn.

UAS-BASED LIDAR MAPS AND DERIVATIVES

LiDAR 3D point clouds

Figure 16-Figure 18 show the UAS 3D point LiDAR data for the Weld River transect site pre- and post-fire. The reduction in understory, reduction in buttongrass biomass, and changes in the tree canopy are clearly visible in the 3D point clouds.

Figure 19-Figure 22 show the four sub-sites at Blake's Opening (see Figure 4 for an overview of the site numbers). Each top-figure shows the 3D point cloud with vegetation, and each bottom-figure show the bare ground model as a surface.



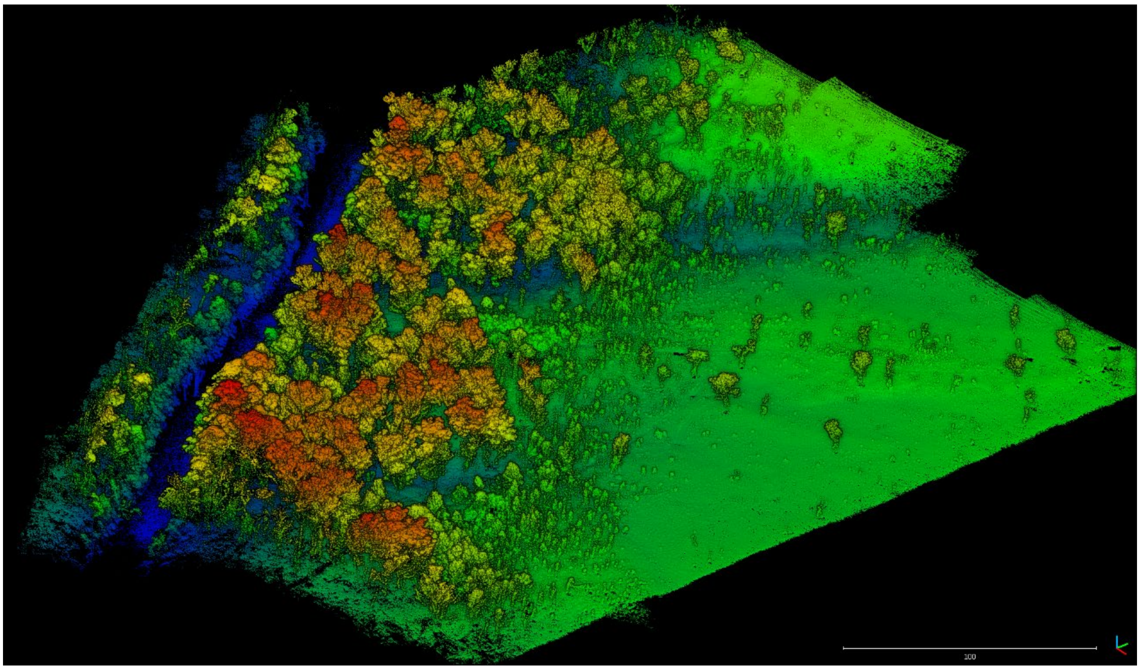


FIGURE 16. UAS LIDAR DATA PRE-FIRE (TOP, 5/09/2018) AND POST-FIRE (BOTTOM, 29/06/2020).

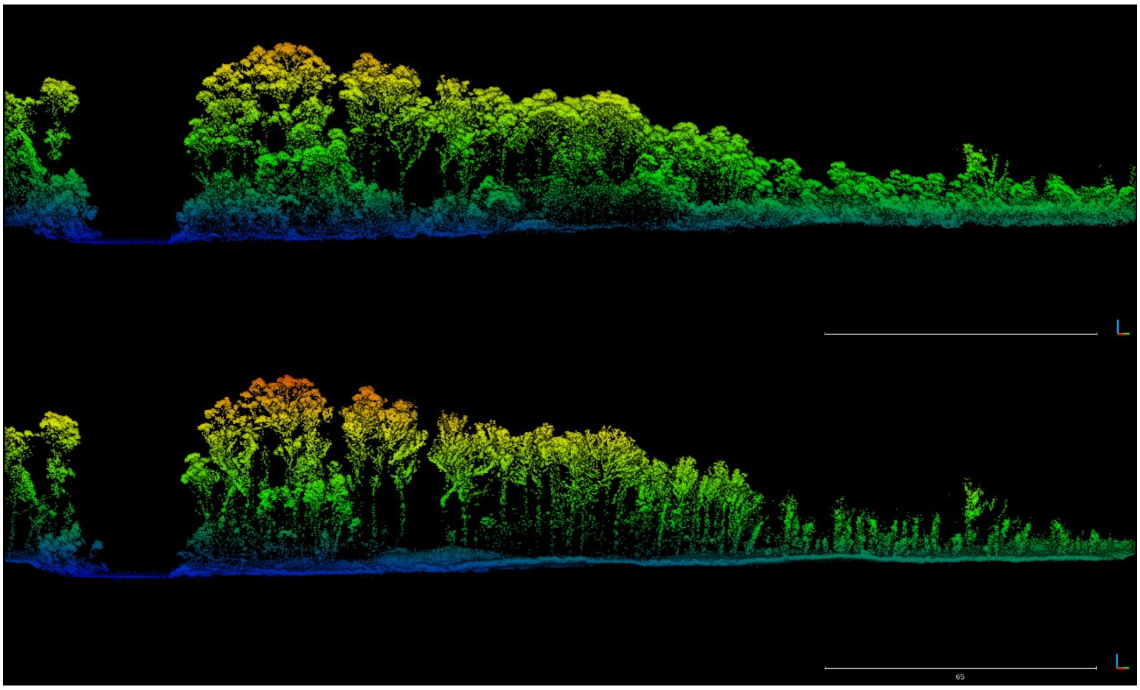


FIGURE 17. PROFILE OF UAS LIDAR DATA PRE-FIRE (TOP, 5/09/2018) AND POST-FIRE (BOTTOM, 29/06/2020).

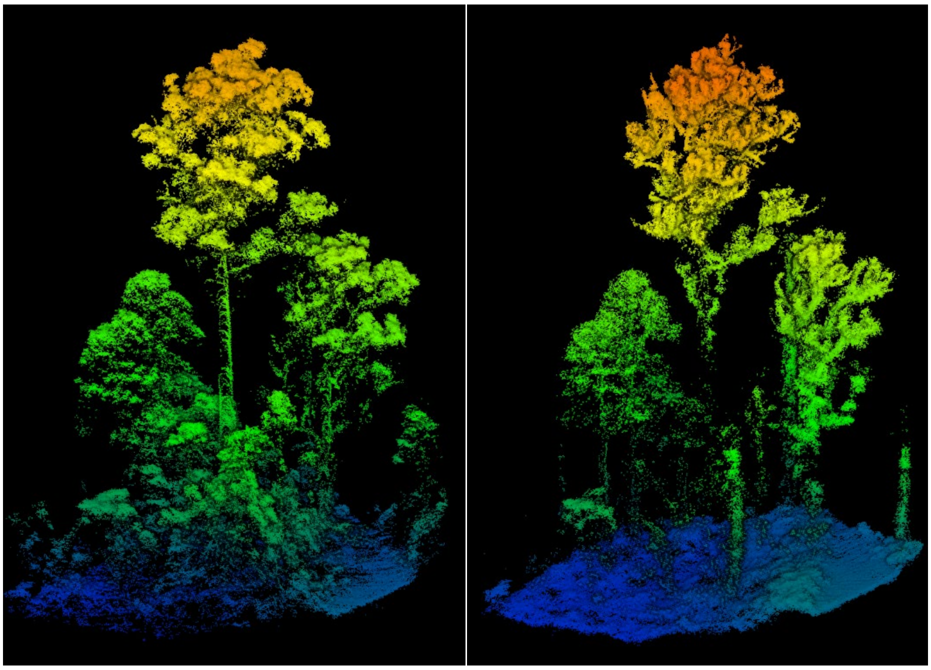


FIGURE 18. 3D POINT CLOUD OF INDIVIDUAL TREES AT THE WELD RIVER SITE UAS LIDAR DATA PRE-FIRE (LEFT, 5/09/2018) AND POST-FIRE (RIGHT, 29/06/2020).

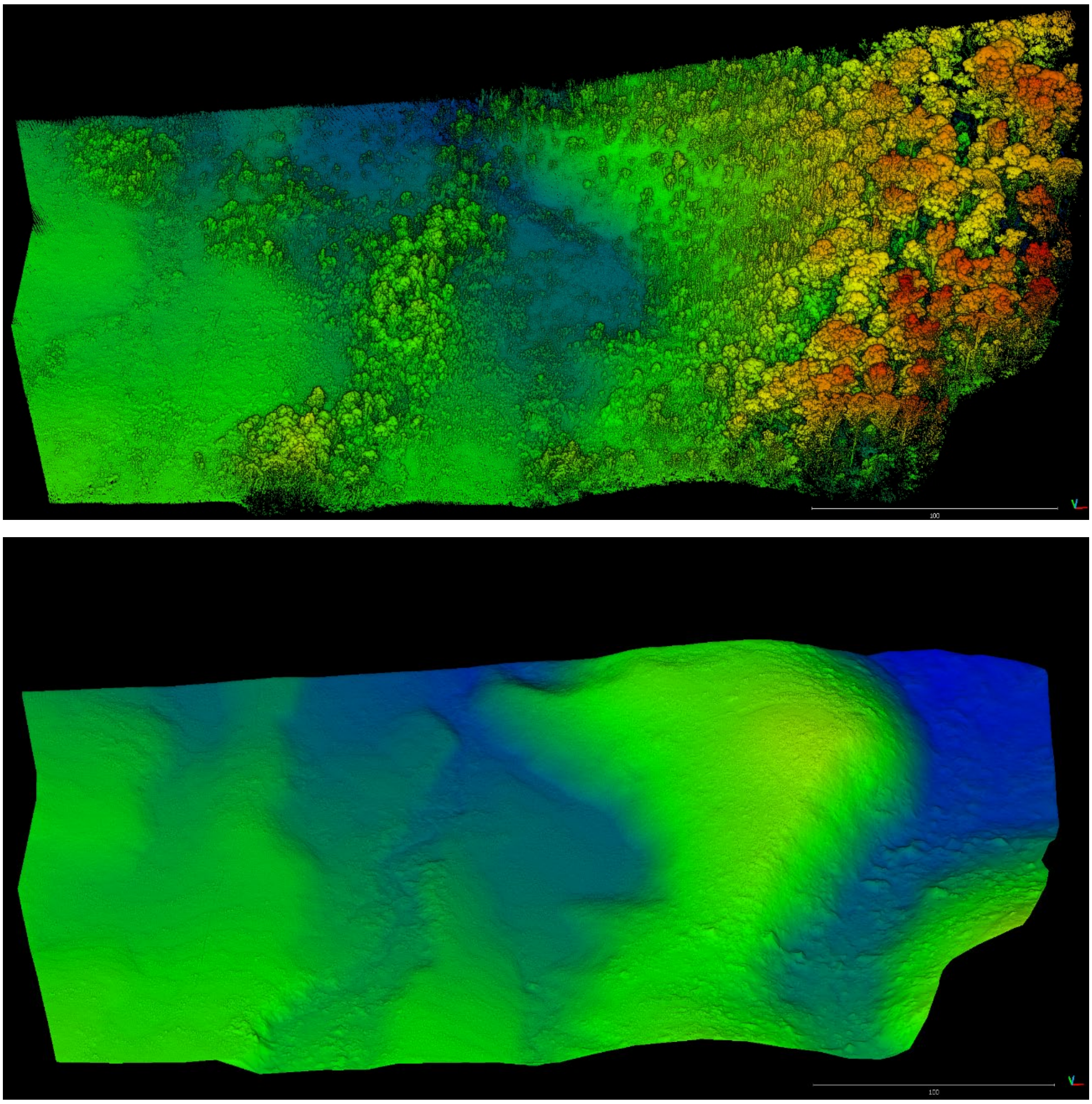
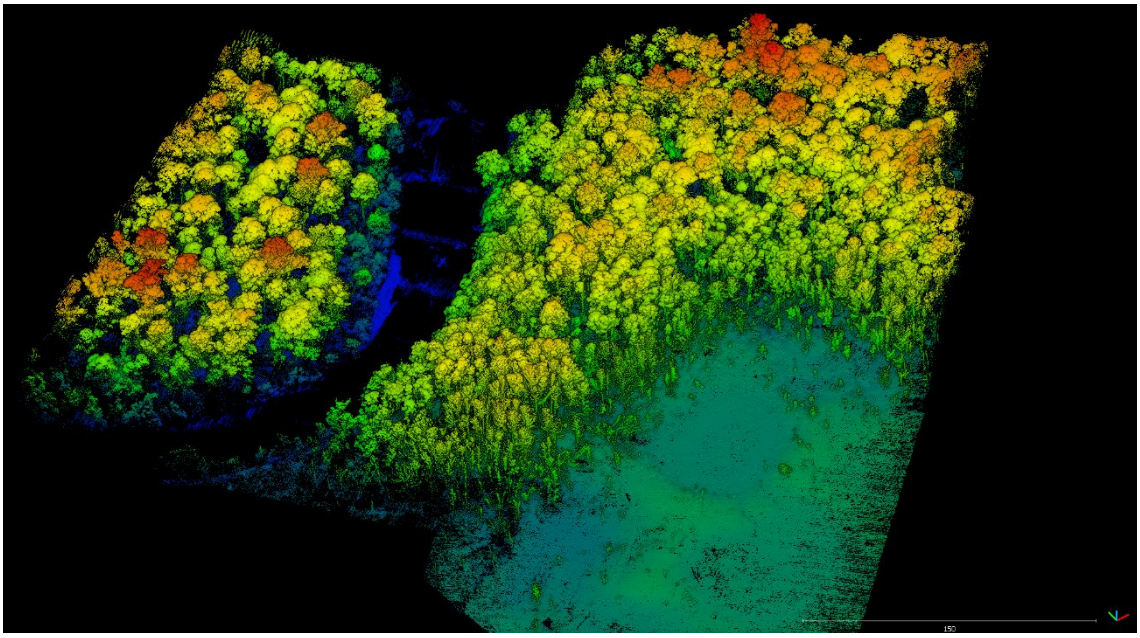


FIGURE 19. UAS LIDAR DATA OF BLAKE'S OPENING SITE #1 WITH TOP POINT CLOUD SHOWING VEGETATION HEIGHT AND BOTTOM MODEL SHOWING BARE GROUND SURFACE.



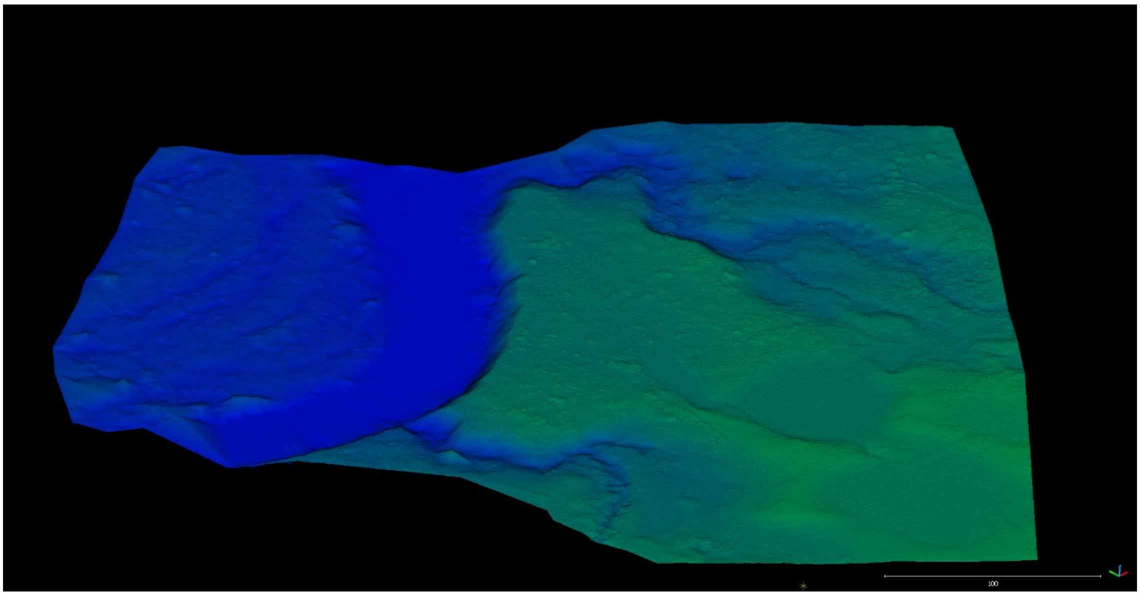
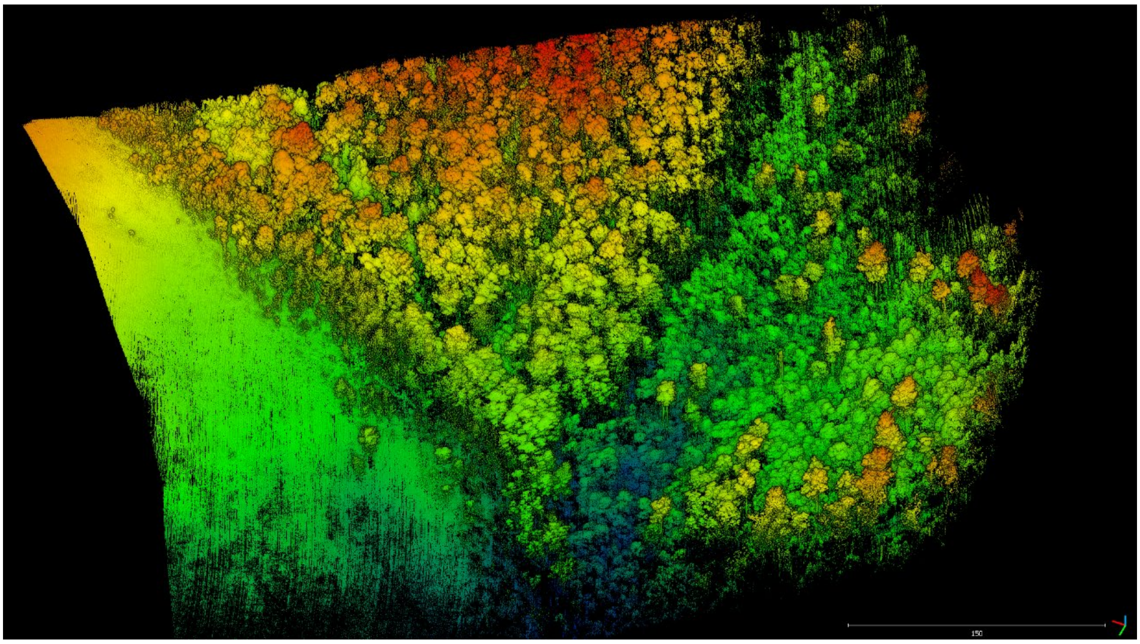


FIGURE 20. UAS LIDAR OF BLAKE'S OPENING SITE #2 AND #4 COMBINED WITH TOP POINT CLOUD SHOWING VEGETATION HEIGHT AND BOTTOM MODEL SHOWING BARE GROUND SURFACE.



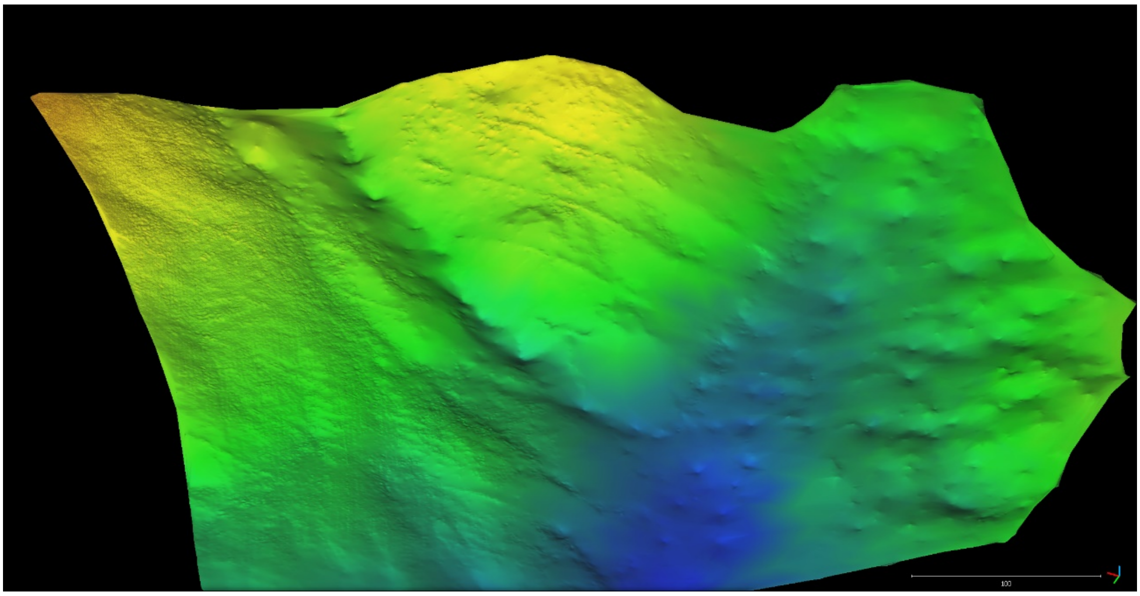
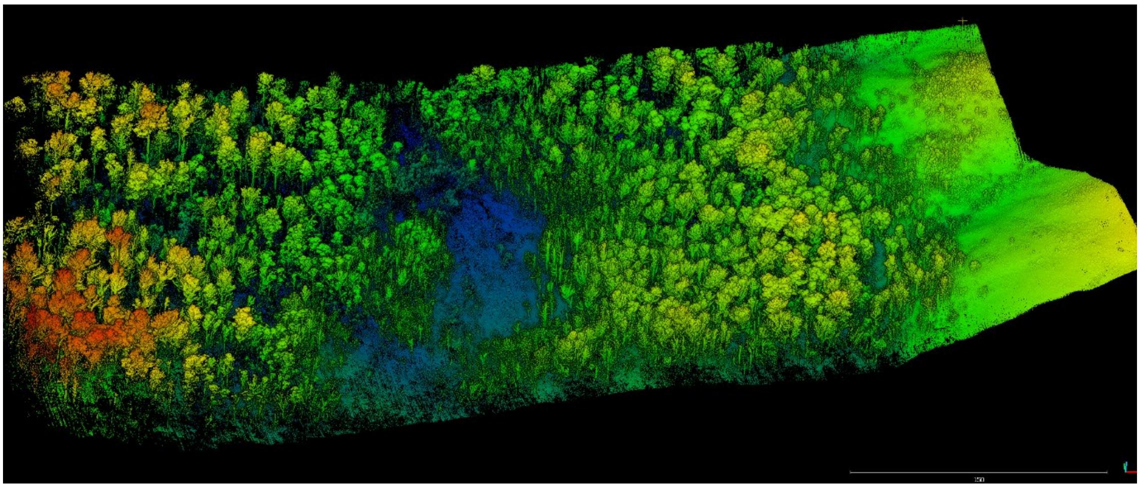


FIGURE 21. UAS LIDAR OF BLAKE'S OPENING SITE #3 WITH TOP POINT CLOUD SHOWING VEGETATION HEIGHT AND BOTTOM MODEL SHOWING BARE GROUND SURFACE.



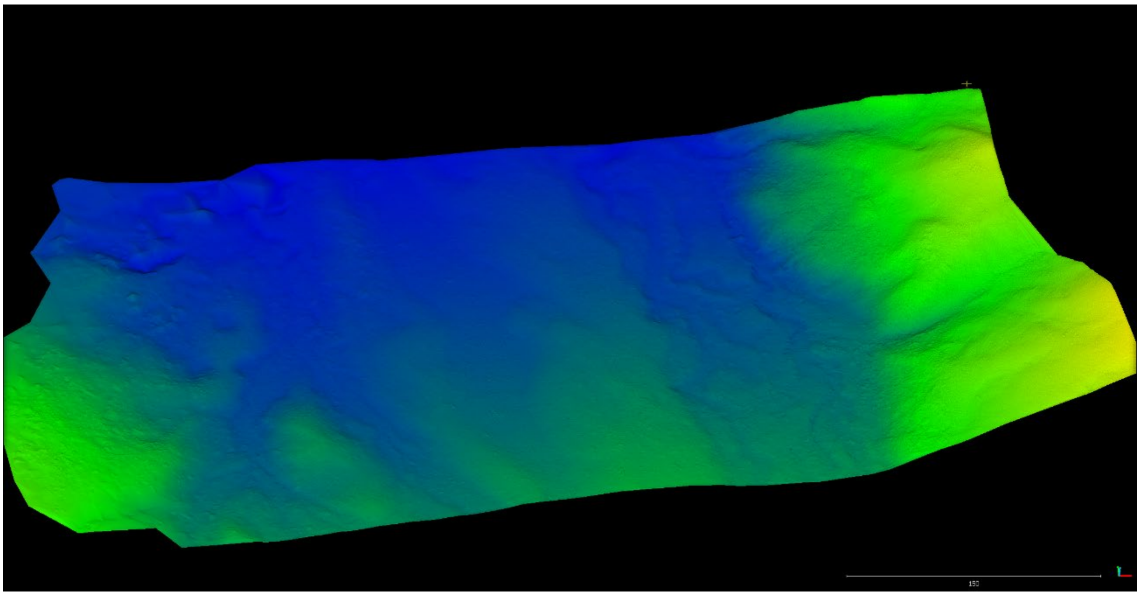


FIGURE 22. UAS LIDAR OF BLAKE'S OPENING SITE #5 WITH TOP POINT CLOUD SHOWING VEGETATION HEIGHT AND BOTTOM MODEL SHOWING BARE GROUND SURFACE.

UAS LiDAR derivatives

Refer to Figure 6 for a canopy height model (CHM) that was derived from the 2018 UAS LiDAR point cloud. Figure 23 shows the height difference between the 2018 and 2020 canopy height models. A negative value indicates a decrease in height value of the maximum canopy height. Figure 24 shows a comparison of a LiDAR derivative of point density for the height stratum 2 – 5 m as a proxy for understory presence. This comparison shows the change in understory extent between pre- and post-fire acquisitions. Figure 25 shows an example of the vertical complexity index (VCI) for Site #4 at Blake’s Opening. The VCI present a proxy for the vertical complexity of forest structure. The higher the VCI value, the more vegetation elements across the vertical profile, e.g. understory, midstory, and overstory.

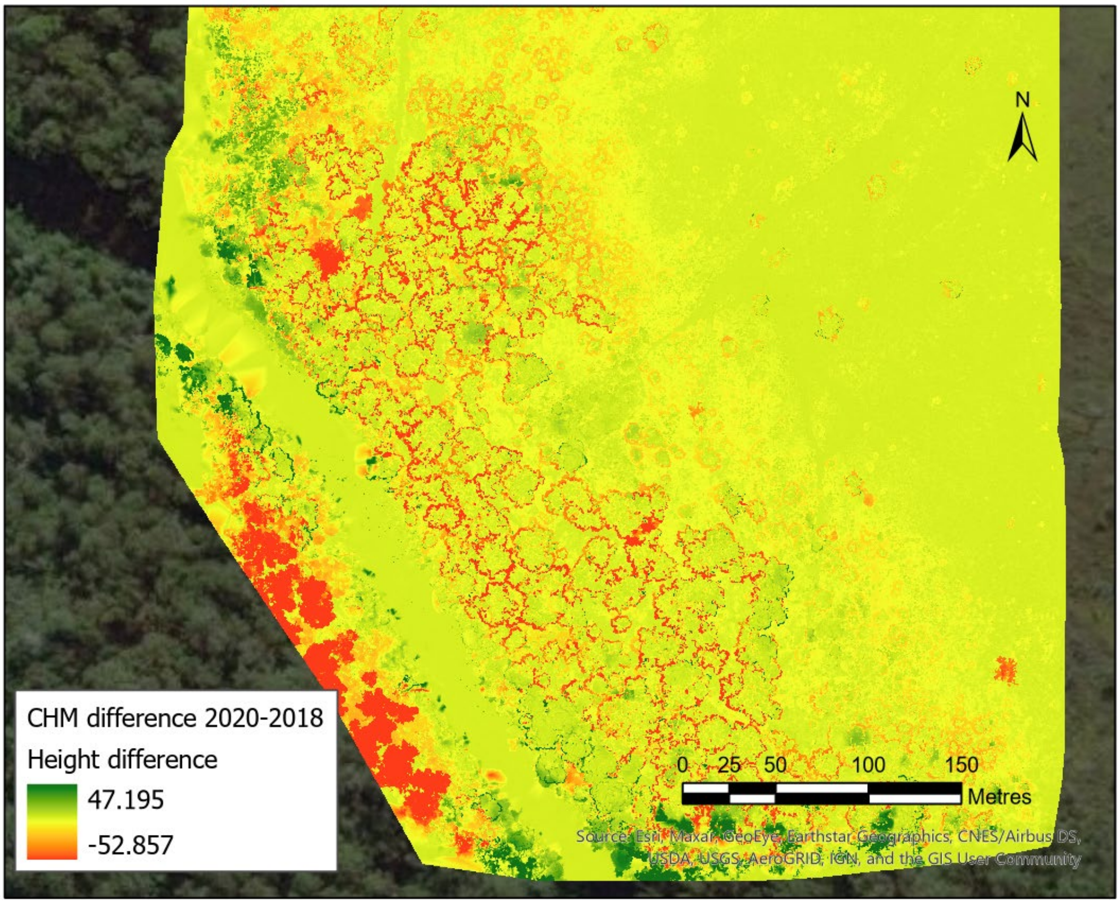
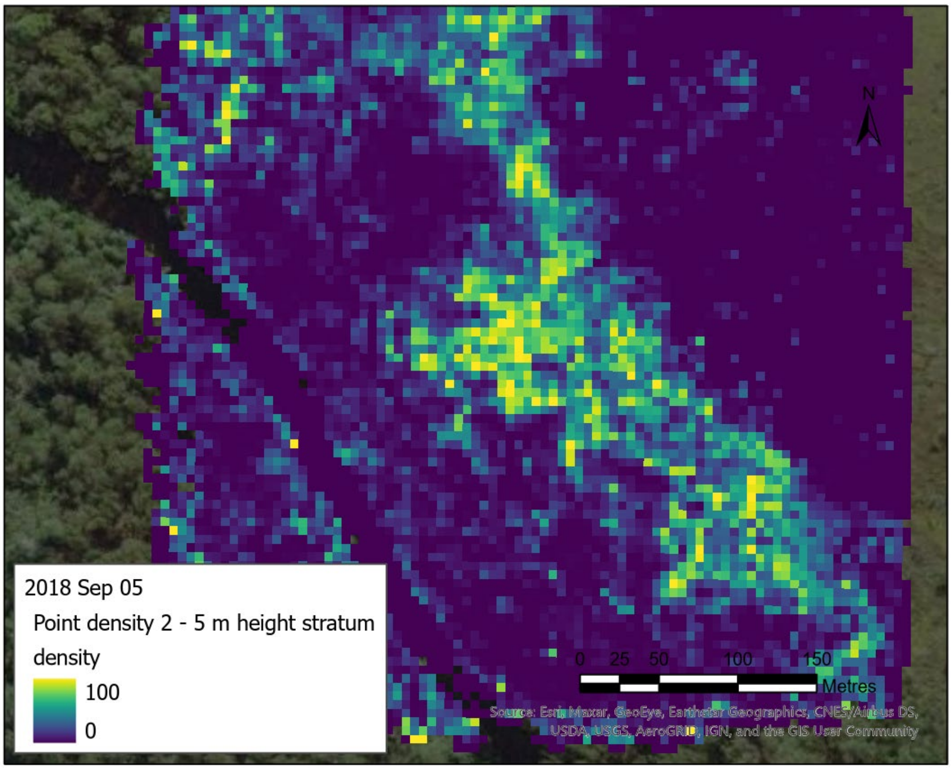


FIGURE 23. DIFFERENCE BETWEEN THE 2018 AND 2020 CANOPY HEIGHT MODELS (CHM)FOR THE WELD RIVER TRANSECT.



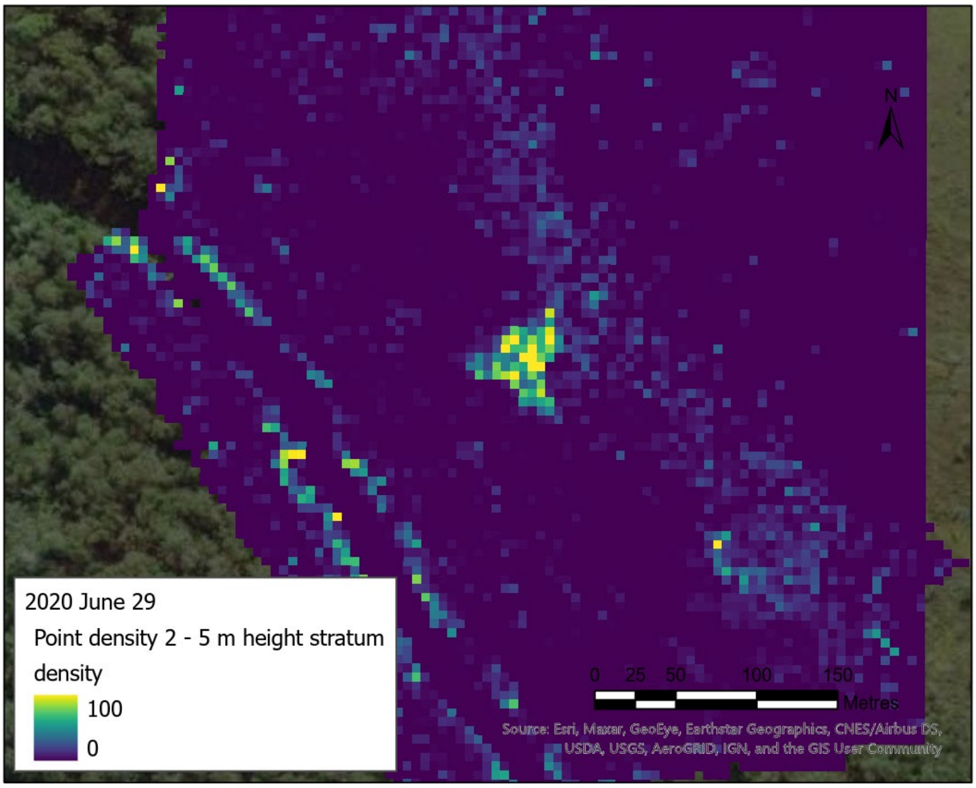


FIGURE 24. COMPARISON OF LIDAR POINT DENSITY IN THE HEIGHT STRATUM OF 2 - 5 M, REPRESENTING THE CHANGES IN UNDERSTORY STRUCTURE.

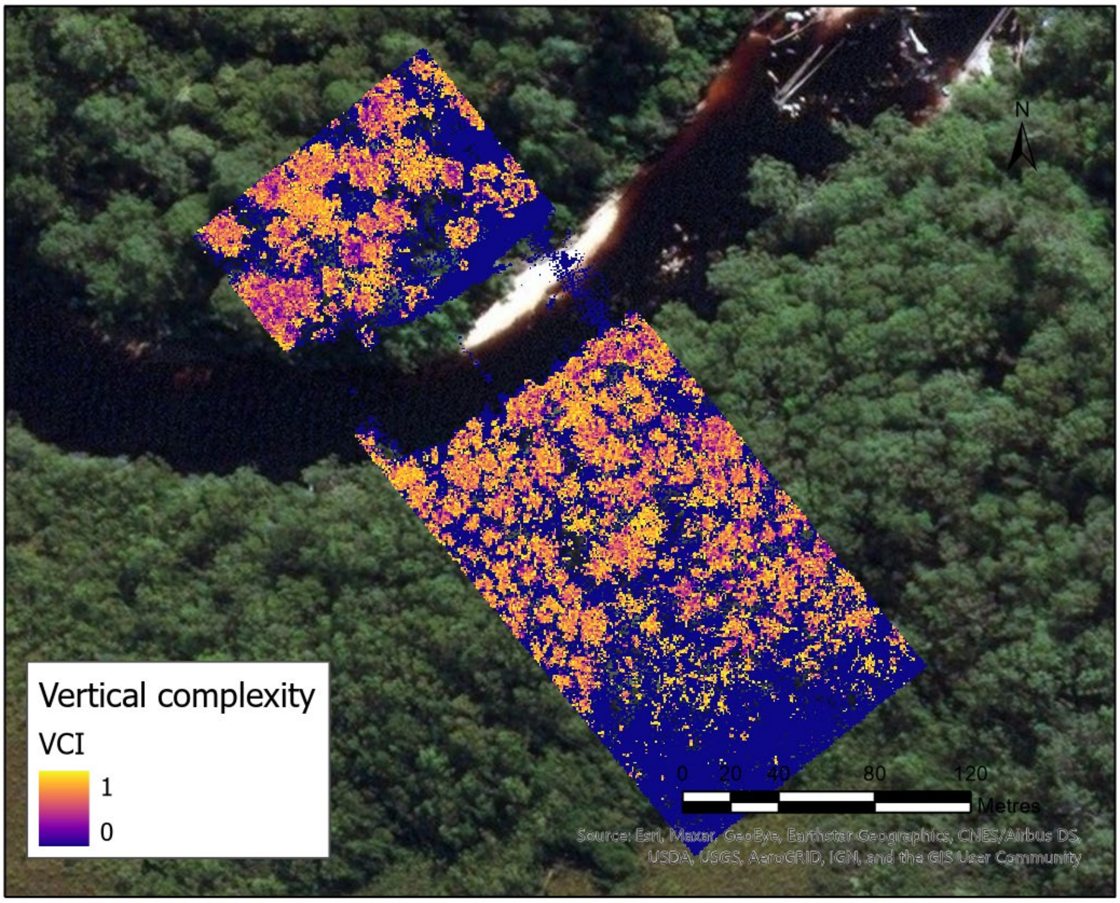


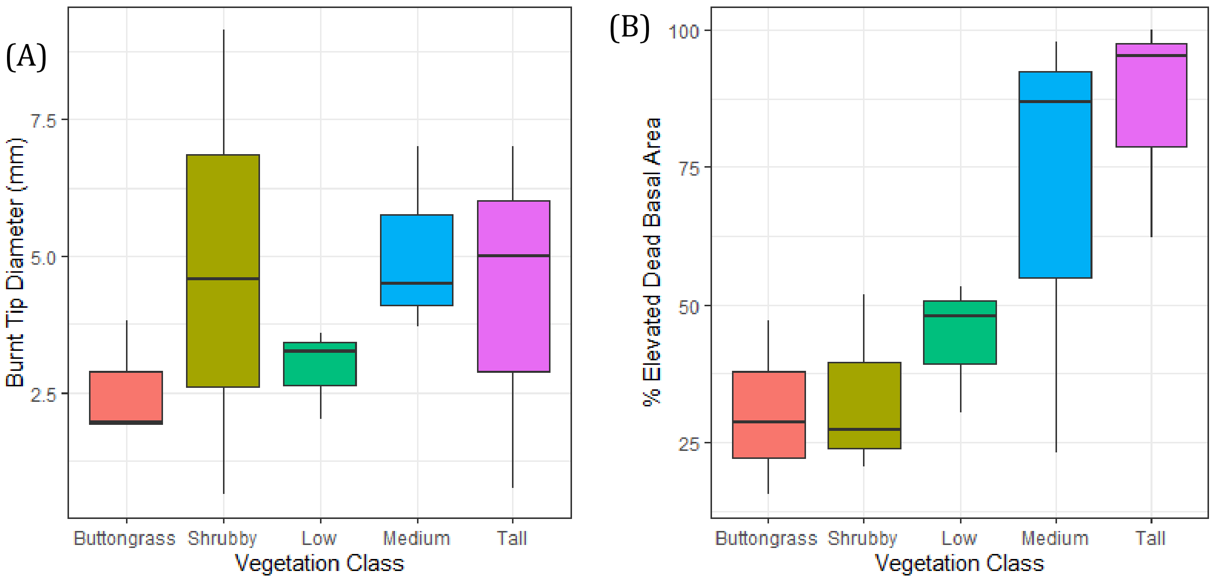
FIGURE 25. EXAMPLE OF THE VERTICAL COMPLEXITY INDEX (VCI) DERIVED FROM THE UAS LIDAR POINT CLOUD FOR SITE#4 AT BLAKE'S OPENING.

FIRE SEVERITY ANALYSES

Fire severity among vegetation classes

Fire intensity, as measured by burnt shrub tip diameter, was the highest in medium, tall, and shrubby forest, and lowest in the low forest (Figure 26a). While values are lowest for the buttongrass, these values are not necessarily comparable to those measured in the forests due to a lack of large shrubs, as buttongrass is known to support intense fires. Importantly fire intensity was highly variable, both within and among transects, but the variability was highest in tall forest and shrubby forest. Understorey survival, as measured by the dead:live ratio in the elevated fuels (Figure 26b), showed a clear trend across the boundary, as taller forest had the highest understorey mortality and shortest forests had the lowest. Meanwhile the inverse was true for overstorey survival, as the tall forests have the highest canopy survival (Figure 26). Lastly, surface fuel load showed clear trends across the buttongrass-forest boundary, with surface fuel loads incrementally increasing from the buttongrass to the medium forests (Figure 26d), possibly reflecting a productivity gradient. The tall forests, however, did not fit neatly into this trend, as fuel loads were highly variable, likely reflecting the high variability of fire severity (Figure 26a).

Canopy consumption in the different strata was also highly variable within all vegetation types (Figure 29), reflecting the mixed severity of the fire and that 16 months of regeneration had occurred before the post-fire LiDAR flight. However, in the tall and medium forests, foliar consumption was lowest in the emergent canopy (20-50 m) and the intermediate canopy (10-20 m), and highest in the elevated fuels (2-5 m and 5-10 m). Foliar loss in the intermediate canopy was highly-variable, reflecting the mix of pyrophilic and pyrophobic species in this canopy layer of wet forests. The fire had the effect of reducing the vertical complexity of shorter forests and buttongrass (Figure 28), but this effect was less substantial in medium forests and almost non-existent in tall forests.



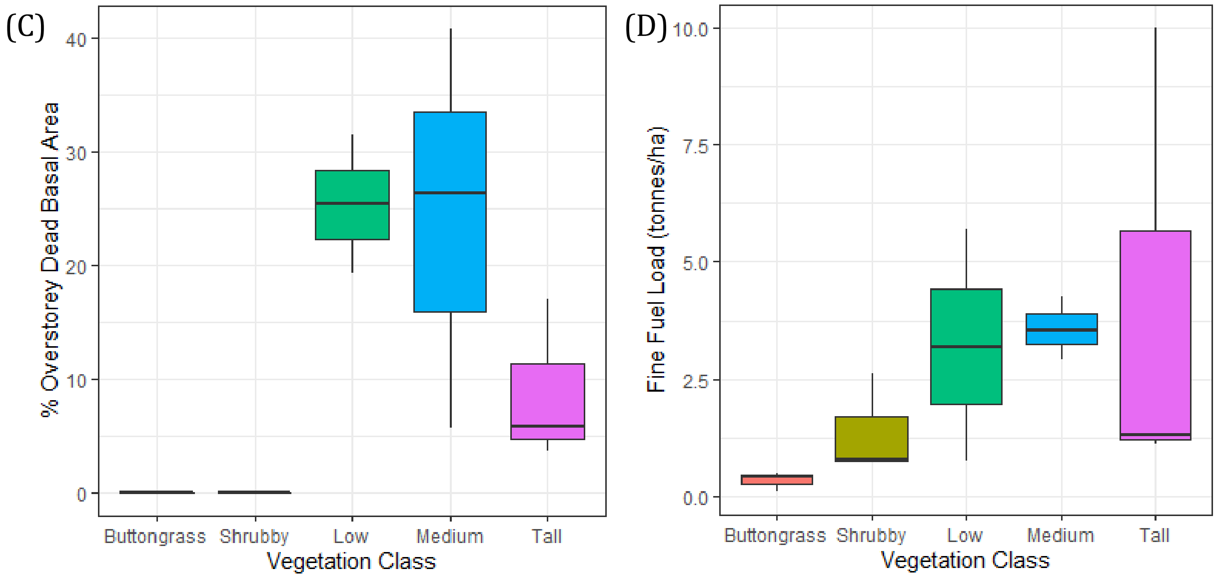


FIGURE 26. BOX AND WHISKER PLOTS CHARACTERISING DIFFERENCES BETWEEN VEGETATION CLASSES IN FIRE SEVERITY AND POST-FIRE FUEL LOAD. (A) DISPLAYS BURNT-TIP DIAMETER, (B) DISPLAYS THE PERCENT OF BASAL AREA PER HECTARE IN KILLED (AS OPPOSED TO RESPROUTING) TREES AND SHRUBS IN THE ELEVATED FUEL LAYER, (C) DISPLAYS THE PERCENT OF BASAL AREA PER HECTARE IN KILLED (AS OPPOSED TO SURVIVING OR RESPROUTING) TREES IN THE CANOPY LAYER, AND (D) DISPLAYS THE FUEL LOAD OF LITTER, TWIGS, AND BARK IN THE SURFACE LAYER.

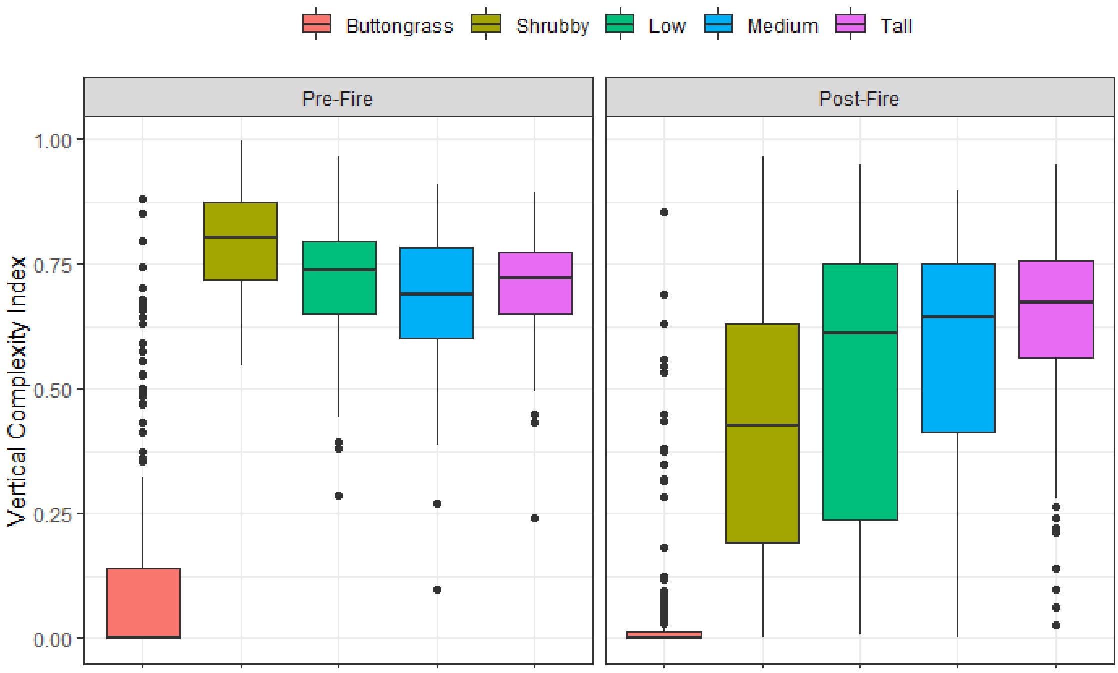


FIGURE 27 VERICAL COMPLEXITY INDEX (VC1) VALUES BEFORE THE FIRE (LEFT) AND AFTER THE FIRE (RIGHT) WITHIN 10M OF EACH TRANSECT BY VEGETATION CLASS. A HIGHER VALUE IS INDICITAVE OF HIGHER STRUCTURAL COMPLEXITY.

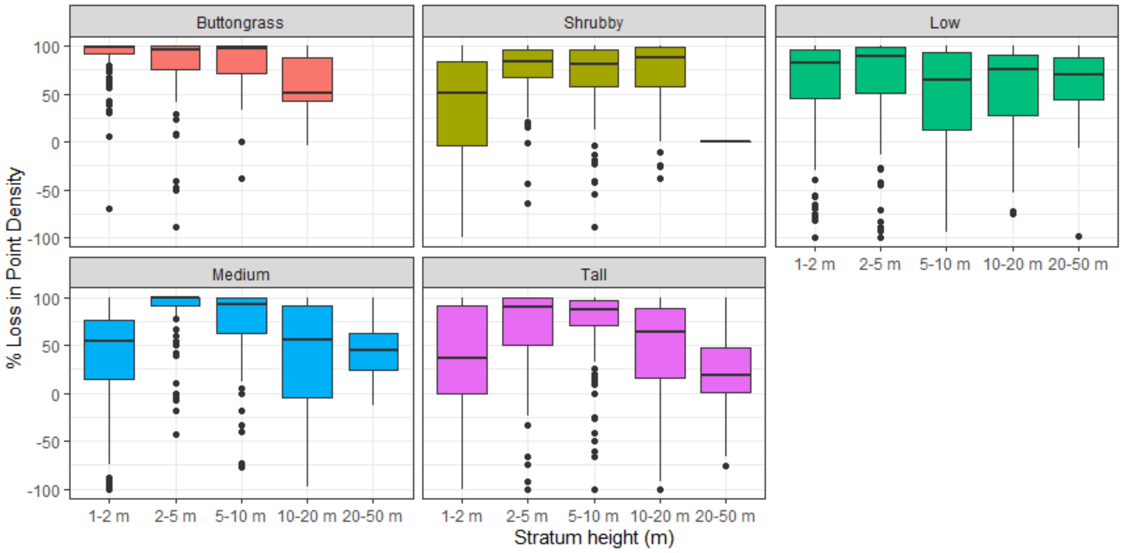


FIGURE 28 FOLIAR LOSS IN 5 DIFFERENT CANOPY STRATA BY VEGETATION TYPE. FOLIAR LOSS IS MEASURED BY THE PERCENT LOSS IN LIDAR POINT DENSITY DUE TO THE FIRE. PANELS AND COLOURS REPRESENT VEGETATION CLASS, AS INDICATED, AND THE X-AXIS REPRESENTS 5 DIFFERENT CANOPY STRATA BASED ON THEIR VERTICAL POSITION.

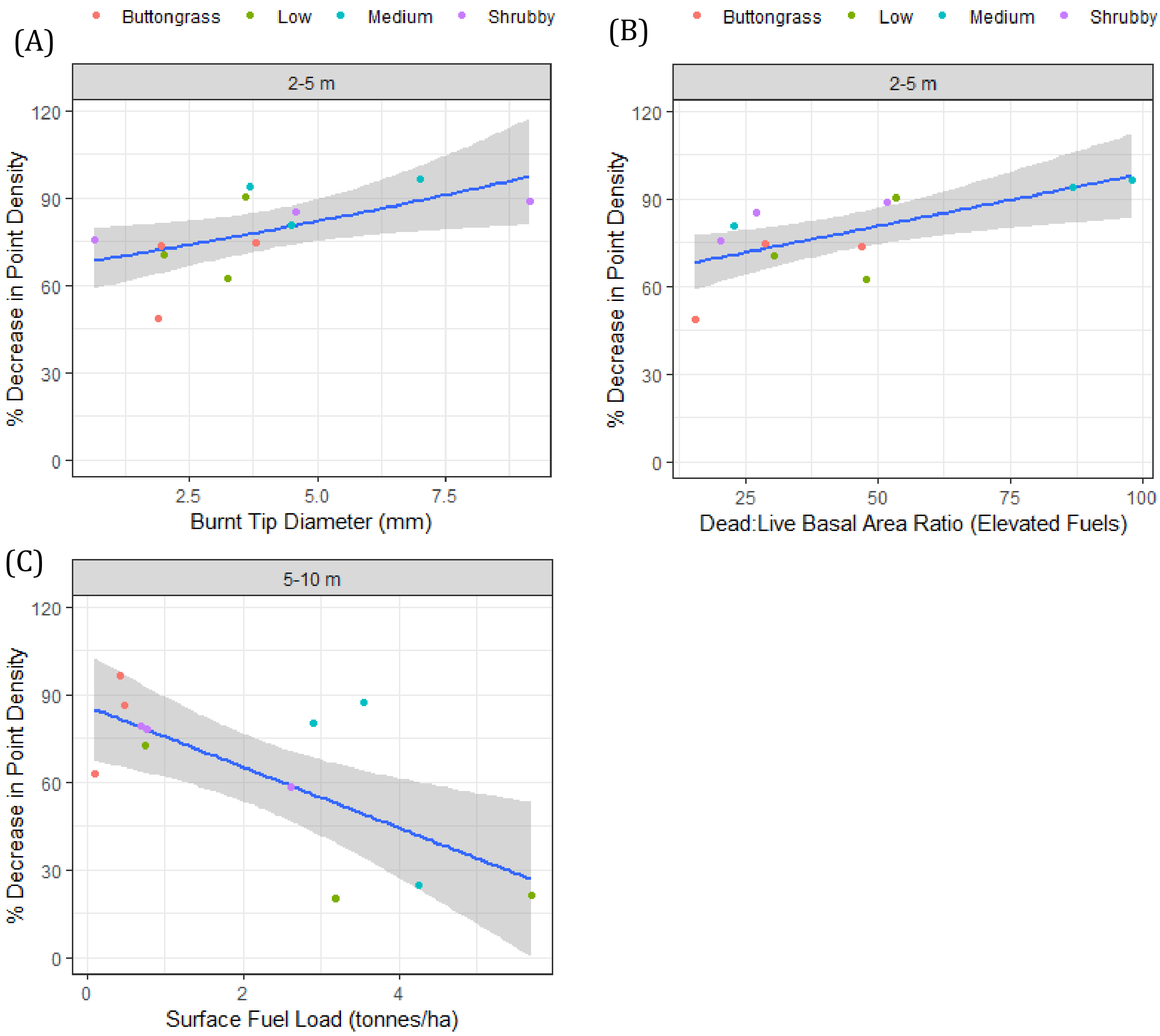


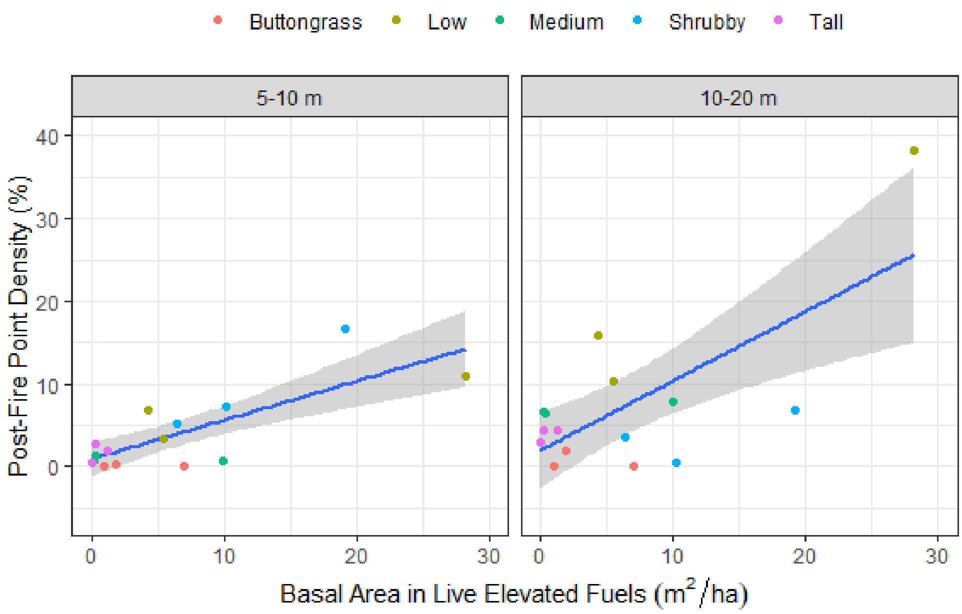
FIGURE 29 SCATTERPLOTS REPRESENTING THE BEST PREDICTORS OF FOLIAR LOSS IN TWO UNDERSTOREY STRATA. FOLIAR LOSS (AS MEASURED BY THE PERCENT DECREASE IN LIDAR POINT DENSITY DUE TO THE FIRE) IS REPRESENTED ON THE Y-AXIS OF EACH PLOT. (A) REPRESENTS THE CORRELATION BETWEEN BURNT TIP DIAMETER AND FOLIAR LOSS, (B) REPRESENTS THE CORRELATION BETWEEN POST-FIRE SURFACE FUEL LOAD AND FOLIAR LOSS, AND (C) REPRESENTS THE CORRELATION BETWEEN POST-FIRE DEAD:LIVE RATIO IN THE ELEVATED FUELS AND FOLIAR LOSS. TO BETTER VISUALISE RELATIONSHIPS, BLUE LINES REPRESENT A GLM FIT AND GREY RIBBONS REPRESENT ONE STANDARD ERROR.

Relationship between field- and LiDAR-based fire severity metrics

Due to the 18-month period between the Riveax Rd fire and the LiDAR remeasurement, many of the relationships between our field-measured fire severity variables and LiDAR-derived canopy defoliation metrics were obscured due to regrowth. However clear patterns emerged in the elevated layer, where many species are fire-sensitive or reporout only basally, indicating that LiDAR is capable of detecting understorey damage to forests even 18 months post-fire. Our analysis revealed strong relationships between foliar loss in the 2-5 m stratum and burnt tip diameter and dead:live basal area ratio (Figure 30a,b), along with a strong relationship between surface fuel load and foliar loss in the 5-10 m stratum (Figure 30c). This latter relationship is reflective of the pyrophobic nature of the understorey species,[Error! Bookmark not defined.] which will drop foliage even after a surface fire, suggesting that the results could be a good indicator of fire severity. It should be noted that Figure 30 excluded the results from the tall forests as the within-transect variability was too high to discern any transect-level trends. For these transects, analysis of LiDAR-derived fire severity will have to be done at the individual plant level.

Capability of LiDAR to detect fuel loads and regeneration

Our results indicated that UAS-based Lidar has the capacity to detect regrowth and fuel re-accumulation 18 months after a fire. Our analysis revealed a strong correlation between the basal area in resprouting plants in the elevated layer and the post-fire point density in the 15-10 and 10-20 m strata (Figure 31a), but the correlation between dead basal area in the elevated layer and point density in the same strata was much weaker (Figure 31b). Lastly, the strongest correlation in all of our analyses was that between our destructively-sampled near-surface fuel load (which included bracken, grass, and all tree seedlings) and the post-fire point density in the lowest forest stratum (Figure 31c), indicating that UAS-based lidar could be used to answer questions about forest regeneration post-fire.



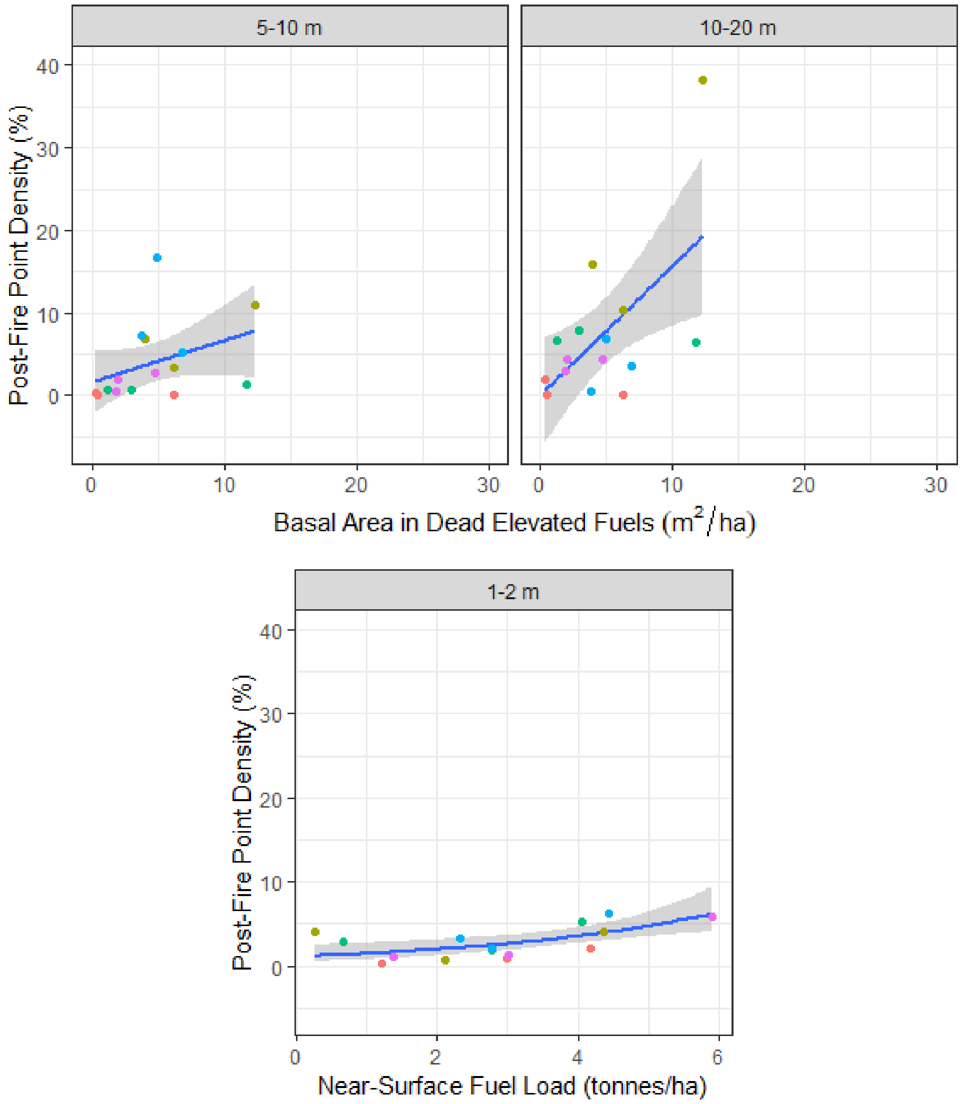


FIGURE 30 DETECTION OF POST-FIRE FUEL ACCUMULATION. (A) REPRESENTS THE CORRELATION BETWEEN POINT DENSITY IN TWO UNDERSTOREY STRATA (AS INDICATED IN THE PANELS) AND THE BASAL AREA OF SURVIVING PLANTS IN THE ELEVATED LAYER. (B) REPRESENTS THE CORRELATION BETWEEN POINT DENSITY IN THE SAME UNDERSTOREY STRATA AND THE BASAL AREA OF KILLED PLANTS IN THE ELEVATED LAYER. (C) REPRESENTS THE CORRELATION BETWEEEN POINT DENSITY IN THE LOWEST STRATUM (1-2 M) AND SURFACE REGENRATION AS MEASURED BY DESTRUCTIVELY SAMPLED NEAR-SURFACE FUEL LOAD. TO BETTER VISUALISE RELATIONSHIPS, BLUE LINES REPRESENT A GLM FIT AND GREY RIBBONS REPRESENT ONE STANDARD ERROR.

Blakes Opening

Elevated and overstorey mortality differences

A total of 1404 shrubs and 388 trees were assessed across the 51 transects. There was a slight difference for elevated mortality across transect types with mortality highest in Buttongrass (~80%) then Forest (~76%) and Scrub (~73%). For overstorey mortality differences were more pronounced with a mortality of 58% for Forest trees and 47% for Scrub trees with no mortality in overstorey fuels in Buttongrass transects where only 4 trees were present. When understorey trees were removed from the analysis we found mortality rates were substantially lower in both Forest and Scrub transects (~13% Forest, ~18% Scrub).

For the broad categories of Eucalyptus, Wet Sclerophyll and Rainforest mortality rate was highest in Rainforest species and lowest in Eucalyptus species. This was true for across fuel types with the difference greater in overstorey fuels then elevated fuels although overall mortality was greater in overstorey trees then elevated fuels possibly due to the higher density of shrubs then trees.

Buttongrass and Ghania mortality and recovery

Both Buttongrass and Ghania showed a similar survival rate with around 90% of assessed tussocks being alive. For buttongrass survival rates was substantially lower in scrub transects compared to buttongrass community (73% vs 95%). No such difference occurred in Ghania tussocks with survival rates virtually even between the two transect types.

Fire recovery rates

Elevated and overstorey fuels

A total of 357 shrubs and 180 trees were assessed as alive with 57 of these shrubs being saplings (seedlings >1.5m). Of the 300 alive shrubs over 95% of these were top killed with basal resprout heights of between 0.1 and 1.2m. For overstorey fuels resprout response was similar with over 90% of assessed live trees having resprouted. Resprouting was present across all broad vegetation classes with resprouting present in both *Anopterus glandulosus and Nothofagus cunninghami trees*.

Seedlings

A total of 16159 seedlings were recorded with the majority of these seedlings found in buttongrass transects. Seedling height varied from 0.1 to 1.5 m with over 80% of seedlings less than or equal to .2m in height whilst less then 1% where between 1-1.5m tall. Seedlings were substantially taller in Forest and Scrub transects then Buttongrass transect. Seedling density was substantially higher in buttongrass transects with almost 12 times as many seedlings per m2 in buttongrass compared to forest transects.

Transect Type	n	Total	Avg Ht (m)	% ht <.2m	% ht >1m	Avg seedling per transect	Avg density (m2)
Buttongrass	26	9726	0.145	0.93	0	374.077	71.685
Forest	12	2364	0.260	0.67	0.027	197.000	6.326
Scrub	13	4069	0.244	0.645	0.009	313.000	34.385
Overall	51	16159	0.187	0.82	0.006	316.843	NA

TABLE 2. BLAKES OPENING SEEDLING OVERVIEW.

CONCLUSIONS

The primary purpose of this project was to obtain high-resolution data with which to assess the severity of the 2019 Riveaux Road Fire in southwest Tasmania. The opportunity to undertake this research was afforded by the 2019 Riveaux Road Fire in southern Tasmania which burned an area for which high-resolution pre-fire LiDAR was available. For this project, post-fire LiDAR was collected, and canopy models and structural derivatives were mapped. These LiDAR derivatives were compared to post-fire on-ground fuel load and fire hazard surveys. We have shown that high-resolution 3D maps of fire severity can be created from UAS-based LiDAR, and specifically that this form of LiDAR is especially effective in mapping the structural variability of forest understorey. We have also shown that 16 months after a mixed severity fire, UAS-based LiDAR is effective at detecting regeneration in the near-surface and elevated fuel layers. Finally, we have documented broad trends in fire severity suggesting that fire severity may have been higher in younger stands, however these results are not conclusive and more research is needed.

The forest plot data collected in this project will contribute to a world-class Australia-wide dataset of pre- and post-fire fuels data in tall wet eucalypt forests, including fuel and fire hazard surveys, LiDAR data, and microclimate data. This will allow for ground-breaking research on fire behaviour in one of the world's most complex forest types. The buttongrass-forest boundary transects provide an excellent framework for further research into the environmental controls of these vegetation boundaries.

FUTURE USE OF OUTCOMES

This project will serve as the starting point to answering a number of fundamental questions about wildfire behaviour and effects in tall wet euclaypt forest and buttongrass, as well as the use of LiDAR to characterise these. Data from this project will contribute to the answering of the following research questions:

FIRE REGIMES OF TALL WET EUCALYPT FORESTS

Research Question(s): What are the drivers of fire severity in wet eucalypt forests? What are the effects of low-severity fires and different forms of silviculture on fire hazard? What forms of forest management best mimic natural fire regimes and reduce fire hazard?

Research Team: James Furlaud, Scott Foyster, Grant Williamson, Lynda Prior, David Bowman

Funding Source: Natural Disaster Risk Reduction Grant Program (NDRRGP) - Social and biophysical effects of alternative strategies to reduce bushfire danger in Hobart.

DISTRIBUTION OF BUTTONGRASS AND RAINFOREST IN SOUTHWEST TASMANIA

Research Question(s): Are vegetation and soil patterns independent of soil parent material in western Tasmania? Does vegetation type govern fire hazard in western Tasmania? Are sedgeland–forest boundaries controlled by soil factors shaped by fire and vegetation, or geophysical factors? Does a fire-soil-vegetation interaction best explain the vegetation patterns in western Tasmania?

Research Team: David Bowman, Lynda Prior, Jamey Furlaud, Scott Foyster

Funding Source: ARC Discovery Grant Does fire control vegetation in the Tasmanian World Heritage Area?

EFFECTIVENESS OF LIDAR IN CHARACTERISING FIRE SEVERITY IN FORESTS

Research Question(s): How well can aerial and UAS-based LiDAR capture defoliation and consumption of different layers of forest canopy. What does this tell us about the effect of fuels, weather, and topography on fire severity in different forests of the world? Can we use LiDAR data to validate fire behaviour models?

Research Team: Arko Lucieer, James Furlaud, David Bowman

Funding Source: Potential ARC Linkage Grant or Discovery Early Career Research Award (DECRA) Grant.

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APPENDIX A: METADATA

LEVEL 3 METADATA

Point Severity Data Field	Unit	Description
Site	Number	Unique site identifier for Level 3 methodology
Site Name	Text	Name of previously established permanent plot (if applicable)
Site Location	m	Location (in Easting and Northing – GDA 1994 MGA Zone 55) of point where data is collected.
Date	Date	The date on which the data was collected
Veg Type	Text	The vegetation type of the site that the data is being collected out
Logging/Disturbance	Text	Details if the site has had a known disturbance and the type and year when that disturbance occurred.
Understorey Crown Scorch	%	Percentage of crown scorch for all understorey trees within 10m radius of site
Canopy Crown Scorch	%	Percentage of crown scorch for all canopy trees within 10m radius of site
Burnt surface	%	Percentage of surface burnt by fire in a 5 m radius of site
Rock Cover	%	Percentage of rock cover in a 5m radius of site
Slope	°	Slope (degrees) of site taken at 10m distance as per methodology
Aspect	°	Aspect (degrees) taken in degrees at 10m distance as per methodology.
Dead	Binary	1=Dead, 0=Alive. Dead is absence of green leaves as per methodology.
Basal	Binary	1=Basal resprouting is present and 0=Basal resprouting absent
Epicormic	Ranking	0-5 scale ranking epicormic resprouting on the vigorous of it. 0 is no epicormic, 1 to 5 is a scale as outlined in methodology
Undamaged	Binary	1=tree/woody stem is alive and with no resprouting, 0=tree is dead/resprouting.
Crown Scorch	%	Percentage of Crown scorch of individual woody stem
Species	Text	Details the species of the woody stem being assessed
Notes	Text	Details any extra notes about the woody stems

LEVEL 2 METADATA

Sheet Name	Description
Fuel Weights	Masses of dead fine fuels, coarse fuels, and near-surface fuels collected from quadrats
Elevated fuels	Structure, density, and charring of live and dead plants in the elevated layer
Downed wood	Count and diameter of downed logs intersecting fuel transects
Trees	Dimensions, charring, and other severity measures for non-stringy bark trees with >10cm DBH adjacent to fuel transects
Hazard Scores	Qualitative Hazard Scores (Hines et al 2010) and visually estimated structural attributes

Fuels Weights data field	Unit	Description

Date	Date	Date on which observation was collected
Site Name	Text	Name of previously established permanent plot
Transect	Letter	Transect Identifier, see section 9.1 of the Ausplot Survey Manual.
Quadrat	m	Location of 1x1m quadrat on transect as measured by distance from the start of the transect Either (7m or 21m)
Type	Categorical	Type of fuel measured
Wet Weight	g	Field weight of given fuel type in quadrat
Dry Weight	g	Oven-dry weight of given fuel type in quadrat
Oven Dried?	Binary	Was the given sample oven-dried? If no, dry weight was calculated as opposed to measured

Elevated Fuels data field	**Unit**	**Description**
Subplot	m	Location along transect (in m from the start of the transect) of the subplot in which five plants were measured
Basal Diameter	cm	Diameter at the base of the stem for the given plant
DBH	cm	Diameter of the stem at breast height (1.3m) for the given plant
Height	m	Height of plant
Char Height	m	Highest point of charring on plant stem
Stem Length	m	Length of stem (applicable to tree ferns only)
Burnt Tip Diameter	mm	Average diameter of all charred branch tips between 0.75 and 1.5m above the ground
Canopy Width	m	Estimated width of widest part of the individual's tree crown if projected onto the ground
Canopy Length	m	Estimated width of individual crown perpendicular to above measurement
Life Form	Categorical	Growth form (e.g. shrub, tree, tree fern, etc.) of plant
Live/Dead	Categorical	Is plant alive?
Rectangle Length	m	Length of rectangle surrounding five plants in subplot
Rectangle Width	m	Width of rectangle enclosing 5 plants in subplot
# Stems	Number	Number of stems for the given plant if there are more than 1 at the height at which diameter was measured

Downed Wood data field	**Unit**	**Description**
Small Woody Fuel Count	Number	Count of small woody fuels (<7.6cm and >2.5cm diameter) intersecting transect along two 2m subsections as indicated
Large Woody Fuels	cm	Diameters of all large woody fuels (>7.6 cm diameter) intersecting transect.

Trees data field	**Unit**	**Description**
Tag #	Number	Number of identification tag nailed to tree

SPP	Categorical	Four letter species code for tree
DBH	cm	Diameter of the stem at breast height (1.3m) for the given plant
Max Scar Ht	m	Highest point of charring on plant stem
Live/Dead	Categorical	Is tree alive
Canopy Scorched %	Percentage	Percent of tree crown that was scorched by fire
Defoliated	Binary	Is the tree defoliated?
Epicormic	Binary	Is there epicormic resprouting on tree?
Basal Regrowth	Binary	Is there basal resprouting on tree?

Hazard Score data field	**Unit**	**Description**
Height to Crown Base	m	Height from ground to lowest point on stem at which crown encircles >1/3 of the stem
Bark Hazard	Categorical	Qualitative hazard score for eucalyptus overstorey bark
Elevated Pct. Cover	%	Estimated percent cover of fuels in the elevated layer
Elevated Pct. Dead	%	Estimated percent dead material in the elevated layer
Elevated Ht.	m	Estimated height of the elevated layer
Elevated Hazard	Categorical	Qualitative hazard score for fuels in the elevated layer
Near-Surface Pct. Cover	%	Estimated percent cover of fuels in the near-surface layer
Near-Surface Pct. Dead	%	Estimated percent dead material in the Near-Surface layer
Near-Surface Ht.	m	Estimated height of the Near-Surface layer
Near-Surface Hazard	Categorical	Qualitative hazard score for fuels in the Near-Surface layer
Surface Pct. Cover	%	Estimated percent cover of litter on the forest floor
Surface Depth	cm	Depth of litter on the forest floor as measured at 5 random points within 5m of assessment point
Surface Hazard	Categorical	Qualitative hazard score for the surface fuels

LEVEL 1 METADATA

Overstorey Severity Data Field	**Unit**	**Description**
Site Name	Text	Name of previously established permanent plot
Date	Date	The date in which the survey took place
Surveyor	Text	The person who did the surveying
Tree id #	Number	Details the Ausplot id number of the tree/stem being assessed
Species	Text	Details the species of the tree/stem being assessed, see methodology notes for abbreviations/names used

Dead	Binary	1=Dead, 0=Alive. Dead is absence of green leaves as per methodology.
Canopy Scorch	%	Percentage of canopy scorched for tree being assessed.
Epicormic	Binary	1=epicormic present and 0=epicormic absent
Basal Regrowth	Binary	1=Basal resprouting is present and 0=Basal resprouting absent
Notes, DBH, Char Height	Text/Number	Details any relevant notes taken in field including notes, DBH (cm) if new or unidentified tree and char heights of trees (m).

UAS-BASED LIDAR VALIDATION TRANSECTS

Overview

Data Category	Description
Fuel Weights	Masses of dead fine fuels, coarse fuels, and near-surface fuels collected from quadrats
Elevated fuels	Structure, density, and charing of live and dead plants in the elevated layer
Downed wood	Count and diameter of downed logs intersecting fuel transects
Overstorey Fuels	Dimensions and severity measures for 5-10 closest trees >10cm DBH within 15m plot radius of centre of transects
Transect Seedlings	Height, location and species of seedlings that intersect transect tape
Transect Dominant Cover	Type and start and end points of dominant vegetation along transect
Transect Buttongrass	Height and location of buttongrass that intersect
Quadrat Seedlings	Total number and average height for each species seedlings in quadrats
Quadrat Bracken and Buttongrass	Average height and total number of bracken and buttongrass in quadrats.

Data fields by category

Fuels Weights data field	Unit	Description
Date	Date	Date on which observation was collected
Site	Text	Name of burnt site
Transect	Letter	Transect Identifier, see section 9.1 of the Ausplot Survey Manual (Wood et al 2015).
Quadrat	m	Location of 1x1m quadrat on transect as measured by distance from the start of the transect Either (7m or 21m)
Type	Categorical	Type of fuel measured

Dry Weight	g	Oven-dry weight of given fuel type in quadrat
Elevated Fuels data field	**Unit**	**Description**
Subsection	m	Location along transect (in m from the start of the transect) of the subplot in which five plants were measured
Basal Diameter	cm	Diameter at the base of the stem for the given plant
DBH	cm	Diameter of the stem at breast height (1.3m) for the given plant
Height	m	Height of plant
Stem Length	m	Length of stem (applicable to tree ferns only)
Scorch Height	m	Height of leaf scorching on plants that did not lose all green foliage
Char Height	m	Highest point of charring on plant stem
Resprout Height	m	Highest point of resprouting on plant stem
Burnt Tip Diameter	mm	Average diameter of all charred branch tips between 0.75 and 1.5m above the ground
Canopy Width	m	Estimated width of widest part of the individual's tree crown if projected onto the ground
Canopy Length	m	Estimated width of individual crown perpendicular to above measurement
SPP	Categorical	Four letter species code for tree
Shrub Location	m	Location along transect (in m from start of transect) and distance from transect (in m Left (L) or Right(R))
Life Form	Categorical	Growth form (e.g. shrub, tree, tree fern, etc.) of plant
# Stems	Number	Number of stems for the given plant if there are more than 1 at the height at which diameter was measured
Basal or Epicormic Sprouting?	Categorical	B indicates presence of basal sprouting, E indicates presence of epicormic sprouting
Live/Dead	Categorical	Is plant alive?
Rectangle Length	m	Length of rectangle surrounding five plants in subplot
Rectangle Width	m	Width of rectancle enclosing 5 plants in subplot
Downed Wood data field	**Unit**	**Description**
100-hr Count (5-9)	Number	Count of small woody fuels (<7.6cm and >2.5cm diameter) intersecting transect along two 2m subsections as indicated

100-hr Count (19-23)	Number	Count of small woody fuels (<7.6cm and >2.5cm diameter) intersecting transect along two 2m subsections as indicated
1000-hr Count	Number	Count of all large woody fuels (>7.6 cm diameter) intersecting transect.
Individual Diameters	cm	Diameters of all large woody fuels (>7.6 cm diameter) intersecting transect.
Ind. % Volume Burned	Proportion	Proportion of cross sectional surface area lost in fire (corresponds to respective columns in 'individual diameter' measurements section)
Overstorey	**Unit**	**Description**
Tag #	Number	Number of identification tag nailed to tree
SPP	Categorical	Four letter species code for tree
DBH	cm	Diameter of the stem at breast height (1.3m) for the given plant
Post Fire Status	Categorical	Is tree alive
Epicormic Resprouting	Perecentage	What percentage of epicormic resprouting is there?
Canopy Resprouting	Percentage	What percentage of canopy resprouting is there?
Basal Resprouting	Binary	Is there basal resprouting on tree?
Canopy Scorched %	Percentage	Percent of tree crown that was scorched by fiire
HCB	m	Height to the base of canopy
HTR	m	Height to the start of resprouting
Ht	m	Height to the top of canopy
Plot radius	m	Diameter of plot radius taken from 15m mark of transect to furthest assessed tree
Transect Seedlings	**Unit**	**Description**
Transect	Categorical	Name of Transect
Location	m	Location along transect (in m from start of transect) where seedling intersects
SPP	Categorical	Four letter species code for seedling
Height	m	Height of individual seedling
Transect Dominant Cover	**Unit**	**Description**
Transect	Categorical	Name of Transect
Start	m	Location along transect (in m from start of transect) where dominant ground cover begins
End	m	Location along transect (in m from start of transect) where dominant ground cover ends

Dom Ground cover	Categorical	Description of dominant ground cover
Transect Buttongrass	**Unit**	**Description**
Transect	Categorical	Name of Transect
Location	m	Location along transect (in m from start of transect) where centre of Buttongrass tussock intersects the transect
Height	m	Height of Buttongrass tussock
Status	Binary	Is buttongrass tussock alive or dead?
Quadrat Seedlings		
Transect	**Categorical**	**Name of Transect**
Quadrat	Categorical	Name of fuel quadrat (in m from start of transect) where seedlings
Location	m	Location along transect (in m from start of transect) where seedling intersects
SPP	Categorical	Four letter species code for seedling
Total	Number	Total number of each species seedlings in each quadrat
Avg Height	m	Average height of seedlings for each species in quadrat
Quadrat Buttongrass and Bracken		
Transect	**Categorical**	**Name of Transect**
Quadrat	Categorical	Name of fuel quadrat (in m from start of transect) where seedlings
Location	m	Location along transect (in m from start of transect) where seedling intersects
SPP	Categorical	Is the species Bracken or Buttongrass?
Total	Number	Total number of each species seedlings in each quadrat
Avg Height	m	Average height of seedlings for each species in quadrat