BLACK SUMMER 2019–20 RESEARCH

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YANCHEP BUSHFIRE ANALYSIS

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Cover: Yanchep Bushfire, September 2020.This area is the transition zone between limestone heath and banksia woodland. It was prescribe burnt 2019 and escaped the bushfire. Image: Joe Fontaine

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ACKNOWLEDGMENTS

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We acknowledge the Whadjuk people of the Noongar nation as the traditional custodians of this country and its waters and that Murdoch University and the Yanchep bushfire stand on Noongar country. We pay our respects to Noongar Elders past and present, and acknowledge their wisdom and advice in our research activities.

Data and support for this project came from the Terrestrial Ecology Research Group at Murdoch University and Bushfire Science team at DBCA/Kings Park. Willa Veber deserves particular thanks for data collection and management of data in this report. Patrick Armstrong and Melissa Blake provided invaluable field and lab support for accomplishing the heathland sampling in 2021.

Dr Ryan Tangney, Dr Ben Miller, and Mr Russell Miller contributed to many discussions on fuel loads and implementation of data analysis.

Spatial analyses and assessment of fire severity profited massively from collaboration with DBCA Biodiversity and Conservation Science – Ricky Van Dongen implemented random forest analyses and along with Bart Huntley helped give a lot of coding suggestions. Valerie Densmore contributed spatial data and together with Leigh Sage contributed to incredibly helpful conversations around fire management and operational considerations.

We emphatically thank the Bushfire and Natural Hazards CRC for their support, enabling us to take advantage of the Yanchep bushfire as an important learning opportunity.

EXECUTIVE SUMMARY

The Yanchep bushfire occurred in 11-15 December 2019 and was one of several noteworthy bushfires in Western Australia during the summer period. This bushfire coincided with some of the worst fire behaviour in NSW and Victoria and all were influenced by related climate processes. The Yanchep bushfire burned over ~12,300 ha spanning a diverse range of vegetation types (coastal dunes and heath, limestone heath, woodlands) and fire management histories.

Despite rapidly expanding literature on fire severity classification, drivers of fire behaviour, and other important operational considerations key knowledge gaps remain in Western Australia. The Yanchep bushfire represents an excellent opportunity to develop fire knowledge for the Western Australia fire community and contribute to growing local fire science capacity. This project sought to classify fire severity using two complementary approaches, map vegetation at a finer scale than previously available, determine baseline biomass and fuel loads across key vegetation types, and assess the roles of fire weather, vegetation, and prior management in determining fire severity.

We were able to classify fire severity successfully (with 78% accuracy) using both field-based training data as well as a battery of remote sensing metrics. Vegetation mapping using soil types and field validation yielded a higher quality map than previously available. Fuel load estimates provide an important range of values across vegetation types and fire histories. Lastly, examining bushfire severity in relation to prior fire, fire weather, and vegetation type showed clear interactions of previous fire in the prior 2-3 years,with beach-associated vegetation burning at lower severity, and limestone heath burning at higher severity.

Collectively, these characteristics provide key insights for end-users in WA and more broadly, enabling fire severity mapping, informing fire operations, providing finer grained vegetation maps and fuel loads, and enabling an understanding of how prescribed burning in coastal plain vegetation types can influence bushfire spread and suppression.

Future applications of this work will hopefully include:

1) Fire severity mapping across the Swan Coastal Plain and then the entirety of the southwestern conservation estate managed by DBCA and eventually all land tenures.
2) Scaling up this proof of concept work to update vegetation maps and associated fuel load estimates in the Perth region. Such products are urgently needed by end-user organisations such as DFES, DBCA, and local government.
3) The basic reconstruction analyses presented in this report can be readily extended to incorporate broader data sets and more nuanced analyses to reveal the interplay of vegetation type, fire history, and fuels-fuel moisture dynamics.
4) Ecological feedbacks to fuel loads and bushfire hazard. Many areas experienced short interval fires and continued efforts can reveal the impact on vegetation regrowth and flow through effects on fuel loads

and overall bushfire hazard (i.e. changed composition and structure effects on future bushfire hazard).

END-USER PROJECT IMPACT STATEMENT

Jackson Parker, *Department of Fire and Emergency Services, WA*

The south-west of Western Australia provides an example of the complexity of bushfire management. In this region rapid urban development has given rise to an extensive urban-rural interface which presents both fire managers and policy makers with substantial challenges on the issues of urban planning, bushfire response and bushfire risk management. This situation is exacerbated by a landscape located within an internationally recognised biodiversity hotspot, with highly specific environmental needs, a diverse geomorphology and sites of cultural significance to the Noongar people. This produces a complex fire-management environment where multiple objectives compete against each other for limited resources. The area burned by 2019 Yanchep bushfire is representative of such a landscape.

The research described in this report addresses the need to better inform the management of bushfire across the south-west in general, and, more specifically, in the rapidly expanding coastal suburbs of the Greater Perth Region. Here, the potential to rapidly and accurately utilise remotely sensed data to quantify bushfire fuel characterstics for the purposes of bushfire risk management and response are well demonstrated. As gathering data of this type through field work can be a slow and costly process, the capacity to quickly and effectively supplement and enhance this data through remote sensing is seen by DFES as a high priority. This need was recognised during by the Keelty (2011) report into the Margaret River Bushfires which, in Recommendation 5, that states "The Department of Environment and Conservation be supported to conduct further research into the fuel management of coastal heath in the south west of Western Australia,". In addition the Fergusen (2016) report into the Waroona Bushfires, Opportunity 5, recognises the need for "the Departments of Fire and Emergency Services and Parks and Wildlife (and, when established, the Rural Fire Service) to investigate options for improving aerial and satellite-based bushfire intelligence gathering".

This research demonstrates a methodology for applying field collected data to the validation and refinement of satellite-based predictions of bushfire fuel characteristics and their influence on bushfire behaviour at near real time. Potentially, this research has can be applied to informing fuel management activities, bushfire behaviour modelling, urban planning processes and post-fire recovery.

PRODUCT USER TESTIMONIALS

Ben Miller, *Department of Biodiversity, Conservation and Attractions, WA*

This report represents a number of important steps towards better understanding of fuels systems and fire dynamics in a complex and poorly understood mosaic of vegetation on Perth's doorstep. The Yanchep fire illustrated perfectly the risk that this system poses to Perth's northern suburbs and nearby natural values. By making these steps, the report additionally identifies directions needed for further investigation and, importantly, likely fruitful approaches for that work.

The study also includes several useful products:

- the verification of the relationship between on-ground burn indices and remotely sensed severity classification approaches in this system, confirming the utitlity of these approaches in this system – and showing where it performs bests, and worst.
- a preliminary but detailed, fuel type map – which confirms the complexity of fuel structure across the area
- quantification of fuel loads and accumulation rates across the fuel types. This identifies two vegetation types – Tall Coastal heath and Limestone heath – as having perticulary high loads in longer unburned phases, and that these high values may establish within 7-15 after fire
- the analysis of drivers of fire severity within the bushfire, is the first of its kind, locally at least, examining fuel agae and type and weather conditions. The analysis shows the potential for this approach as a powerful tool for interpreting fire behaviopur and risk.
- The documentation of severity patterns within one short-interval burnover event, where the wildfire ran over an area recently prescribed burned. This shows how burn completion influences fire oucomes in a case study.

INTRODUCTION

Tragedies such as the Black Summer bushfires offer important learning opportunities to understand drivers, predictors, and impacts of fire. The expanding research base from Victoria and New South Wales has increasingly pointed at preceding drought and fire weather during the events as leading drivers (Bowman et al 2021, Boer et al 2020). In turn these climate drivers influenced attributes like live fuel moisture, making biomass available to burn that would not have been so historically (Nolan et al 2020). These recent contributions sit within longer running and broader lines of research regarding the role of litter fuels, past fire and forest management to bushfire rate of spread, intensity and severity. The majority of the recent literature has focused on SE Australia and forested vegetation types despite the wide geography and span of vegetation types impacted by the Black Summer bushfire season.

The weather patterns occurring in southeastern Australia from ~September 2019 – January 2020 were extreme and interacted with antecendent drought. While the areas of intense drought were restricted to southeastern Australia, the meteorological events extended across the whole of southern Australia. For example, spring 2019 in southwestern Australia was also marked by long runs of hot days and summer magnitude temperatures occurring much earlier. Large fire events in WA included the Yanchep Bushfire, Stirling Ranges, and Great Western Woodlands spanning 11 December 2019 to mid-January 2020.

In Western Australia, vegetation types impacted by Black Summer bushfires were distinct from those in eastern Australia and exist in a context of annual summer drought, something not typical for eastern Australia. Because of these key differences, and some important data gaps, reconstruction of bushfire impacts and providing key baseline measurements such as fire severity, vegetation distribution, and fuel loads represent important contributions to end-users in the region. Funding from the Bushfire and Natural Hazards CRC has enabled this work to proceed.

Over the five-month period of this project we sought to exploit existing data, collect some additional information and synthesise it to provide the following outputs for the 2019 Yanchep Bushfire:

1) Fire severity classification
2) Vegetation mapping
3) Fuel load estimation for multiple vegetation types
4) Assess the relative contribution of prescribed burning, fire weather, and vegetation to fire severity.

BACKGROUND

FIRE SEVERITY

Fire severity is a fundamental attribute of the fire regime and its classification has a long history pre-dating remote sensing. In both fire operations and fire science there are clear benefits to having quantitative estimates of fire impacts. Operationally, treated blocks have been considered in a homogeneous fashion without regard to fuel consumption and therefore future security during bushfires or as edges for further prescribed burns. By quantifying severity, a correlate of fuel consumption, operational decisions may become finer grained and more strategic. From a fire science and biodiversity point of view, fire severity quantification may be compared over pertinent timeframes and contrasted against species life history needs and used to inform conservation efforts and management recommendations.

Since NASA made the LandSat archive open access the volume of remote sensing research on fire has expanded rapidly. The Monitoring Trends in Burn Severity (MTBS; mtbs.org) program in western North America has been a noteworthy contributor by generating fire severity maps for every mapped fire on publicly owned land since 1985 (start of LandSat 5 which enabled estimation of burn indices with availability of IR spectrum). Since the inception of the MTBS program, a persistent challenge has been the optimisation and correct classification of remotely sensed burn indices. Key and Benson (2006) developed the Composite Burn Index (CBI) in the USA. Collected in postfire settings, the CBI yields a score of 0-3, capturing the key attributes impacted by fire and influencing reflectance in satellite pixel values. These include soil change, combustion of surface and understory fuels, and damage to mid- and over-story trees. This index has been used extensively to train remotely sensed indices and yield excellent classification outcomes (Parks et al 2014, Harvey et al 2013, 2014).

In parallel, there has been extensive research to identify optimal fire severity indices. Initially work centred on the differenced Normalised Burn Ratio (dNBR; Key and Benson 2006, Parks et al 2013) but subsequent research has identified relativised indices that are more robust to heterogenous vegetation. The dNBR metric is correlated with the absolute amount of vegetation change and therefore, does not perform well across mixed vegetation types (i.e. heath vs forest). Further, the large body of fire severity literature from North America has been built around the annual cycle where images are limited to summer periods to avoid snow and capture deciduous trees when their leaves are present.

Because of the numerous differences in phenology, geomorphology and vegetation patterns between Australia and North America, mapping of fire severity using remote sensing has only become widespread in Australia in recent years. By applying developments in machine learning and more frequent satellite imagery, Collins et al (2018) pioneered widespread and scale-able fire severity mapping in southeastern Australia Eucalypt forests. Key insights from Collins et al (2018) were the ability to sample satellite data year-round, restricting the post-fire image to within ~30-60 days of fire to avoid regrowth from resprouting trees and understory, and the use of multiple indices to increase classification accurary. However, in Western Australia the vegetation cover types, dynamics, phenology, and data availability differ markedly from southeastern Australia. Importantly, post-fire high resolution visible + IR imagery routinely captured in Victoria is not available in Western Australia. Therefore, we aimed to apply the field-based CBI system to generate a data set able to train remotely sensed fire indices to generate reliable and transparent fire severity maps.

VEGETATION

The Yanchep bushfire occurred in a complex landscape and spanned a wide range of geologies and vegetation types, encompassing most of the types present on the broader Swan Coastal Plain surrounding Perth. The soils of the coastal plain are sandy and importantly span a range of geological ages. Soil age combined with sand depth and the availability of groundwater exert the greatest influences on species composition and peak biomass. The best available vegetation maps of the coastal plain (Heddle et al 1979) are out of date and do not reflect more recent soil mapping and 40+ years of additional research and digital tools. At present, government departments responsible for fire and fire risk management (DBCA, DFES, DPLH) lack fine-grained vegetation maps which can be linked to biomass, fuel loads, and fire hazard. For example, all intact native vegetation has been deemed to be 'bushfire prone' yet clear differences in hazard and likelihood of fireline intensities exceeding suppression capability are not well described.

FIGURE 4. MAJOR VEGETATION TYPES PRESENT IN THE YANCHEP BUSHFIRE AREA. MOST COVER TYPES ARE HEATH WITHOUT A TREE LAYER (A-D) AND INFLUENCED BY PROXIMITY TO THE OCEAN, SOIL PH, AND SOIL DEPTH. FURTHER INLAND, BANKSIA WOODLAND (E) APPEARS ON DEEPER, MORE ACIDIC SANDS ALONG WITH MINOR (<1%) OCCURRENCES OF OTHER TREED AREAS SUCH AS WETLANDS AND PATCHES OF TUART FOREST (NOT PICTURED).

DRIVERS OF FIRE SEVERITY

Long-running debates abound in the scientific literature regarding drivers of fire severity (dead fuels, fire weather, live fuel moisture, vegetation type, management, etc) and consequent management options across a range of contexts. The literature has largely, but not fully, been focused on forested ecosystems. In Mediterranean climate systems, fuels become available every summer yet the thresholds for burning and consequent ease of suppression are not well understood. In the Perth metropolitan region, a range of vegetation types are found ranging from forest and woodland to several heath types. Prescribed burning is a tool widely employed across forest and woodland vegetation types but less in heath. Heath is regarded as a go-no go fuel type which is difficult to ignite under prescribed fire conditions and once ignited can be difficult to manage.

FUEL LOAD ESTIMATION

A major knowledge gap in the Perth region is to enable a dynamic estimate of fuel loads partitioned by vegetation type, fire history, and other contributing factors (e.g. weeds). Whilst such information has a long history of being collected across eastern Australia and in the forest regions of Western Australia, information elsewhere is scarce. Two key papers, Burrows and McCaw (1990) and Westcott et al (2014) report some values for Banksia woodlands and northern heathlands respectively, neither pertains sufficiently to the Yanchep bushfire. Burrows and McCaw (1990) examined a narrow set of Banksia woodland SE of the Yanchep bushfire on acidic sands that are known to support lower biomass and slower growing vegetation. Westcott et al (2014) examined comparable limestone heathlands but 200 km north where annual rainfall is ~150-200 mm less and therefore with lower peak biomass and likely different dynamics and fire regime. No published data are known to exist for coastal heathlands on higher pH sands nor for vegetation occurring immediately behind beaches.

RESEARCH APPROACH

FIRE SEVERITY

Data Collection. Applying the CBI methodology of Key and Benson (2006), we sampled across the Yanchep bushfire and surrounding recent prescribed burns. Each plot was scaled to represent a LandSat pixel (25-30m). Data for the Yanchep bushfire were collected in January 2020. Further data from other burns were collected Jan 2020, Dec 2020, and May 2021. The development and adaptation of protocols to suit the vegetation has been in close collaboration with WA DBCA fire scientist, Dr Valerie Densmore. In collaboration, this approach will be joined with DBCA's broader efforts to collect >800 CBI points from a range of post-fire vegetation types and generate a robust and transparent fire severity mapping process (see Appendix A for example datasheet). In Perth metropolitan area, we sampled N=12 unique fires (2 wildfires, 10 prescribed burns) and obtained N=182 sample points within fire boundaries.

Data Analysis. Associating field-based CBI data with remotely sensed indices was undertaken following two complementary approaches (Table 1). By using two approaches we have gained a more robust outcome and been able to compare methods used by a wide diversity of fire scientists across Australia and western North America.

TABLE 1. TWO COMPLEMENTARY METHODS USED TO CLASSIFY FIRE SEVERITY IN THE YANCHEP BUSHFIRE.

	Method 1	Method 2
Sensor-data source	Sentinel-2 (ESA)	Sentinel-2 & LandSat 8 (GeoScience Aus)
Pre-fire sampling period	3 months	1 month
Post-fire sampling period	3-5 weeks	4 weeks
Data extraction from multiple dates	Median	Maximum
Output	Raster of entire polygon then extraction of point values	Point values (classification of polygon at later stage)
Threshold determination	Quartiles of RBR by field-determined class	CBI scores and then optimisation of classification

Our first approach utilised the open-source Google Earth Engine platform (code available). The fires sampled for CBI were analysed as described above (Table 1). Our second approach performed by spatial data scientist Mr Ricky van Dongen at DBCA utilised a random forest classification approach (Table 1).

Fire severity indices were derived from GeoScience Australia data corrected for Australian atmospheric conditions though differences from Google Earth Engine products were minor. The random forests model had a range of potential inputs and were informed by Collins et al 2018 and experience with WA vegetation dynamics. The indices included pre and differenced: i35, NBR, NDVI, NWDI, NIR, as well as RBR. The i35 index is a correlate of vegetation cover that performs particularly well in monitoring dynamics in WA.

VEGETATION

Vegetation classification

Building from an existing plot network in woodland vegetation, we further sampled vegetation throughout and surrounding the Yanchep bushfire area. At each location we sampled vegetation using a transect line-intercept method. Locations were chosen on the basis of vegetation type, slope position, and fire history. These locations also served as samples for biomass estimation (see below). By sampling across a large area we were confident in the allocation of broad vegetation types.

Fuel load accumulation

Using the sample points reported above, we sampled across the biomass accumulation trajectory within each vegetation type along with some stratification of slope position. Each sampling location was a 20-m transect with data collected at every meter for surface fuels and shrub layer biomass and cover.

TABLE 3. SAMPLING EFFORT OF FUELS TRANSECTS WITHIN AND SURROUNDING THE YANCHEP BUSHFIRE REGION.

Vegetation Type	0-2 yrs	3-6 yrs	7-15 yrs	16-30 yrs	>31 yrs	TOTAL
Beach-associated vegetation	1	1	2	0	7	11
Low Coastal Heath	3	2	2	3	4	14
Tall Coastal Heath	2	1	2	3	8	16
Limestone Heath	4	0	4	4	0	12
Banksia Woodland	60	12	32	17	17	138

†Banksia woodland samples span 2016-2021 and are contributed from a project exploring fire interval effects on Banksia Woodland vegetation dynamics. All other transect data collected 2019-2021 (41 of 53 in 2021).

Surface fuel accumulation. Surface fuel amounts (i.e., leaf litter and woody material ≤ 25 mm diameter) were sampled from 0.2 × 0.2 m (0.04 m2) quadrats every second metre along transects. All fuels within quadrats were collected, including sampling parts of larger items that extended beyond the limits of the quadrat by sampling what fell within the quadrat. Surface fuel samples were dried for 48 hrs at 105 °C and sieved using slotted sieves (4 mm and 1 mm) to remove sand. Dried samples were separated into size classes (i.e., leaf litter, woody material 0-6 mm diameter, woody material 6 - 25 mm diameter, bark material, charcoal, woody fruits or cones (e.g., from Banksia or Eucalyptus species)), and weighed individually. For analysis, surface fuel elements were pooled into two distinct classes: (1) fine surface fuels including leaf litter and small twigs < 6 mm in diameter, and (2) total surface fuels including fine fuels (as above) plus coarse woody material between 6 – 25 mm in diameter, fallen bark, charcoal, and woody fruits.

Understory biomass accumulation. Understory biomass was assessed every metre along transects by recording the number of contacts with live and dead vegetation on a vertically held rod (8 mm diameter) up to 3 m aboveground (Evans and Love 1957, Burrows and McCaw 1990). Contacts were recorded in specific height strata (i.e., 0 – 0.05 m, 0.05 – 0.1 m, 0.1 – 0.2 m, 0.2 – 0.3 m, 0.3 – 0.6 m, 0.6 – 0.9 m, 0.9 – 1.2 m, 1.2 – 1.5 m, 1.5 – 1.8 m, 1.8 – 2.0 m, and 2.0 – 3.0 m) but were pooled into near-surface (0 – 0.3 m), elevated (0.3 – 1.5 m) and subcanopy (1.5 – 3.0 m) height strata for analysis. For every individual plant contacted, we recorded species, maximum plant height (cm), maximum perpendicular canopy widths (cm), and status of the whole plant (live or dead).

Understory biomass (0 – 3 m aboveground) was estimated using allometric equations to convert plant canopy volume (calculated from recorded plant dimensions) to dry aboveground biomass. Canopy volume (cm3) was applied to a series of plant functional type-specific allometric models relating canopy volume to total aboveground dry biomass (kg). Plant functional types were based on growth form (i.e., grass, graminoid, herbaceous, shrub and tree) and, for woody species (shrub and tree), fire response type (i.e., resprouting or fire-killed) to reflect differences in expected biomass allocations (Supplementary Section 1). Grasses were not commonly encountered and thus were pooled with graminoids (i.e., plants with grass-like growth forms such as sedges and rushes). Here, we define herbaceous species as those with non-woody stems. Dry biomass, for shrubs taller than 3 m, was scaled to represent that which occurred within the sampling domain (i.e., 0 – 3 m aboveground). The biomass of trees taller than 3 m was excluded here, even where vegetation contacts occurred below 3 m, as most of their biomass in the understory stratum is bole material. For entirely dead plants, we assumed a 50% reduction in biomass. Allometric models were sourced from the literature (Paul et al 2016, Westcott et al 2014), developed from pre-existing data or from data collected as part of this project. Allometric models were optimised by comparing regression models of varying function (i.e., linear, power, quadratic), assumed plant canopy shape (i.e., cube, cylinder, sphere, and ellipsoid) and log-transformed predictor variables. Model selection was based on the highest correlation coefficient (R2).

Understory biomass density (i.e., aboveground dry biomass [kg] / horizontal canopy extent [cm2] × contact rod sampling area [cm2]) was calculated for each individual plant, summed within each metre where multiple plants occurred, averaged across each transect, and then scaled to the transect sampling area to obtain an estimate of transect-level biomass (Mg ha-1). These data are presented as fine understory biomass (i.e., leaves and twigs < 6 mm diameter) and total understory biomass (i.e., fine understory biomass plus twigs and branches > 6 mm diameter).

BUSHFIRE SEVERITY RECONSTRUCTION

Using publicly available fire history, fire progression (provided by DBCA), and derived vegetation types, we analysed the impact of the fire. We quantified fire severity in both continuous terms (RBR) and categorical (five fire severity classes). We used RBR over dNBR as a means by which to have consistent comparison across vegetation types with a wide range in biomass and structural variation. Categorical data were taken from our classified raster based on CBI plot data (see previous section for explanation).

For each metric, we partitioned the severity raster by polygons and then computed summary values. Further analysis using random forests and other computer learning algorithms are warranted but time precluded a full analysis.

To try to isolate the effects of prescribed burning, we examined a small recent prescribed burn in the southern portion of the Yanchep bushfire that was completely run over by the bushfire in the first 24 hours during some of the worst conditions (high temperatures, low relative humidity, sustained easterly winds). The prescribed burn (SWC_077) was conducted in October 2018 and was patchy with a portion of the burn spreading and another not burning well in 2018.

Therefore, to investigate influences on the severity of the Yanchep bushfire we investigated three major attributes of management interest:

1) Severity in areas recently that had experienced fire (prescribed or wildfire) in the prior 5 years.
2) Severity based on date and bushfire progression.
3) Severity by vegetation type.

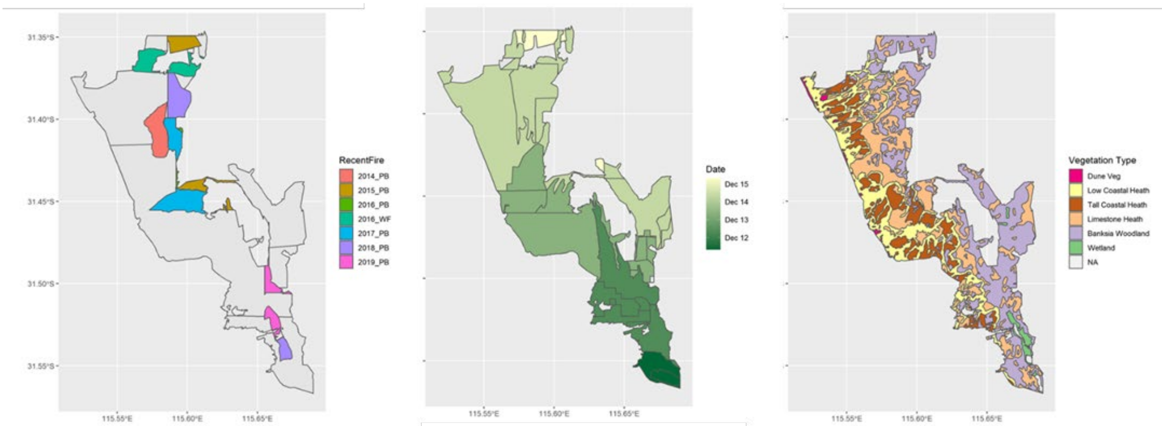

FIGURE 6. RECENT FIRE HISTORY (A), BUSHFIRE PROGRESSION (B) AND VEGETATION TYPE (C) WITHIN THE YANCHEP BUSHFIRE. THESE THREE ATTRIBUTES ARE COMMONLY CITED AS IMPORTANT CONTRIBUTORS TO BUSHFIRE SEVERITY.

FINDINGS

FIRE SEVERITY

Across 12 fires and 182 plots, field assessed composite burn index scores were well related to remotely sensed relative burn ratio with an R2=0.71 (Figure 1A). Further, separation of fire severity classes was generally very good where inner quartiles of classes did not overlap (Figure 1B). Overlap between classes of low and moderate severity were evident but expected given the difficulty of these subtle classes being differentiated beneath tree canopies.

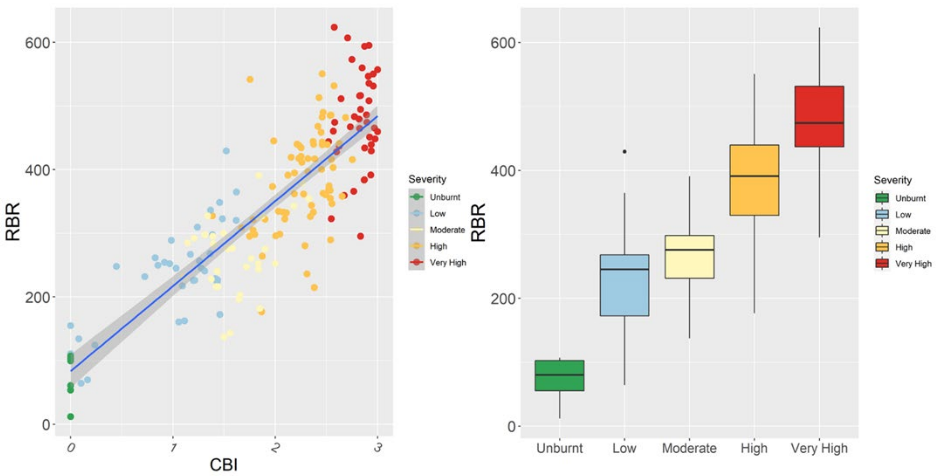

FIGURE 1. CANOPY BURN INDEX (CBI) VERSUS REMOTELY SENSED RELATIVE BURN RATION (RBR) WITH SEVERITIES IN COLOUR (A) AND BOXPLOTS OF RBR BY SEVERITY CLASS (B). A SIMPLE LINEAR REGRESSION OF THE DATA IN (A) YIELDS AN R2=0.71. BREAKS BETWEEN CLASSES ARE LARGELY WELL RESOLVED IN BOXPLOTS EXCEPT LOW VS MODERATE.

Application of a random forest analytical approach to 200+ points (field CBI + unburned reference points) yielded a classification accuracy of 0.78. For the two most relevant regions (Dandaragan Plateau and Perth), the RBR and dNDVI had the highest weightings.

TABLE 2. VARIABLE IMPORTANCE VALUES FOR RANDOM FOREST CLASSIFICATION OF FIRE SEVERITY IN TWO VEGETATION REGIONS RELEVANT TO THE YANCHEP BUSHFIRE.

type	di35max	dNBRmax	dNDVImax	dNDWImax	dNIRmax	prei35	preNBR	preNDVI	preNDWI	preNIR	RBRmax
Dandaragan Plateau	45.8	55.9	51.8	49.3	30	39.3	27.8	28.7	30.8	43	59.7
Perth	29.3	47	61.7	43.3	29.2	27.8	20.3	25	26.2	26.5	52.2

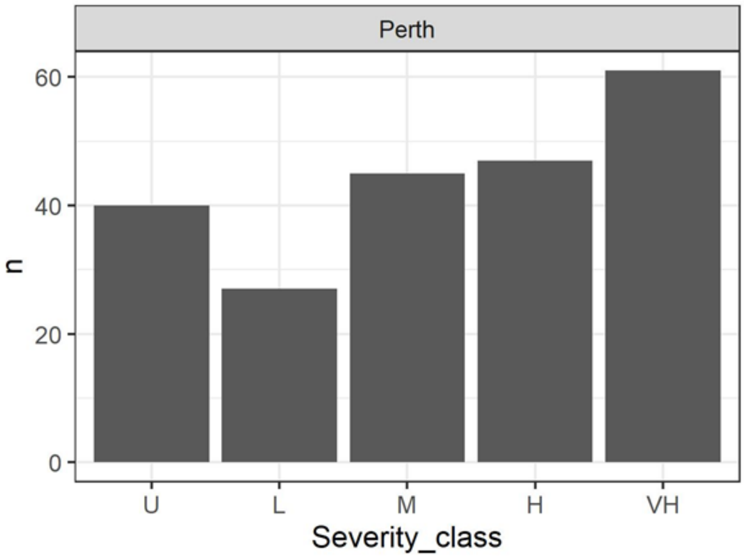

Table 4. Error matrix for fires within the Perth ibra

Reference	UB	NS	PS	CS	CB
UB	30	4	3	2	0
NS	3	1	2	0	0
PS	6	0	22	6	3
CS	0	0	12	6	17
CB	1	0	4	6	92

FIG 2. NUMBER OF CLASSIFIED SEVERITY POINTS WITH EACH CLASS AND THE ERROR MATRIX FROM A RANDOM FORESTS MODEL. THE CLASSIFICATION ACCURACY WAS 78%. FIRE SEVERITY CLASSES ARE: U/UB UNBURNED, NS/L LOW SEVERITY, PS/M MODERATE SEVERITY, CS/H HIGH SEVERITY, CB/VH VERY HIGH SEVERITY WITH CANOPY CONSUMPTION.

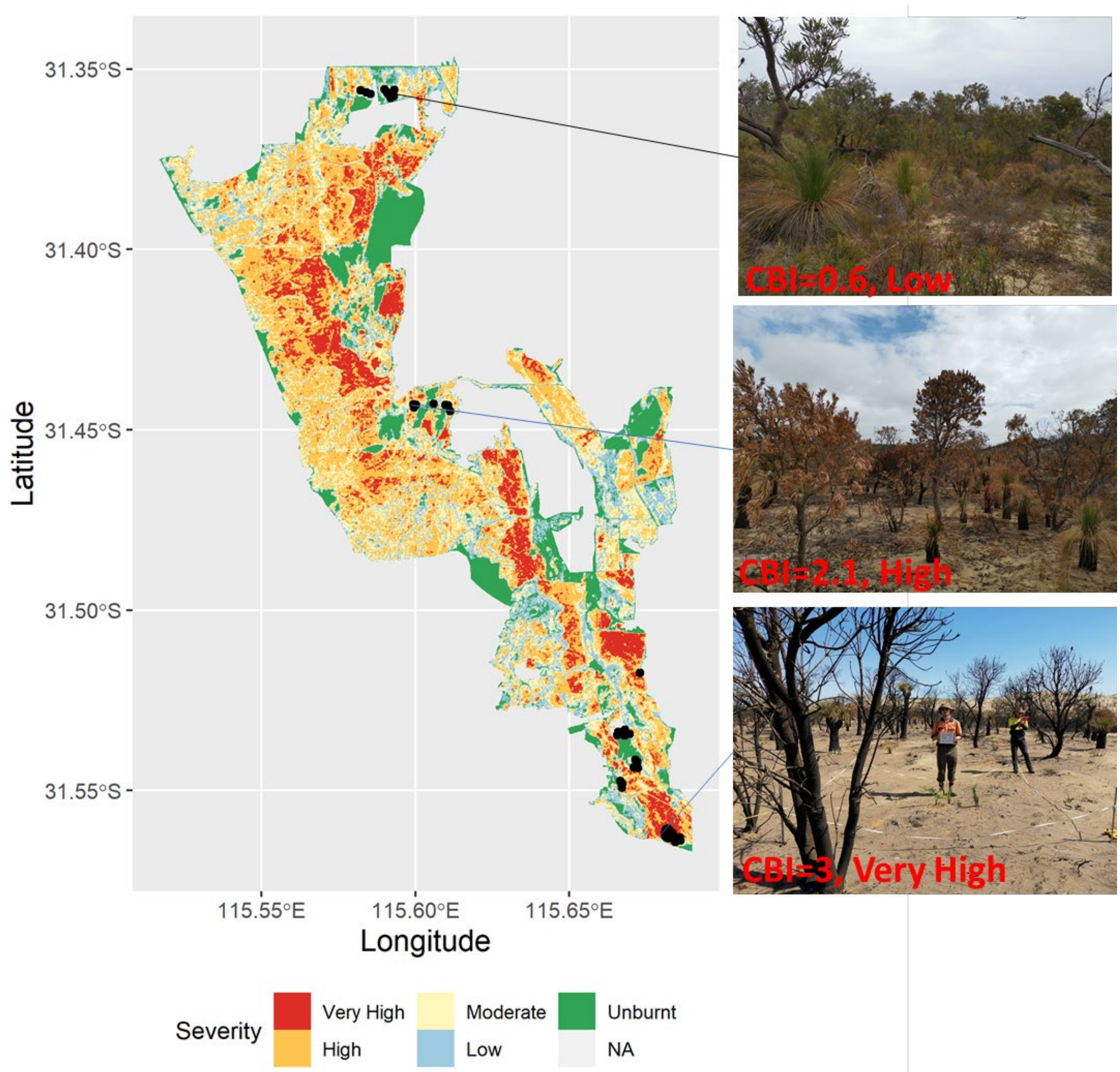

FIG 3. FIRE SEVERITY CLASSES WITHIN THE YANCHEP BUSHFIRE USING RBR THRESHOLDS AND BLACK POINTS REFLECTING CBI PLOTS WITHIN THE BUSHFIRE PERIMETER. PHOTOS AT RIGHT DEPICT A RANGE OF SEVERITY CONDITIONS, MEASURED JANUARY 2020.

VEGETATION

Vegetation classification

Five major vegetation types occur across the Yanchep bushfire area (Fig 5).

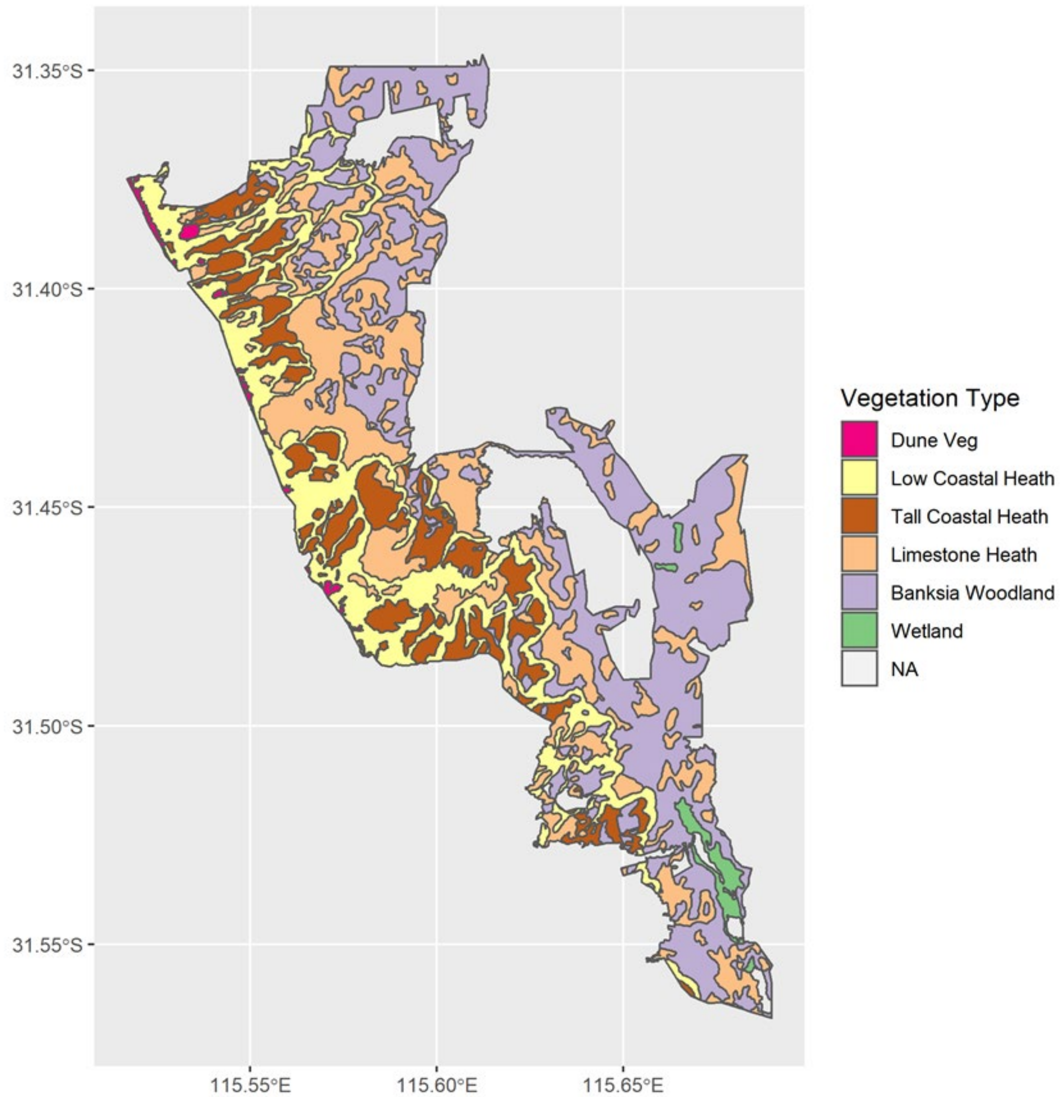

FIG 5. DISTRIBUTION OF MAJOR VEGETATION TYPES ACROSS THE 2019 YANCHEP BUSHFIRE. THE UNDERLYING CLASSIFICATION WAS BASED ON GEOLOGY AND THEN VALIDATED IN THE FIELD.

Fuel loads

Litter fuel loads varied strongly by both vegetation type and fire history. Beach-associated vegetation had the lowest mass (0-4 tons ha-1) and limestone heath having the largest values (>10 tons ha-1 beyond 16 years after fire; Fig 6).

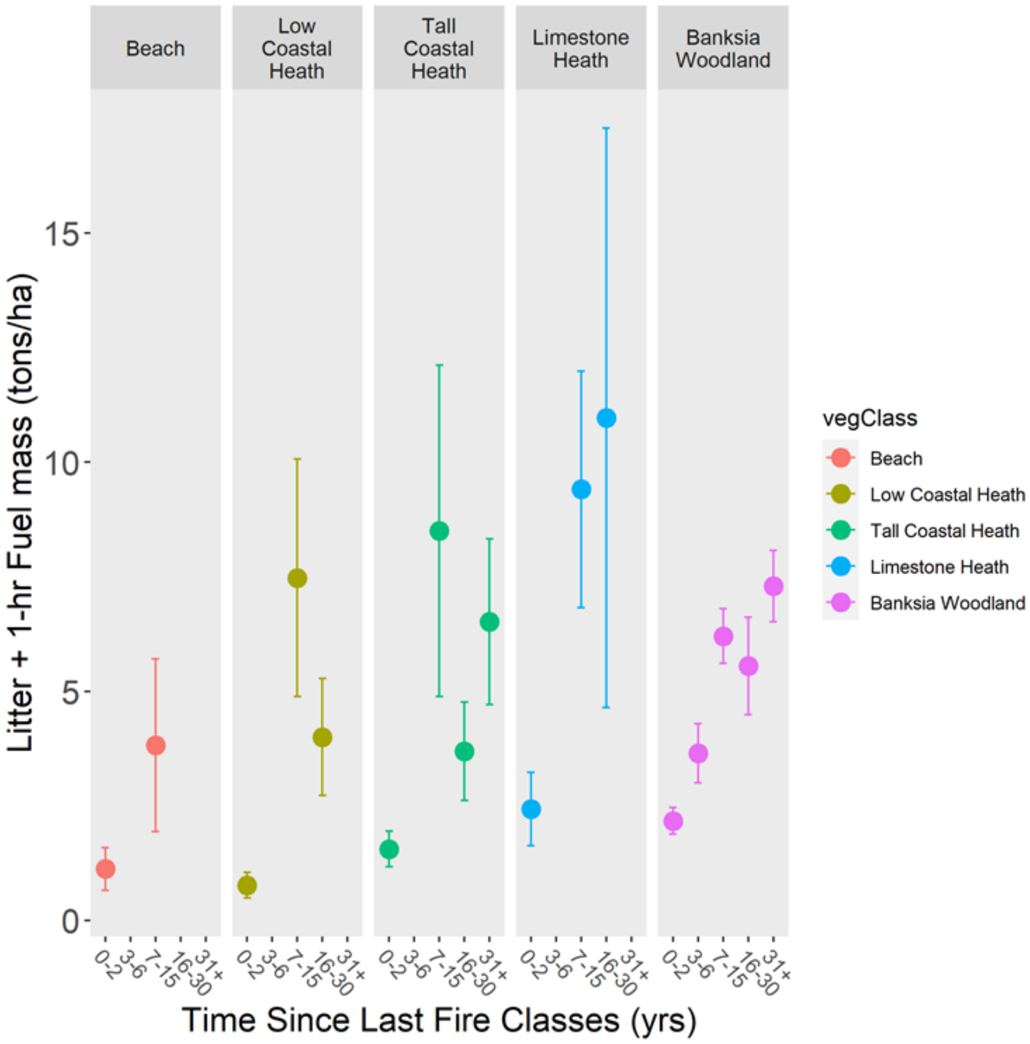

FIG 6. MEAN (95% CONFIDENCE INTERVAL) LITTER AND 1-HR FUEL MASS (TONS HA-1) ACROSS FIVE VEGETATION TYPES AND FIVE FIRE HISTORY CLASSES.

DETERMINANTS OF FIRE SEVERITY

Prior fire management

With the Yanchep Bushfire, 10 prior fires (9 prescribed burns, 1 wildfire) had occurred from 2014-2019. Fires 2014-2017 had relatively consistent distributions of RBR and severity classes. From 2018 onwards, there were substantial increases in unburned areas (Fig 7). This suggests that fires within two years prior to the bushfire interacted with the Yanchep bushfire behaviour. Further the east flank of the bushfire was formed by substantial areas of 2016 and 2018 spring prescribed burns. Conversations with DBCA fire management officers confirms that these areas were substantially helpful in containing the bushfire as it spread from SW-NE on a strong SW sea breeze.

Areas that burned with high severity in Oct 2018 were characterised by lower severity in 2019 with the opposite also true (Fig 8). Importantly areas burnt at low severity in 2018 also burnt with low severity in 2019. This small example demonstrates the operational significance of mapping burn severity thereby informing on-ground crews about the security of recent burn cells. It also illustrates one case of clear interaction between successive fire events <2 years apart. Research plots located in the area prior to the 2018 burn have been monitored and will continue to be measured providing key information about vegetation response and biodiversity implications.

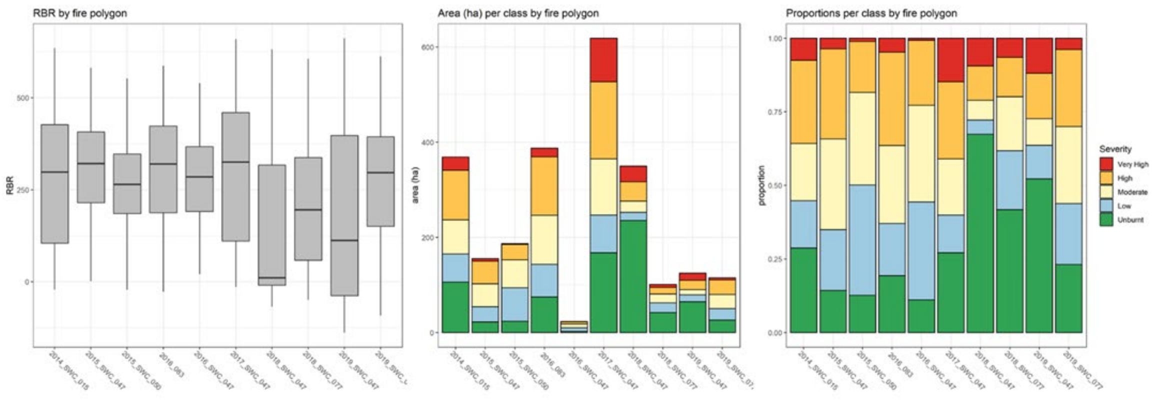

FIG 7. BOXPLOTS OF RBR, AREA BY SEVERITY CLASS, AND PROPORTIONAL SEVERITY BY PREVIOUS FIRE EVENTS (2014-2019) WITHIN THE YANCHEP BUSHFIRE.

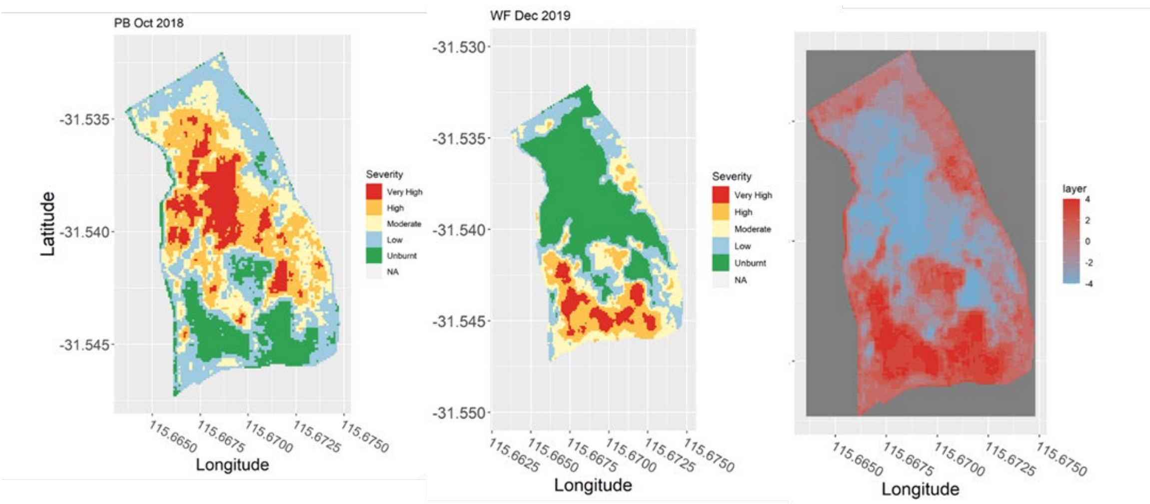

FIG 8. BURN SEVERITY IN A PRESCRIBED BURN (A; 25 OCT 2018), YANCHEP BUSHFIRE (11-12 DEC 2019), AND THE DIFFERENCE IN SEVERITY CLASSES BETWEEN THE TWO EVENTS. CLEAR INTERACTION IS APPARENT BETWEEN THE BURN AND BUSHFIRE WITH NOTABLE LOW-LOW AND MOD-MOD AREAS IN THE NE REGION OF THE AREA.

Fire weather

As expected, afternoon time periods coincided with the highest proportion of very high severity impacts on 4 of the 5 days of the bushfire (Fig 9). The first full day of the bushfire saw the largest amount of very high severity fire, an observation consistent with many bushfire events in southwest of Australia where large bushfire events are often associated with hot periods of strong easterly winds.

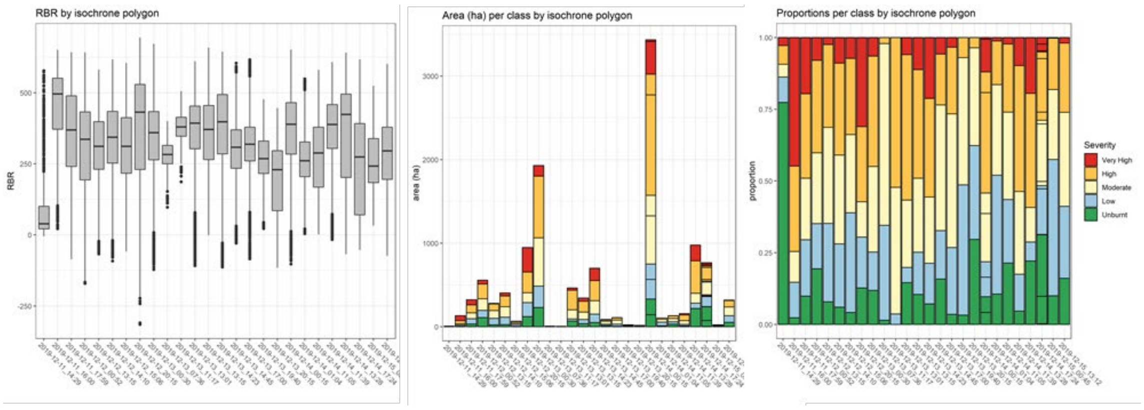

FIG 9. BOXPLOTS OF RBR (A), AREA BY SEVERITY CLASS (B), AND PROPORTIONAL SEVERITY (C) BY EACH RECORDED PROGRESSION POINT FOR THE YANCHEP BUSHFIRE 11-15 DECEMBER. CLEAR SPIKES IN VERY HIGH SEVERITY FIRE COINCIDED WITH AFTERNOONS ON 4 OF THE 5 DAYS OF THE BUSHFIRE EVENT WITH THE WORST BEING THE SECOND DAY DURING THE MOST EXTREME CONDITIONS.

Vegetation type

Limestone heath burned with greatest RBR and proportional very high severity fire (Fig 10). Dune vegetation (the generally narrow strip of vegetation on the first 1-2 dunes behind the beach) burnt with the lowest severity. This is an important observation given the prevalence of this vegetation type in close-proximity to homes in metropolitan Perth. It suggests that this vegetation is less prone to carrying and propagating bushfire even under the elevated conditions present during the Yanchep Bushfire.

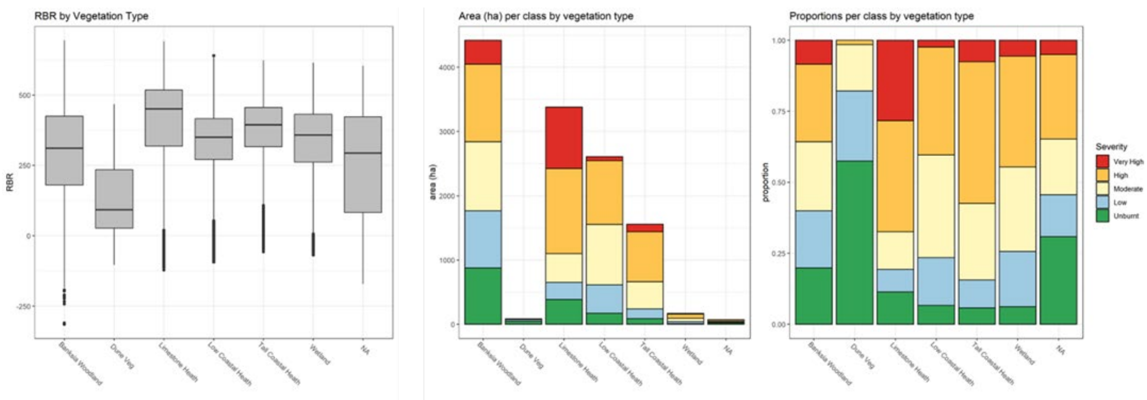

FIG 10. BOXPLOTS OF RBR (A), AREA BY SEVERITY CLASS (B), AND PROPORTIONAL SEVERITY (C) BY EACH MAJOR VEGETATION TYPE PRESENT WITHIN THE YANCHEP BUSHFIRE AREA. LIMESTONE HEATH BURNT AT THE HIGHEST SEVERITY AND DUNE VEGETATION AT THE LOWEST.

KEY MILESTONES

Our key milestones were:

1) Producing a fire severity map and associated analysis
2) Quantifying fuel loads
3) Classifying and mapping vegetation types
4) Yanchep bushfire reconstruction.

All four of these milestones have been met. A longer timeframe would have permitted a more in-depth analysis and nuance in key analyses however we are pleased with our outcomes and what we were able to achieve.

UTILISATION AND IMPACT

SUMMARY

Over the brief four-month project period, our team have had a number of meetings and updates with key end-users. Because of the short time frame, we do not yet have outputs online or in peer-reviewed journals. It is important to note that a fuel accumulation manuscript is at an advanced stage and fire severity manuscripts should be in peer review by late 2021.

Most importantly, this project has occurred at a time when it was able to provide added momentum to processes under way within DBCA (fire severity) and DFES (fuel load estimation, designation of fire-prone areas in coastal zones). These synergies have accelerated capacity building within departments.

DBCA-Fire Science

>5 meetings with Dr Ben Miller, head of fire science. Dr Miller is a collaborator with Murdoch on related projects and has toured the Yanchep bushfire repeatedly with our team.

DBCA-Swan Coastal Fire

The fire management team who were the first responders and who are responsible for the Yanchep region have been keen to be involved. To date we have collected CBI data alongside DBCA fire staff and met with them several times to deliver updates in autumn 2021. Further, we have attended prescribed burns with several crews and had the chance to speak about our findings and relate to experiences during the bushfire.

- On 15 June, Joe Fontaine will present findings to a key DBCA committee that spans fire operations and science.
- A field trip with DBCA fire staff to the Yanchep bushfire has been planned and delayed several times due to autumn burning. We will make it happen in winter 2021.

DFES

We have had two remote meetings with key DFES staff. At least one more is scheduled and we aim to organise a fieldtrip alongside other staff (local bushfire management officers).

UTILISATION POTENTIAL

Utilisation potential and impact of project outputs is extremely high

- Fire severity mapping will be rolled out across DBCA and it is crucial that it be as transparent and accurate as possible. These products will be used operationally to inform suppression and fire fighter safety. Severity products will inform future burning decisions and biodiversity conversation.

Accurate vegetation maps and fuel loads are lacking and reflecting in the high pressure on DFES to revise their bushfire prone mapping as well as AS-3959 asessments. These products will directly inform such decisions and and, in particular, assist with assessment of near coastal vegetation.

CONCLUSION

Over a four-month period we have strengthened links with end-users, provided important outputs and data for fire severity modelling and assessment, and continued to feed information into state government regarding the Yanchep bushfire impacts and drivers. It has also been a two-way street with our team gaining much greater insight into operational considerations around fire as well as broader, complex decision making around fire risk management.

The research in this report really begins to put Western Australian fire science alongside other bushfire science being done in the eastern states of Australia. Our team look forward to continuing our work and progressing these results to assist state government, help build capacity, and generate peer-reviewed publications thus ensuring transparency and quality.

NEXT STEPS

Future research directions include:

1) Expansion and scaling up of fire severity mapping in southwestern WA. The methods deployed here have demonstrated proof of concept and we can now begin to map past fires.
2) Quantitative analysis of interactions among successive fires. With the development of a catalogue of fire severity maps, it is possible to quantitatively assess the longevity of fire effects and how they vary under a range of conditions (mild to extreme). This analysis will support strategic planning, increase fire fighter safety during operations, and inform biodiversity and climate change impact assessment.
3) Fusing diverse data sources to understand fire behaviour. This project was not quite long enough to pull together the diverse datasets being generated by the Black Summer reconstructions. Future work should aim to join these for a more robust analysis of drivers of fire severity (fuel moisture, fuel load, climate).
4) Tracking of biodiversity responses (vegetation composition and structure) and their feedbacks to fire hazard. A number of locations experienced short interval fires (<1 yr to 6 years) and offer an important opportunity to evaluate ecological feedbacks to future fuel loads and bushfire hazard.

TEAM MEMBERS

RESEARCHERS

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END-USERS

Mr Jackson Parker, Director: Bushfire Technical Services, DFES

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Dr Valerie Densmore, fire science, DBCA

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Mr Leigh Sage, Swan District Fire Coordinator, DBCA

Emma Clignan, Sam Hurd, Swan Coastal Fire, DBCA

Owen Donovan, Nature Conservation, Swan Coastal District, DBCA

End-user organisation	End-user representative	Extent of engagement (Describe type of engagement)
DBCA-Science	Ben Miller	>5 meetings, field visits to bushfire area, in depth science dialog
DFES	Jackson Parker	2+ meetings, delivery of project outputs, consultation re: utilization + implementation
DBCA-Swan Coastal District	Leigh Sage	4+ meetings, field trip, dialog re: fire operations and influence of prescribed burning on bushfire

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