



Fire extent and severity mapping

Report for 2020–21 and 2016–17 fire years

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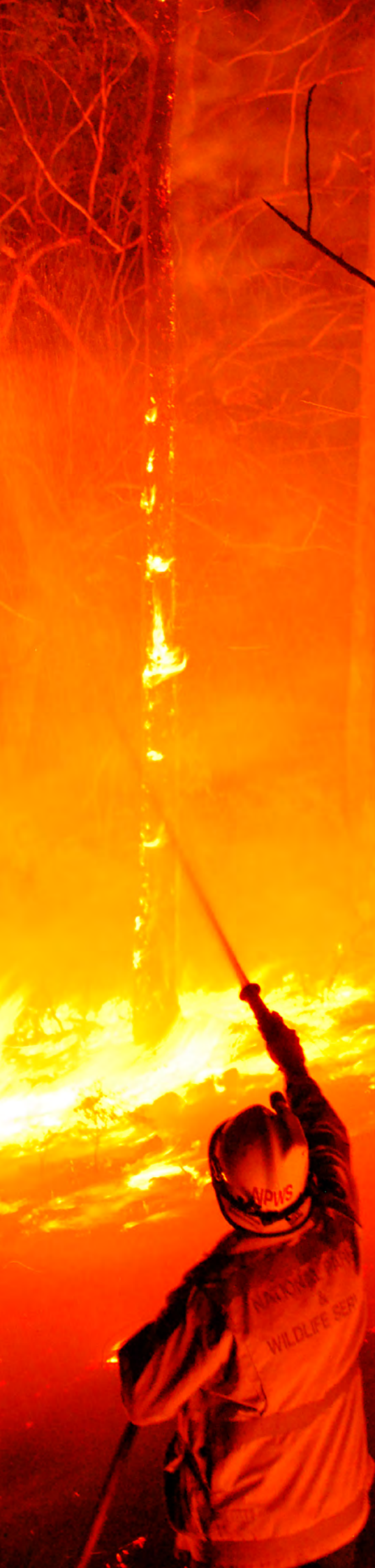
Introduction

Information about the severity of fire on the landscape is critical for understanding the relationship between fuels and fire behaviour, as well as species, ecosystems and landscape ecology. Remote sensing scientists from the Department of Planning and Environment's (the department's) Science, Economics and Insights Division, in collaboration with the NSW Rural Fire Service (RFS), have developed a remote sensing-based, semi-automated approach to fire extent and severity mapping (FESM) in New South Wales.

Although bushfires are part of a natural cycle in our environment, they are increasing in frequency, severity and extent and continuing to encroach on the wildland-urban interface. This makes fire an increasing threat for environmental management in New South Wales. We produce maps of individual fires in near real-time through each fire season via the FESM system. These maps are combined into an annual mosaic at the end of each season. Analyses of these maps support us in understanding vegetation changes due to fire. This enables our scientists to better understand how future fire events may unfold and the potential impacts of these events on the environment. The analyses and data can assist governments, fire managers, and conservation and landscape ecology researchers to understand and respond to the environmental effects of fire for ongoing fire research and post-fire recovery efforts.

This report summarises the FESM analysis for 2020–21; the fire year following the black summer of 2019–20. In addition, FESM data for the 2016–17 fire year is included here. This is the second report in the series, following [last year's report covering the 2019–20, 2018–19 and 2017–18 fire years](#). Together, these reports provide 5 consecutive years of statewide severity mapping. Future annual reports will routinely be issued in August each year, and will cover the most recent fire year (i.e. the FESM annual report for 2021–22 will be released in August 2022).

This summary report is accompanied by data spreadsheets for 2020–21 and 2016–17. The FESM spatial data are made available on the Sharing and Enabling Environmental Data (SEED) portal at the end of each fire year. More information about the FESM system can be found on our [Fire extent and severity maps webpage](#). Our website also includes information about [understanding the effects of the extreme 2019–20 season of mega-fires](#), what influences fire regimes and climate change, and links to current research being undertaken through the [Bushfire Risk Management Research Hub](#).



How the FESM system works

FESM is a remote sensing assessment of fire extent and severity that measures the loss or change in vegetation caused by fire. FESM uses machine learning trained on fire severity class samples from approximately half a million training data points, interpreted from high resolution post-fire aerial photography. The FESM fire severity classes are described in Table 1.

Table 1 Fire extent and severity mapping classes and descriptions

Severity class	Description	Percentage foliage fire-affected
Unburnt	Unburnt surface with green canopy	0% canopy and understory burnt
Low	Burnt understory with unburnt canopy	>10% burnt understory >90% green canopy
Moderate	Partial canopy scorch	20–90% canopy scorch
High	Complete canopy scorch/ partial canopy consumption	>90% canopy scorched <50% canopy biomass consumed
Extreme	Complete canopy consumption	>50% canopy biomass consumed

In July 2020, the operational automated system developed by the department in collaboration with the NSW RFS was launched, delivering fire extent and severity maps in near real-time. While FESM is based on the best available information, it is anticipated that future versions of the algorithm will incorporate refined methods and enhanced training data for improvements in accuracy.

Further information on the FESM method is available on our [Fire extent and severity maps webpage](#).

Accuracy and future improvements

The FESM approach has been peer reviewed and rigorously validated, and continues to be updated and refined. The accuracy statistics for FESM have been independently assessed using high-resolution post-fire aerial photography as well as post-fire field surveys.

Independent aerial photo and field validation data used to assess the accuracy of the latest FESM version 3 ('FESMv3') algorithm shows that accuracy is:

- between 85% and 95% for unburnt and extreme severity classes
- between 75% and 85% accuracy for low, moderate and high severity classes.

FESM is known to have reduced accuracy with topographic roughness, high canopy density and in wetter areas that change significantly in optical reflectance signals over short time periods, especially through summer. To help inform the improvement of future FESM models, detailed assessments of the performance of the modelling across vegetation type, terrain and climatic regions using high-resolution aerial photography interpretation and post-fire field assessments are ongoing.

Due to limited coverage of the Sentinel 2 satellites prior to the launch of the full constellation, fires in 2016–17 were mapped exclusively using the Landsat platform. Due to the differences between sensors, FESM algorithms were trained separately for each sensor type. Landsat is a lower resolution sensor and the FESM algorithm has far fewer training data points than the Sentinel 2–based FESM algorithm. However, model accuracy and area calculations were comparable between severity classes mapped by Sentinel 2 and Landsat algorithms. A comprehensive assessment of the differences in fire extent and severity mapping between sensor algorithms is provided in Appendix A. The Landsat FESM algorithm will be used to map historical fires from 1989–90 to 2016–17 as required.



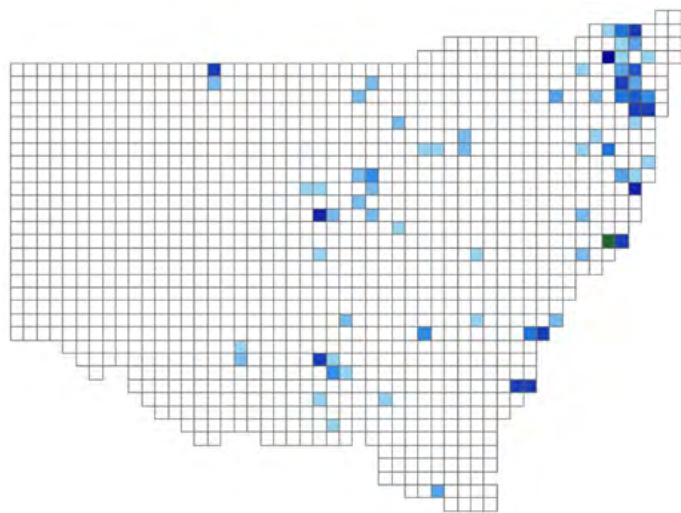


NSW statewide assessment of fire extent and severity for the 2020–21 fire year

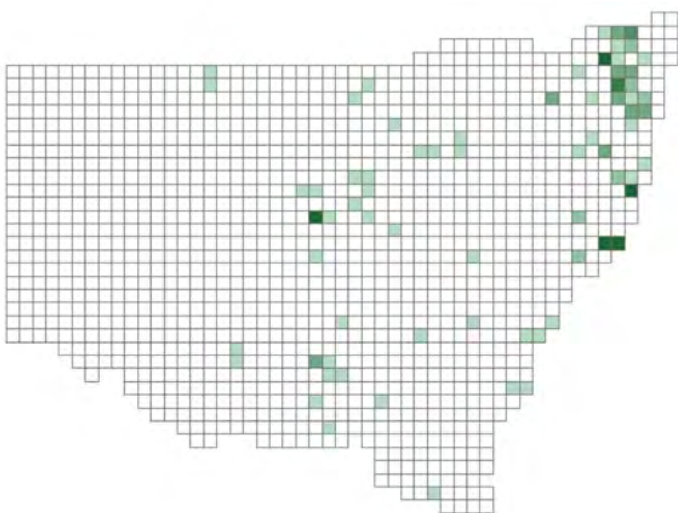
The fire season following the black summer of 2019–20 had very low fire activity. The high rainfall and relatively mild temperatures due to drought-breaking conditions, followed by an extreme La Nina event have reduced the flammability of fuels across much of New South Wales.

A high proportion of total fire occurred in the north-east of the State, which is typical of the bioregional patterns in fire activity in New South Wales (Figure 1). Notably, in 2020–21 there was a relatively high distribution of fires through central and western New South Wales, which is likely to have been driven by accumulation of high grassy biomass following heavy rainfall that becomes flammable as it cures with summer temperatures.

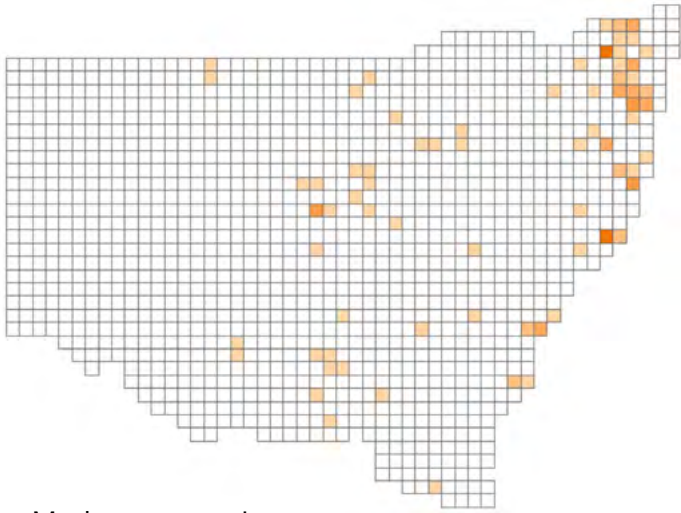
Figure 2 provides examples of FESM for 5 fires that occurred during the 2020–21 fire year in different parts of the State.



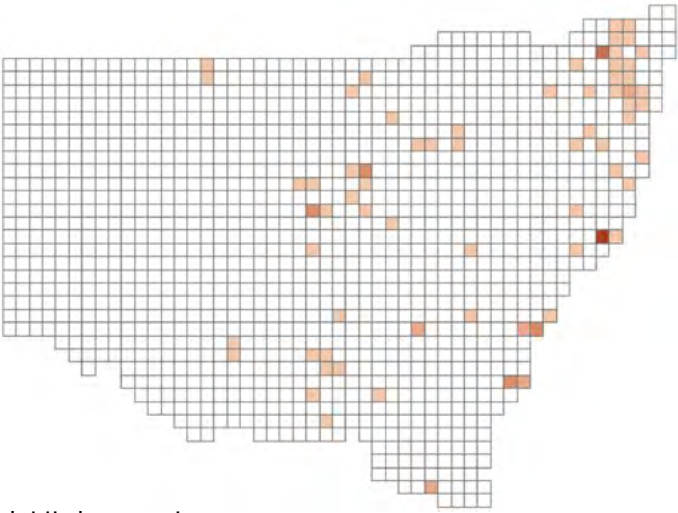
a. Fire extent



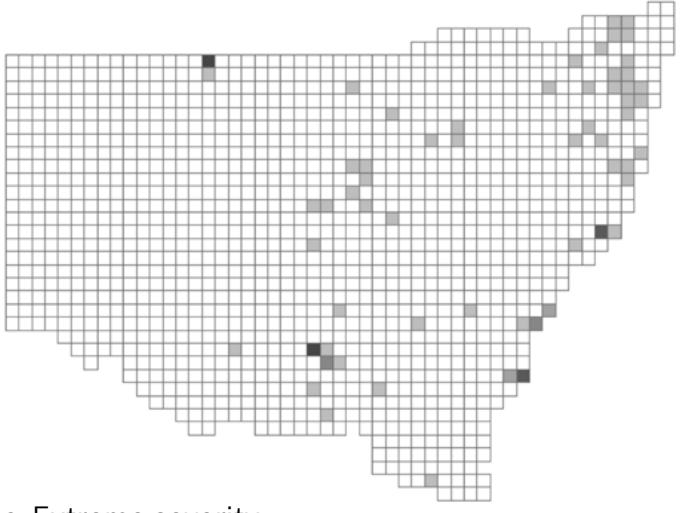
b. Low severity



c. Moderate severity



d. High severity



e. Extreme severity

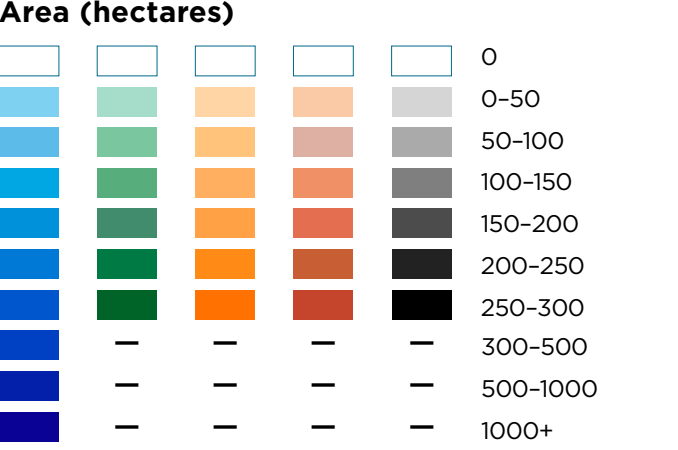


Figure 1 Geographic distribution of fire extent and fire severity across New South Wales for the 2020–21 fire year; (a) fire extent, (b) low severity, (c) high severity, (d) moderate severity and (e) extreme severity

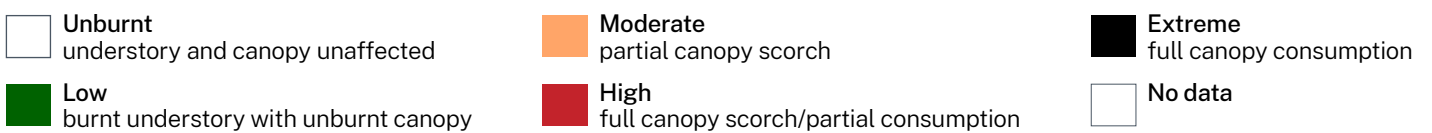
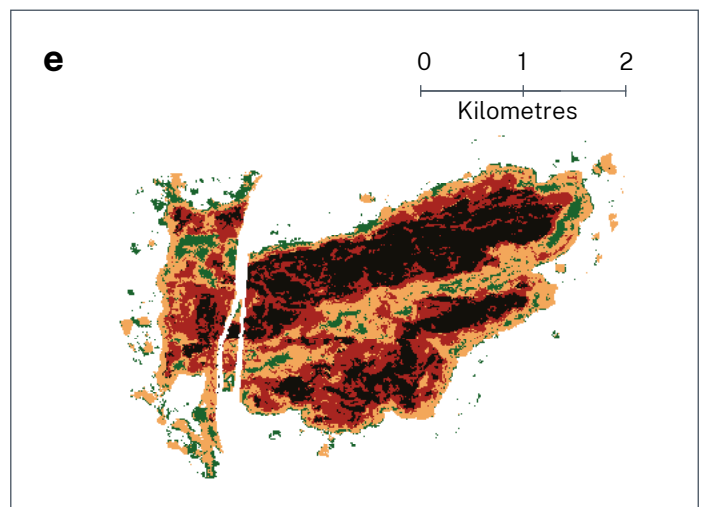
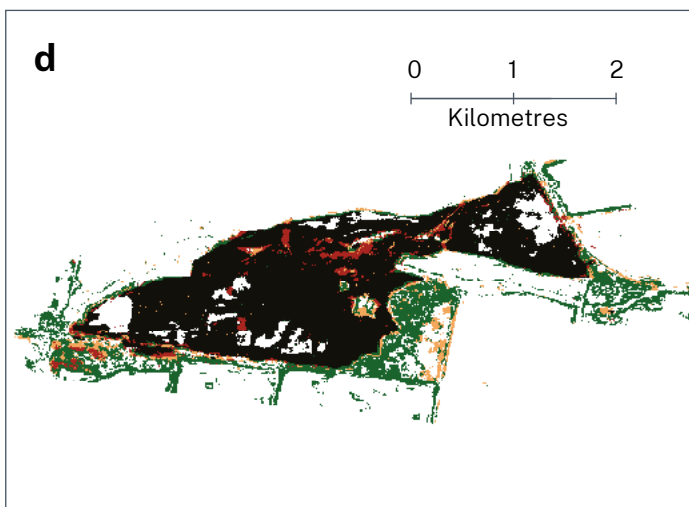
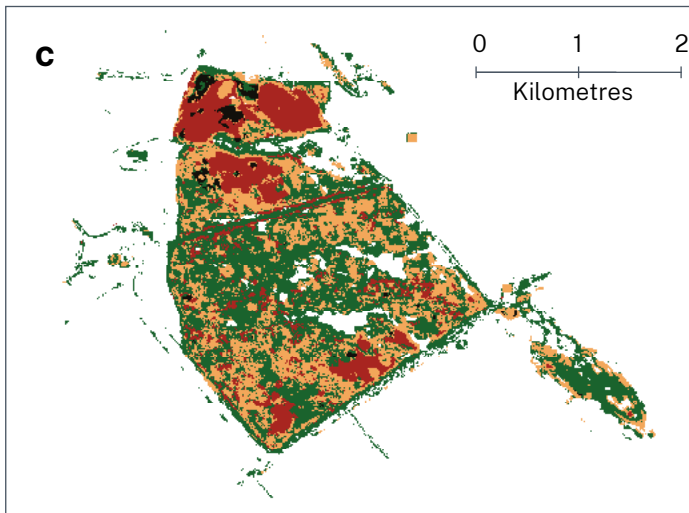
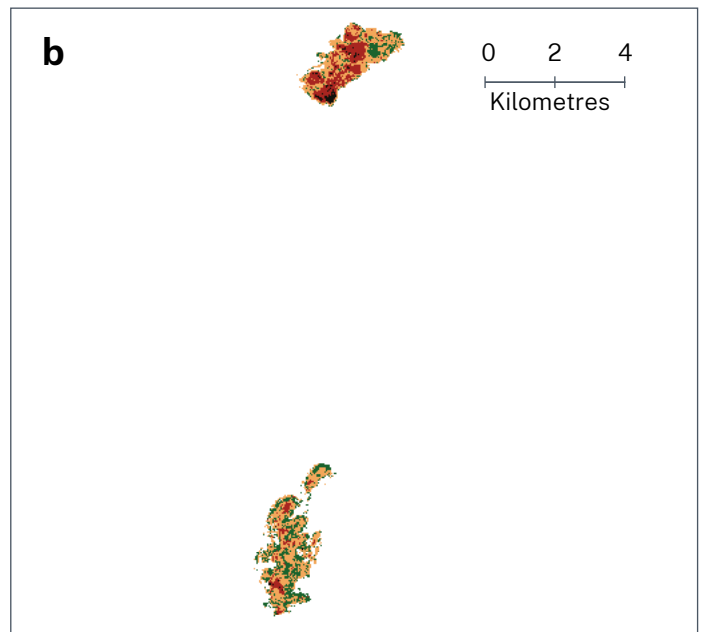
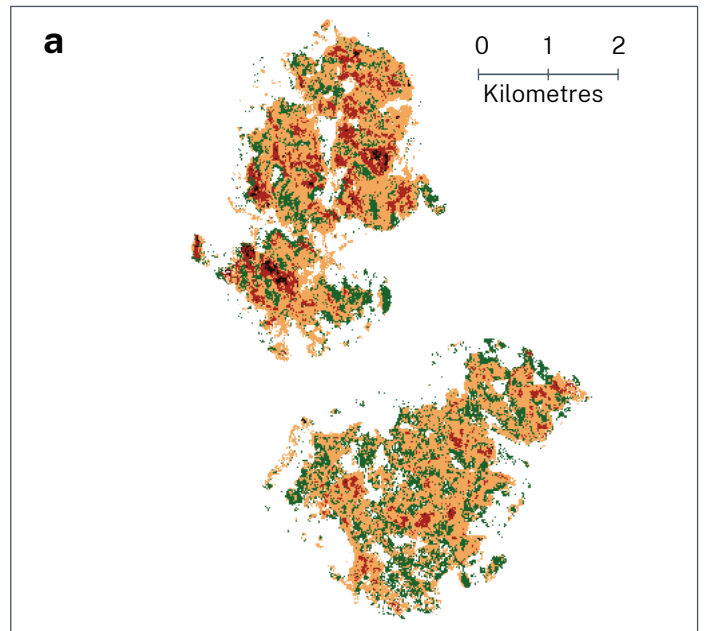


Figure 2 Fire extent and severity mapping for 2020–21 with 5 map insets (A–E) of example fires from across the State

Reporting breakdowns for the 2020–21 fire year

To help decision-makers and conservation efforts, NSW fire extent and severity are reported on in a variety of ways across land management and ecological units. The complete datasets are available on the [SEED portal](#). This section summaries NSW fire extent for 2020–21 across:

- local government areas (LGAs)
- Local Land Services (LLS) regions
- land tenure
- Interim Biogeographic Regionalisation for Australia (IBRA) bioregions
- lands managed by National Parks and Wildlife Service (NPWS)
- vegetation formations (Keith 2004)
- soil textures.

Fire extent across local government areas

MidCoast, Tenterfield and Clarence Valley LGAs had the highest burnt area in 2020–21, and all are located in the north of the State (Figure 3). Notably, Clarence Valley and Tenterfield LGAs also had significant burnt area in the previous fire year, 2019–20, with over 40% and 25% of the total LGA area burnt, respectively.

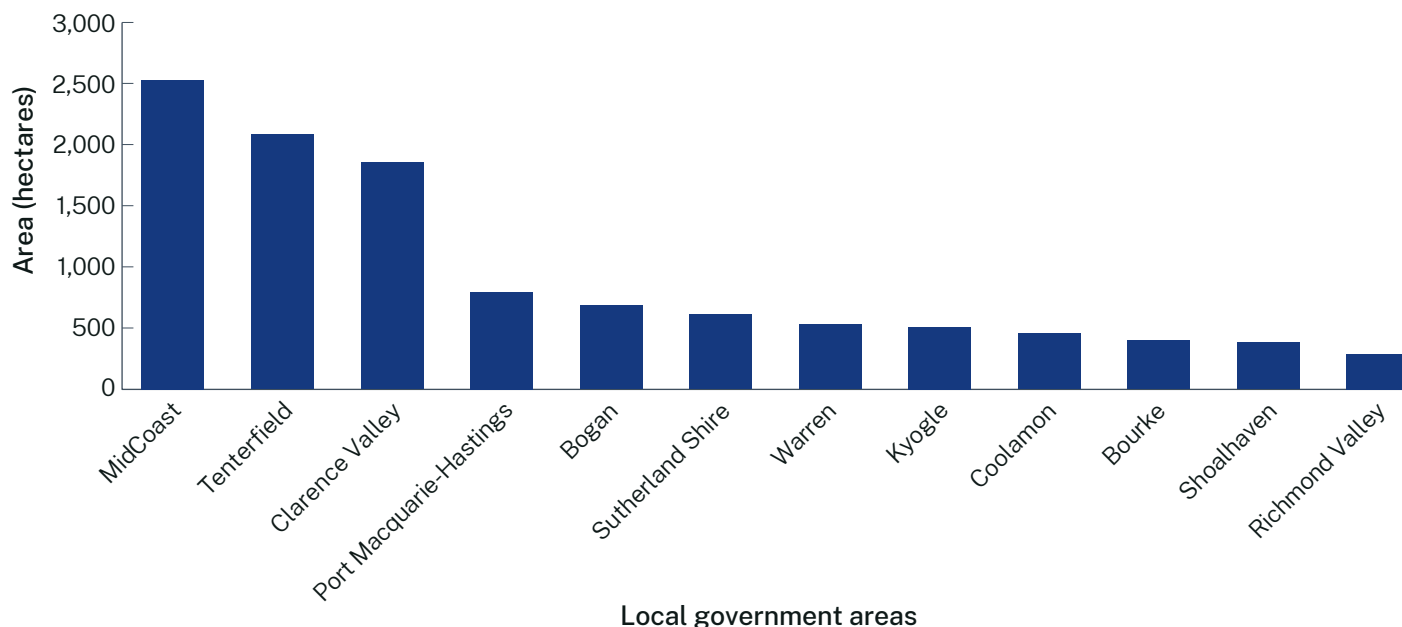


Figure 3 The area burnt in each local government area (LGA) in the 2020–21 fire year. LGAs that had more than 200 hectares burnt have been included here

Fire extent across Local Land Services regions

The North Coast LLS region had the greatest area burnt in New South Wales in 2020–21 (Figure 4).

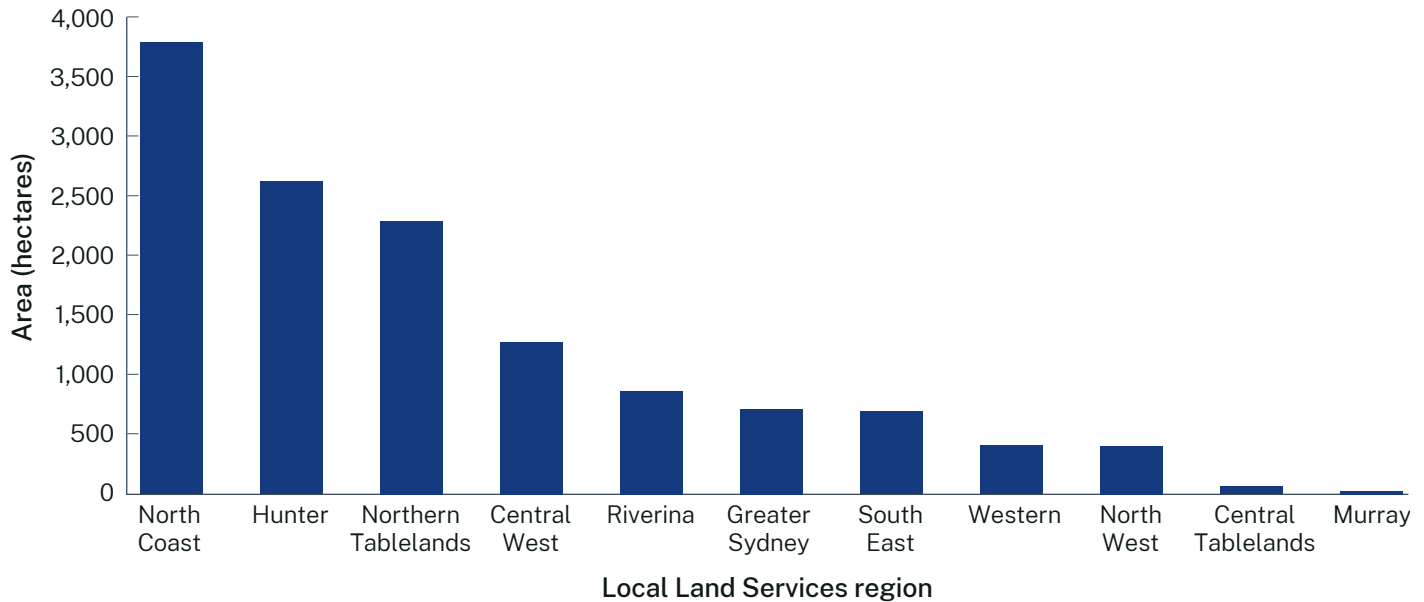


Figure 4 The area burnt for each Local Land Services (LLS) region in the 2020–21 fire year. All LLS regions with burnt areas have been included here

Fire extent across tenure

Freehold land had the greatest area burnt in 2020–21, followed by national parks (Figure 5). This follows a more common pattern in the distribution of fires across tenure classes in other fire years, in sharp contrast to 2019–20 where national park and state forest had by far the greatest proportion of area burnt.

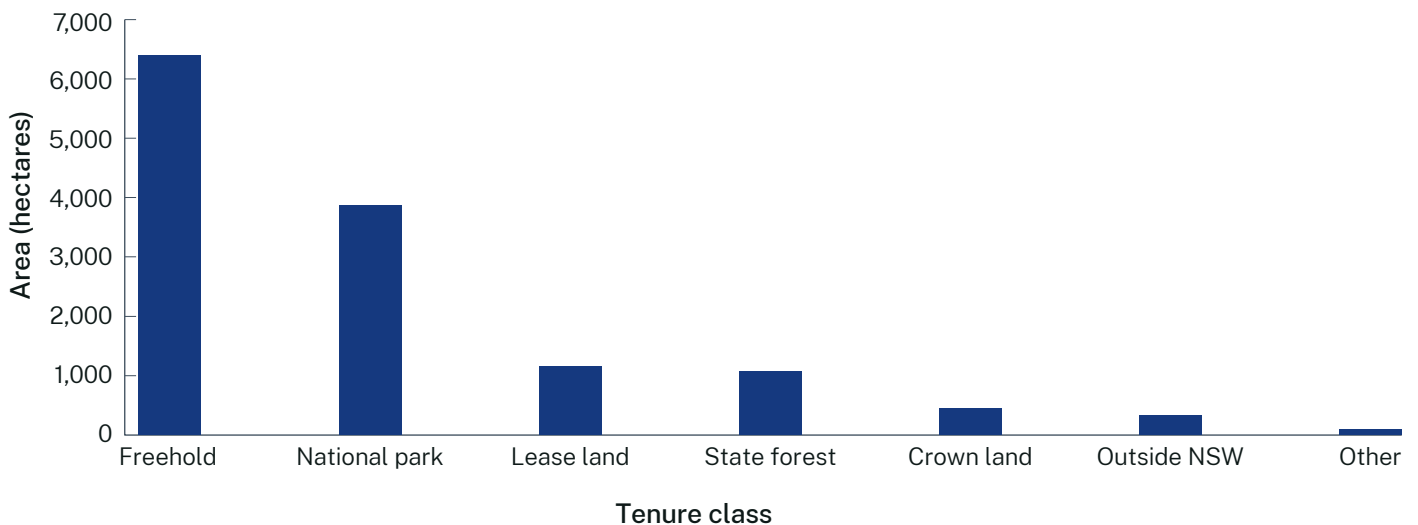


Figure 5 The area burnt for each tenure class in the 2020–21 fire year. All tenures have been included here

Fire extent across Interim Biogeographic Regionalisation for Australia bioregions

The NSW North Coast Bioregion had the largest area burnt in 2020–21, followed by South Eastern Queensland (Figure 6). Notably, the South East Corner and Australian Alps bioregions had no fire activity in 2020–21, in sharp contrast to the previous fire year 2019–20 where almost 60% of the South East Corner and 30% of the Australian Alps bioregions were burnt.

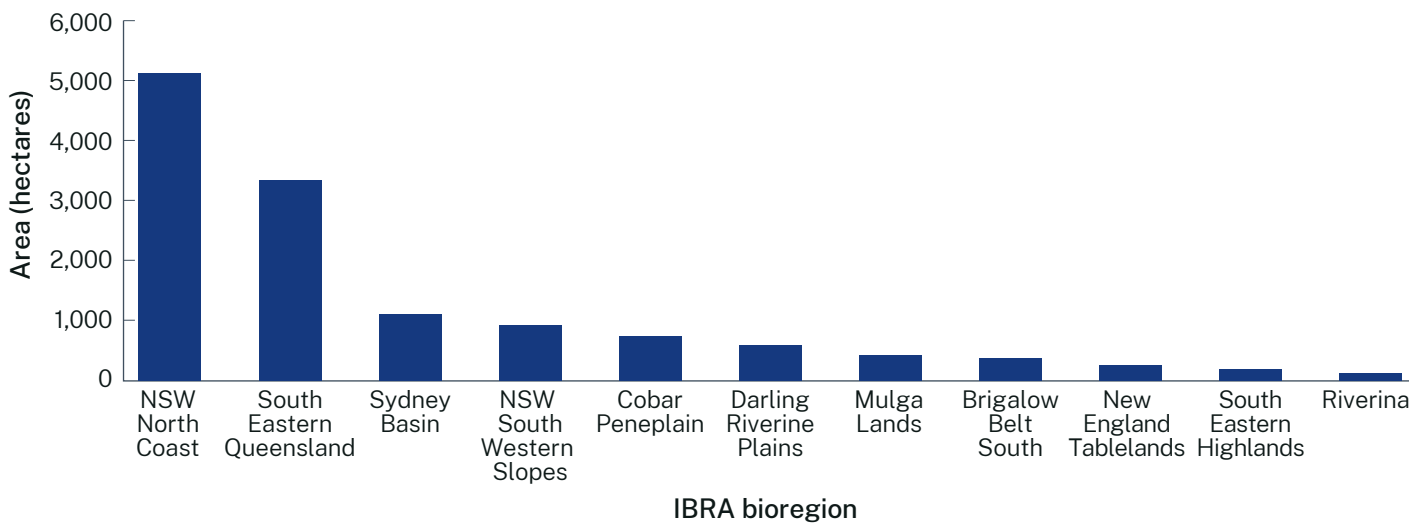


Figure 6 The area burnt in each Interim Biogeographic Regionalisation for Australia (IBRA) bioregion in the 2020–21 fire year. All bioregions with burnt areas have been included here

Fire extent across NPWS-managed lands

Myall Lakes National Park had the largest wildfire in 2020–21 (2,424 hectares), which was nearly 5 times larger than the next biggest area burnt within Royal National Park (500 hectares) (Figure 7). Notably, Myall Lakes National Park also had a large wildfire (1,137 hectares) in the previous fire year 2019–20, while Royal National Park had a large wildfire (2,540 hectares) in 2017–18.

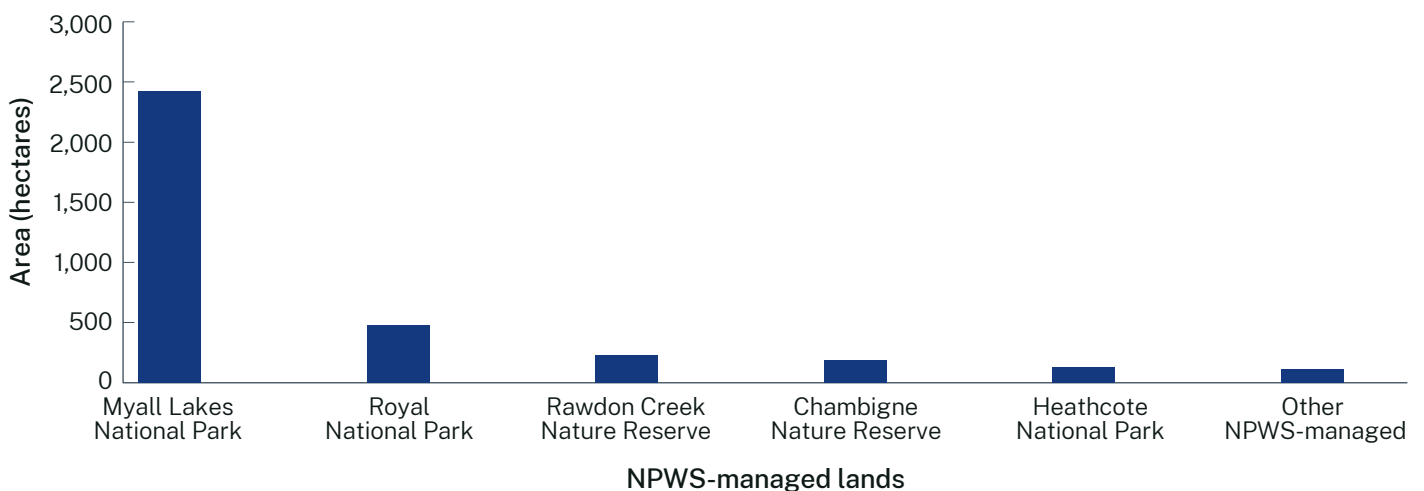


Figure 7 The area burnt in NPWS-managed lands in the 2020–21 fire year. NPWS-managed lands that had more than 100 hectares burnt have been included here

Fire extent across NSW Keith vegetation formations

Cleared vegetation (i.e. non-native vegetation) had the largest area burnt in 2020–21, followed by dry sclerophyll forests (Figure 8). Wetlands, heathlands and woodlands all had less than 1,000 hectares burnt area 2020–21.

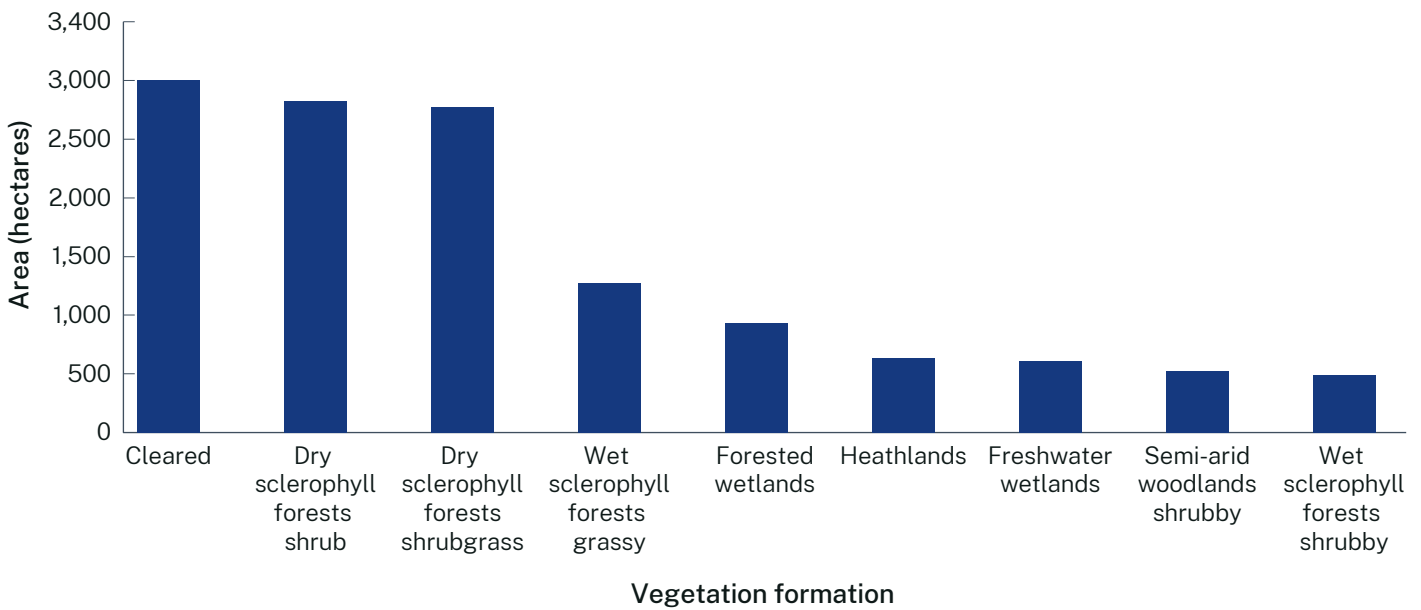


Figure 8 The area of Keith vegetation formations burnt in the 2020–21 fire year. Vegetation formations that had more than 200 hectares burnt have been included here

Fire extent across soil texture types

Sandy loam and clay loam had the greatest area burnt in 2020–21 (Figure 9a). However, highly organic/peat soil texture types had the greatest proportion of class area burnt, at 0.20% (Figure 9b). Soil texture classes with high organics or low clay percentages (e.g. highly organic, sandy loam and loose sand) are more vulnerable to damage following hot fires.

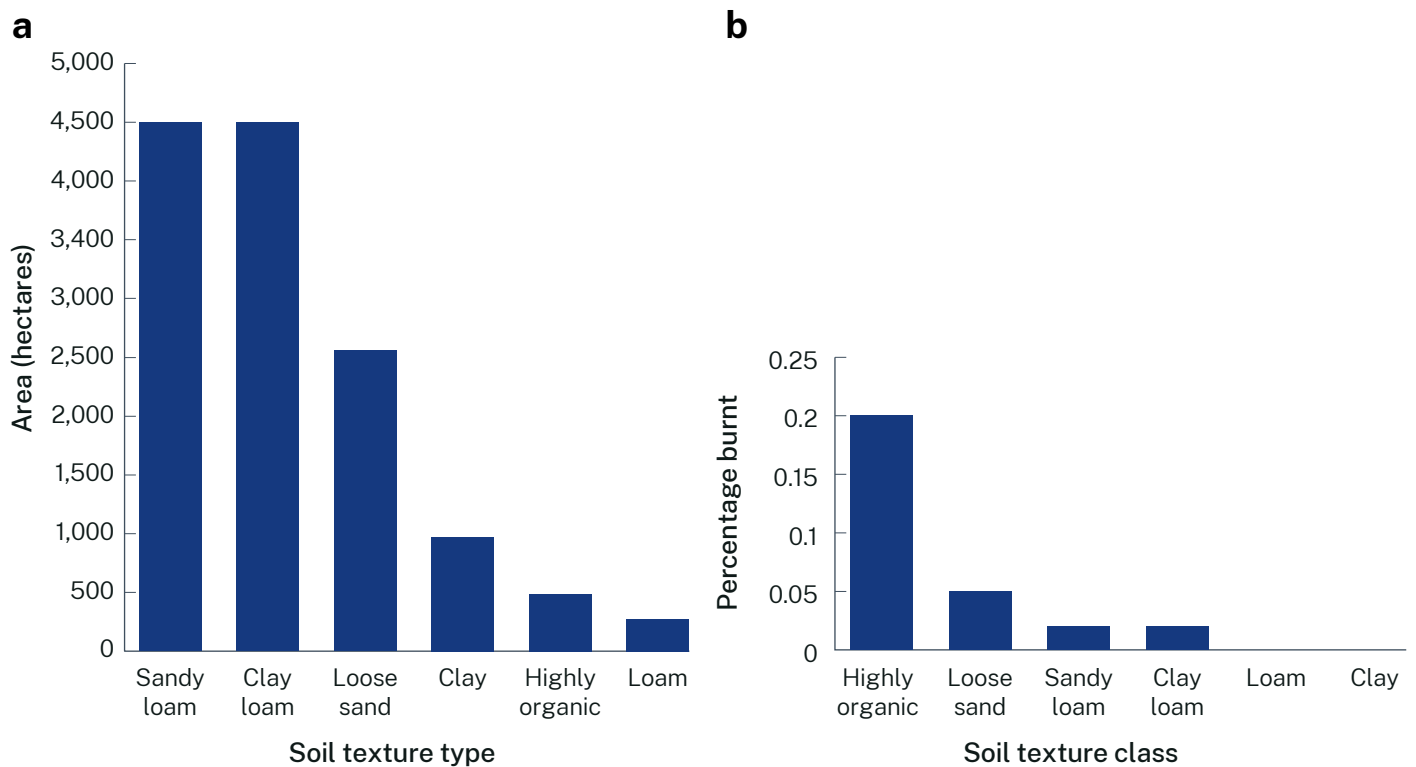


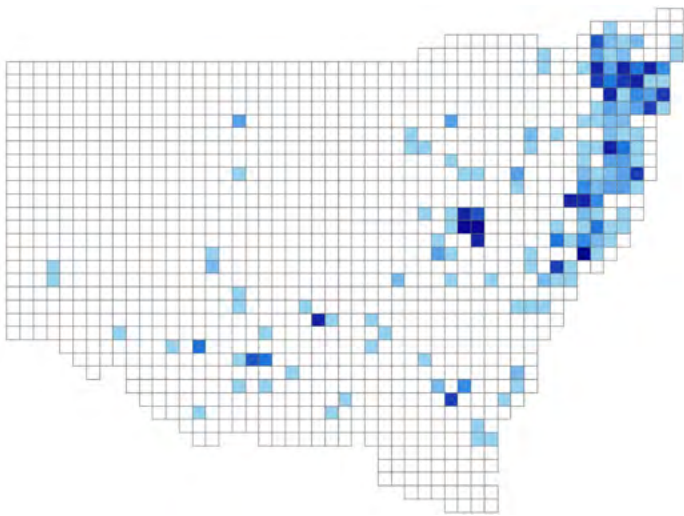
Figure 9 The area burnt (a) and proportion of class area (b) across soil texture classes in the 2020–21 fire year

Comparison with previous years

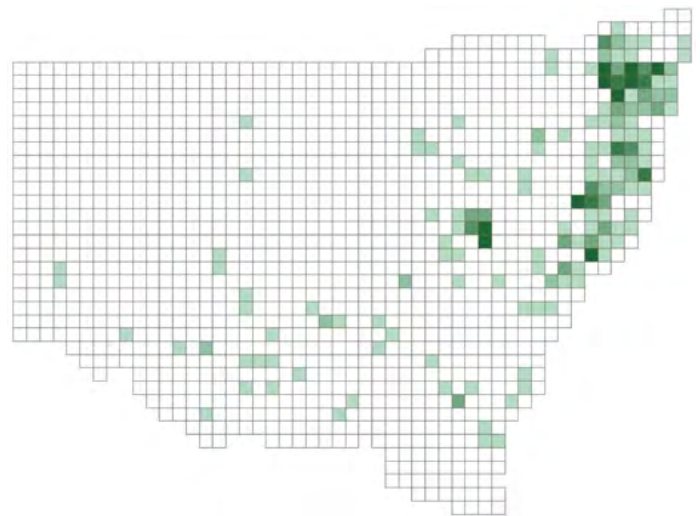
This section compares the 2020–21 fire year with previous fire years including 2019–20, 2018–19, 2017–18 (previously reported, see DPIE 2021) and 2016–17 (presented here). This provides a comparative assessment of 5 consecutive years of statewide severity mapping. Future reports will compare a rolling window of the previous 5 years.

A high proportion of total fire occurred in the north-east of the State in 2016–17, which is typical of the bioregional patterns in fire activity in New South Wales (Figure 10). This biogeographic distribution closely resembles most other fire years (2017–18, 2018–19 and 2020–21), except the anomalous 2019–20 which had much larger proportion of areas burnt in the Sydney Basin, South East Corner and Australian Alps bioregions in the south-east of the State.

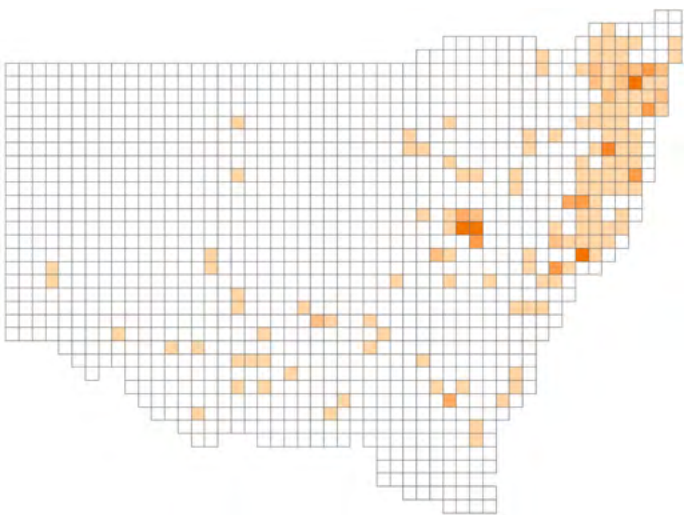
Notably, in 2016–17 there was a very large wildfire with a large area of high and extreme severity in central New South Wales, west of the Great Dividing Range. This was the Sir Ivan fire, a so-called ‘Black Swan’ fire event (i.e. a fire without precedent and thought to be impossible). The Sir Ivan fire burned 55,000 hectares in the Warrumbungle Shire and generated a pyrocumulonimbus cloud (i.e. a fire thunderstorm). This was the first pyrocumulonimbus event in New South Wales since the previous record in 2013, which was also in the Warrumbungle Shire (the Wambelong fire).



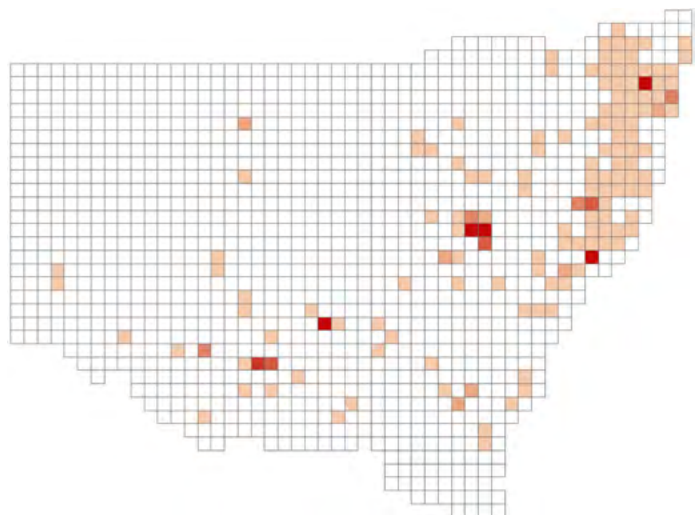
a. Fire extent



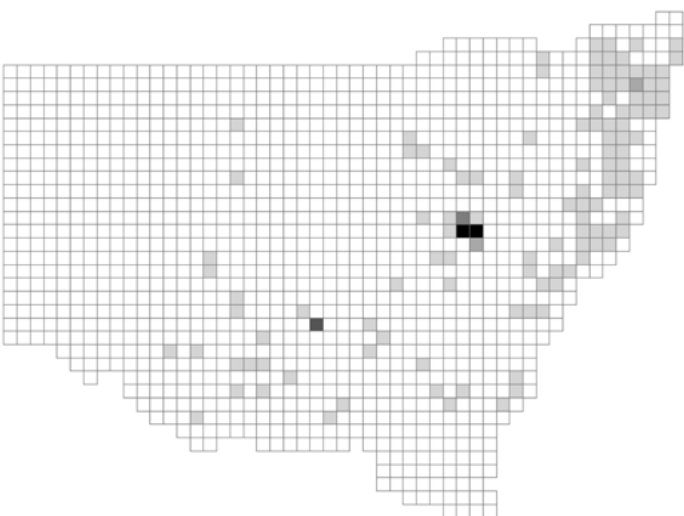
b. Low severity



c. Moderate severity



d. High severity



e. Extreme severity

Area (hectares)

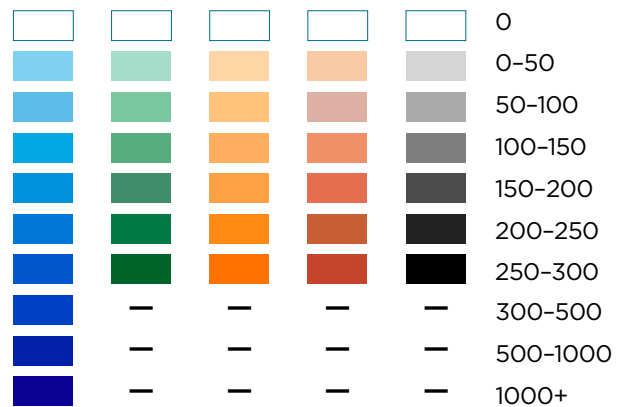


Figure 10 Geographic distribution of fire extent and fire severity across New South Wales for the 2016-17 fire year; (a) fire extent, (b) low severity, (c) moderate severity, (d) high severity and (e) extreme severity



The proportion of each severity class within the fire extent differed between the fire years (Figure 11). The largest proportion of extreme severity and the smallest proportion of low severity occurred in 2019–20 compared to the other fire years. The proportion of the extreme severity class in 2019–20 was more than double that of 2016–17 (21% and 8%, respectively). The proportion of low severity in 2016–17 was double that of 2019–20 (47% and 24%, respectively). The fire severity class proportions of the recent fire year (2020–21) was similar to other fire years with the highest proportion of low severity and the lowest proportion of extreme severity.

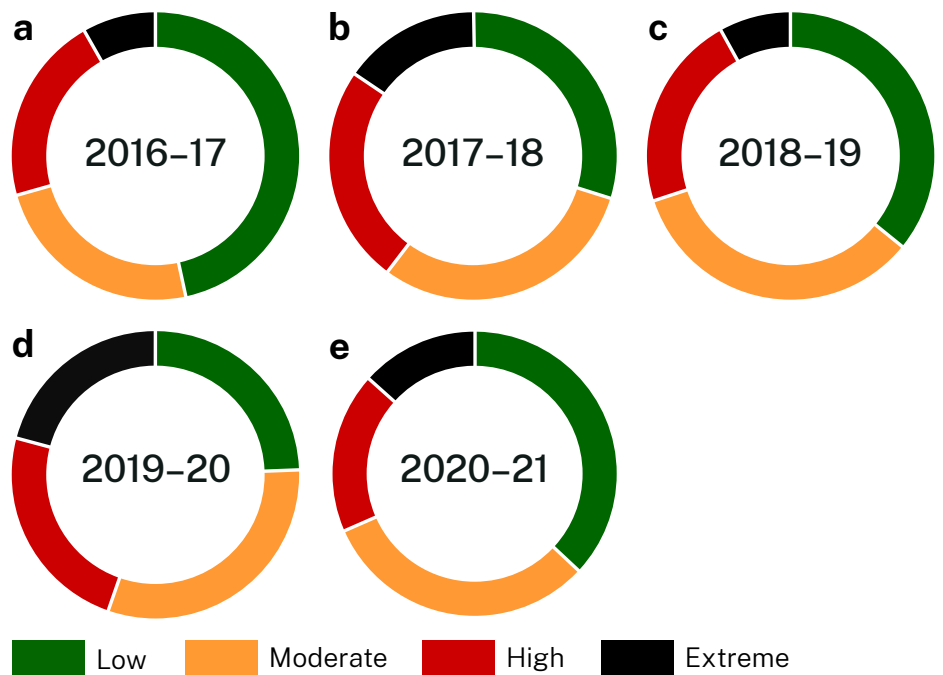


Figure 11 Comparison of the proportion of each severity class in New South Wales in (a) 2016-17, (b) 2017-18 (c) 2018-19, (d) 2019-20 and (e) 2020-21 fire years

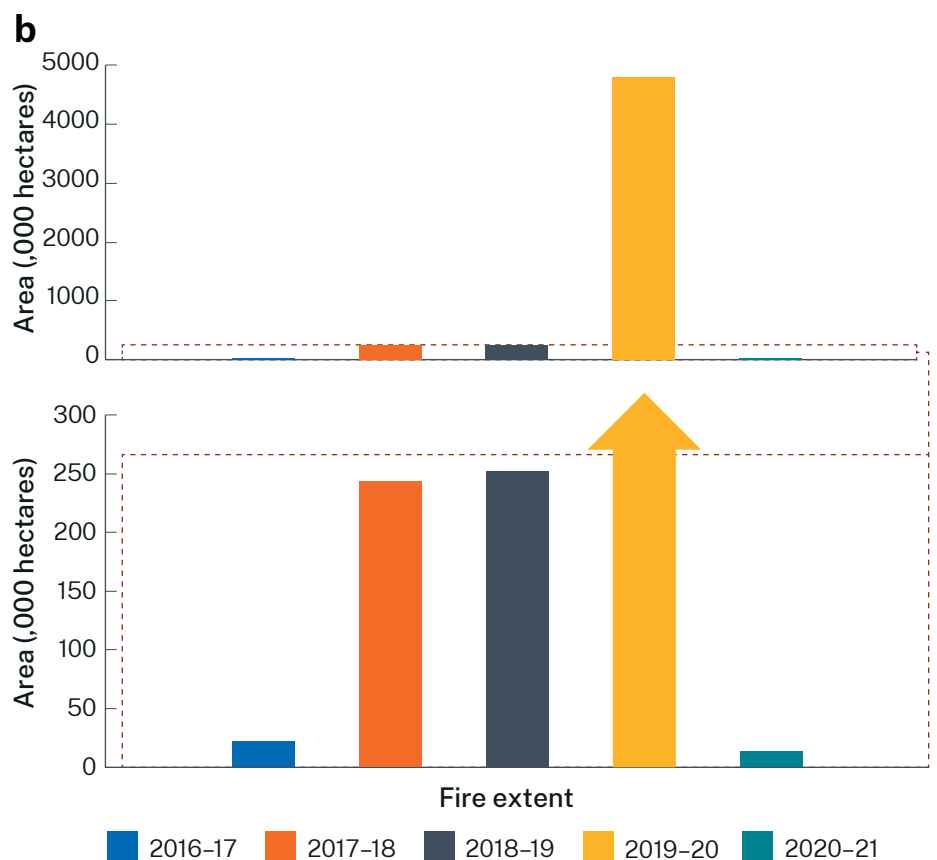
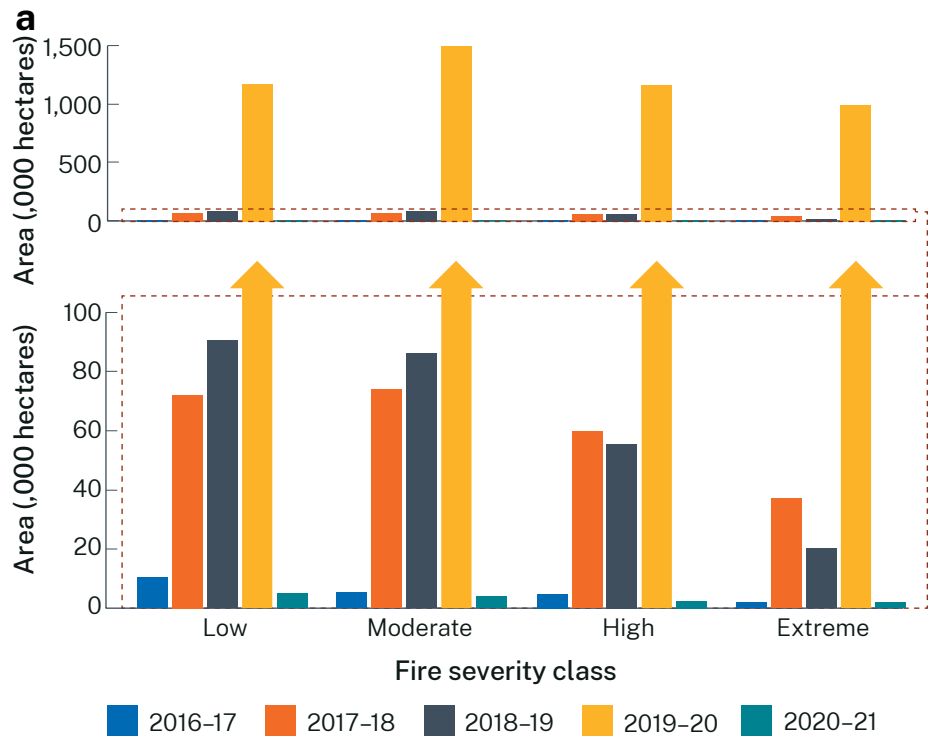


Figure 12 Comparison (a) NSW fire severity, and (b) fire extent between the 5 fire years from 2016-17 to 2020-21. Note the two panels of each figure are on different scales, with the lower panel excluding 2019-20 data above 100,000 and 300,000 hectares for a and b respectively



More information

Webpages and fact sheets

[Landcover monitoring and reporting webpage](#), NSW Department of Planning, Industry and Environment

[Fire extent and severity maps webpage](#), NSW Department of Planning, Industry and Environment

DPIE 2021, *Supporting fire management with the fire extent and severity maps: Fire mapping by machine learning*, NSW Department of Planning, Industry and Environment,

Pyrocumulonimbus event spatial data are available on the [Hire Fire Risk Project website](#).

Data availability

Fire extent and severity mapping datasets for all fire years are available on the [SEED portal](#)

Fire extent and severity mapping results for the 2016-17 fire year, www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Animals-and-plants/Nativevegetation/fire-extent-severity-mapping-results-2016-17.xlsx

Fire extent and severity mapping results for the 2020-21 fire year, www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Animals-and-plants/Nativevegetation/fire-extent-severity-mapping-results-2020-21.xlsx

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Gibson R, Danaher T, Hehir W and Collins L 2020, A remote sensing approach to mapping fire severity in south-eastern Australia using Sentinel 2 and random forest, *Remote Sensing of Environment*, 240 (111702), www.sciencedirect.com/science/article/pii/S0034425720300717?via%3Dihub.

Keith D 2004, *Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*, NSW Office of Environment and Heritage, Sydney.

Peterson, DA, Fromm MD, McRae RH, Campbell JR, Hyer EJ, Taha G, Camacho CP, Kablick GP, Schmidt CC and DeLand MT 2021, Australia's Black Summer pyrocumulonimbus super outbreak reveals potential for increasingly extreme stratospheric smoke events, *Climate and Atmospheric Science*, 4(1): pp.1–16.

White LA and Gibson RK 2022, Comparing fire extent and severity mapping between Sentinel 2 and Landsat 8 satellite sensors. *Remote Sensing*, 14, 1661. <https://doi.org/10.3390/rs14071661>





Appendix A

Comparing fire extent and severity mapping between satellite sensors

Background

The NSW fire extent and severity mapping (FESM) has been developed for application on both Sentinel 2 and Landsat imagery. From the 2017–18 fire year to current and future fire years, Sentinel 2 imagery is used; while Landsat imagery is used for historical mapping (1989–90 to 2016–17). Due to differences between sensors (Table A1), FESM algorithms have been trained separately for each sensor type. The assessment presented here compares the Sentinel 2 and Landsat 8 FESM algorithms through independent accuracy assessments. Differences in the area mapped in each severity class, and the statistical agreement between FESM outputs are also compared between algorithms (see White and Gibson 2022, for further details).

Table A1 Details of Sentinel 2 and Landsat 8 satellite sensors in New South Wales.

	Sentinel 2	Landsat 8
Imagery availability	Late 2015 to present	2013 to present
Imagery resolution (pixel size)	10 metre	30 metre
Sensor re-visit time in NSW	Every 5 days	Every 15 days
Timeframe used for FESM	2017–18 fire year to present	2016–17 fire year and prior
Spectral wavelengths	Blue: 0.45–0.51 Green: 0.53–0.59 Red: 0.64–0.67 NIR: 0.85–0.88 SWIR1: 1.57–1.65 SWIR2: 2.11–2.29	Blue: 0.490 Green: 0.560 Red: 0.665 NIR: 0.842 SWIR1: 1.610 SWIR2: 2.190

Notes: NIR = near infra-red; SWIR = short-wave infra-red



Independent accuracy assessment

To compare the accuracy of the Sentinel 2 and Landsat 8 algorithms, random forest models were trained and tested using sampling data derived from high-resolution aerial photograph interpretation (API) of fire severity classes from a set of 8 case study fires. Spectral data from each sensor derived from a suite of severity indices was extracted at the training sample locations. An independent cross-validation assessment was conducted, where each case study fire was iteratively excluded from training the model, and then used to test the model performance.

The independent accuracy assessment results indicate Sentinel 2 and Landsat 8 algorithms have demonstrated very similar levels of accuracy. The mean difference between sensor algorithms was between 0.01 and 0.05 across severity classes (Table A2).

Table A2 Comparison of the balanced accuracy statistics for each severity class, as well as the Kappa and overall balanced accuracy statistics for Sentinel 2 and Landsat 8 FESM algorithms

	Sentinel 2	Landsat 8	Difference
Unburnt	0.98	0.96	0.02
Low severity	0.83	0.86	-0.03
Moderate severity	0.66	0.67	-0.01
High severity	0.84	0.79	0.05
Extreme severity	0.91	0.89	0.01
Kappa score	0.72	0.71	0.01
Overall accuracy	0.80	0.82	-0.02

Area comparisons

We selected 27 test fires between 2018 and 2020 (Figure A1). Each test fire was mapped using both the Sentinel 2 and Landsat 8 algorithms. Selected pre- and post-fire imagery dates for each sensor were less than 2 weeks apart (average 4 days).

The FESM outputs between sensor types were generally similar overall. There was less than 5% difference in the average fire area mapped as unburnt, moderate and extreme severity between sensors (Figure A2). For low severity, the average area was approximately 11% lower with the Sentinel 2 algorithm than the Landsat 8 algorithm. For high severity, the average area was approximately 6% higher with the Sentinel 2 algorithm than the Landsat 8 algorithm. The difference of approximately 1% in the proportion of unburnt area mapped between sensors indicates a very high similarity in fire extent mapping between sensors.

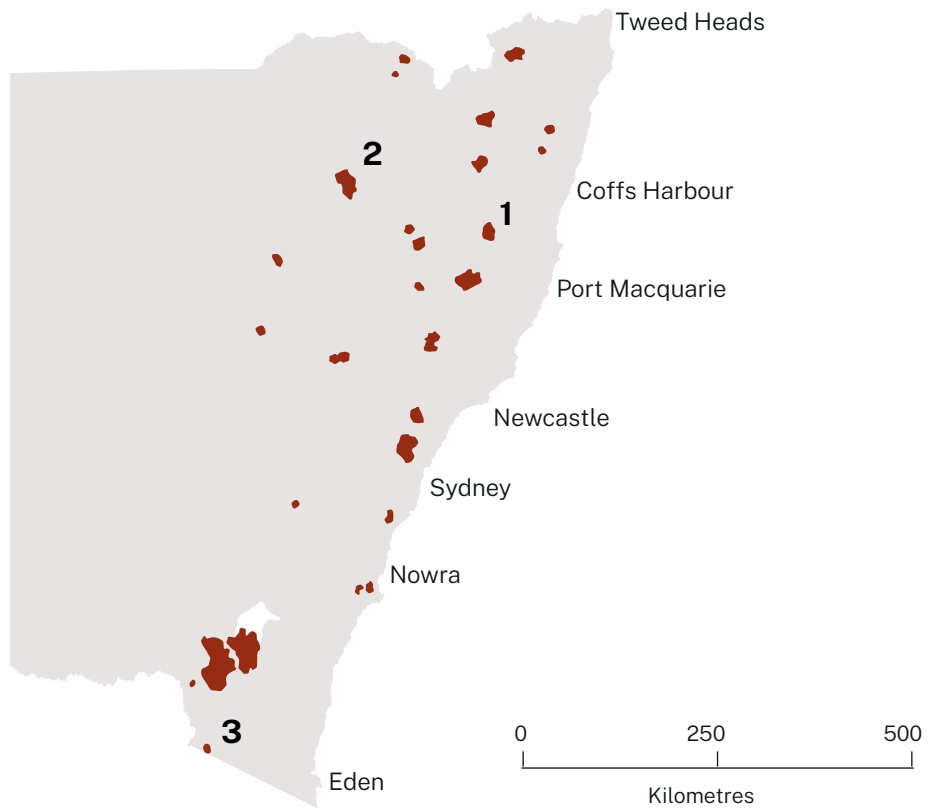


Figure A1 Location and relative size of test fires (FESM outputs for numbered fires are shown in Figure A3)

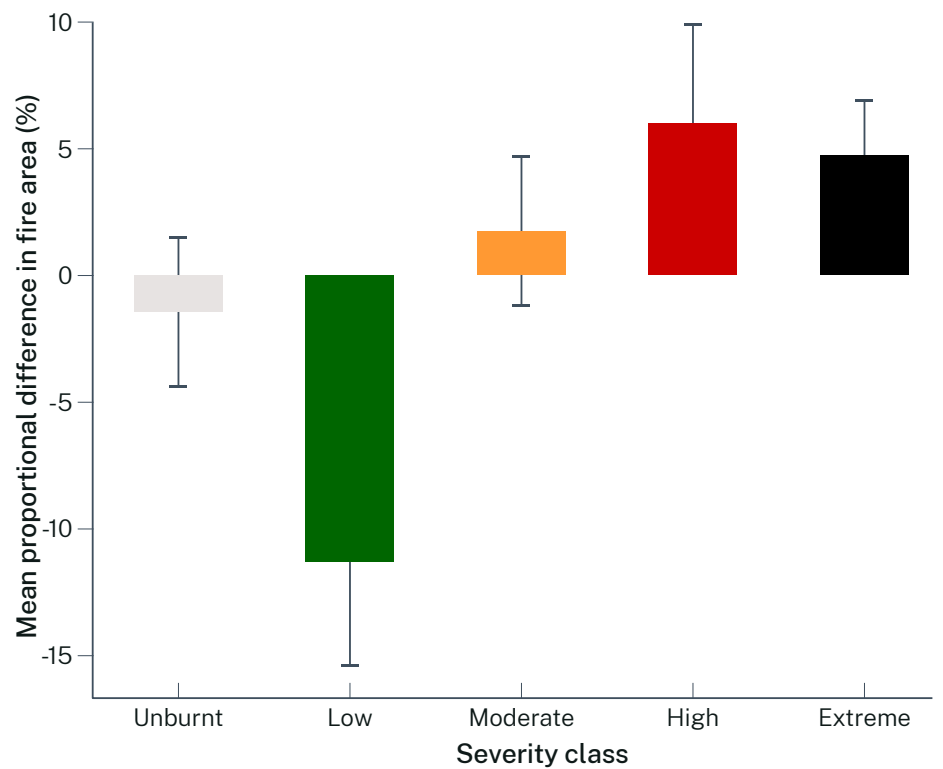


Figure A2 Mean difference in the proportion of fire area in each fire severity class when mapped with Sentinel 2 imagery compared with Landsat 8 imagery



Statistical agreement

A statistical measure of the level of agreement in FESM outputs mapped by the different sensor algorithms was also calculated for all test fires using random sampling points for test fires. The Kappa statistic is a measure of the similarity between categorised data, beyond that which would occur by chance, and can be used to compare spatial models. A weighted Kappa statistic was used to account for the ordinal scale of severity classes, which ensures a difference between ‘unburnt’ and ‘low’ is not penalised to the same degree as a difference between ‘unburnt’ and ‘extreme’. The mean weighted Kappa score across all fires was 0.61 which indicates a substantial level of agreement between sensor algorithms (Table A3, Figure A3).

Table A3 Kappa score definitions

Kappa score	Level of agreement
>0.81	Almost perfect
0.61-0.8	Substantial
0.4-0.6	Moderate
0.21-0.4	Fair
0-0.2	Slight
<0	Poor

The level of statistical agreement in FESM outputs between sensors varied between fires. While most FESM outputs from Sentinel 2 and Landsat 8 algorithms appeared very similar (weighted Kappa scores of up to 0.76), some fires had lower scores (weighted Kappa scores as low as 0.42). The higher resolution of Sentinel 2 imagery compared with Landsat 8 imagery is likely to account for some of the differences in FESM outputs between sensors. Preliminary analysis of explanatory factors suggests that some variation in agreement between sensors may result from terrain roughness and foliage cover (Figure A4).

Conclusion

Model accuracy and area calculations were comparable between severity classes mapped by Sentinel 2 and Landsat 8 algorithms. Given the similarities, the Landsat FESM algorithm will be used to map historical fires from 1989–90 to 2016–17, as required, to compare with Sentinel 2 outputs.

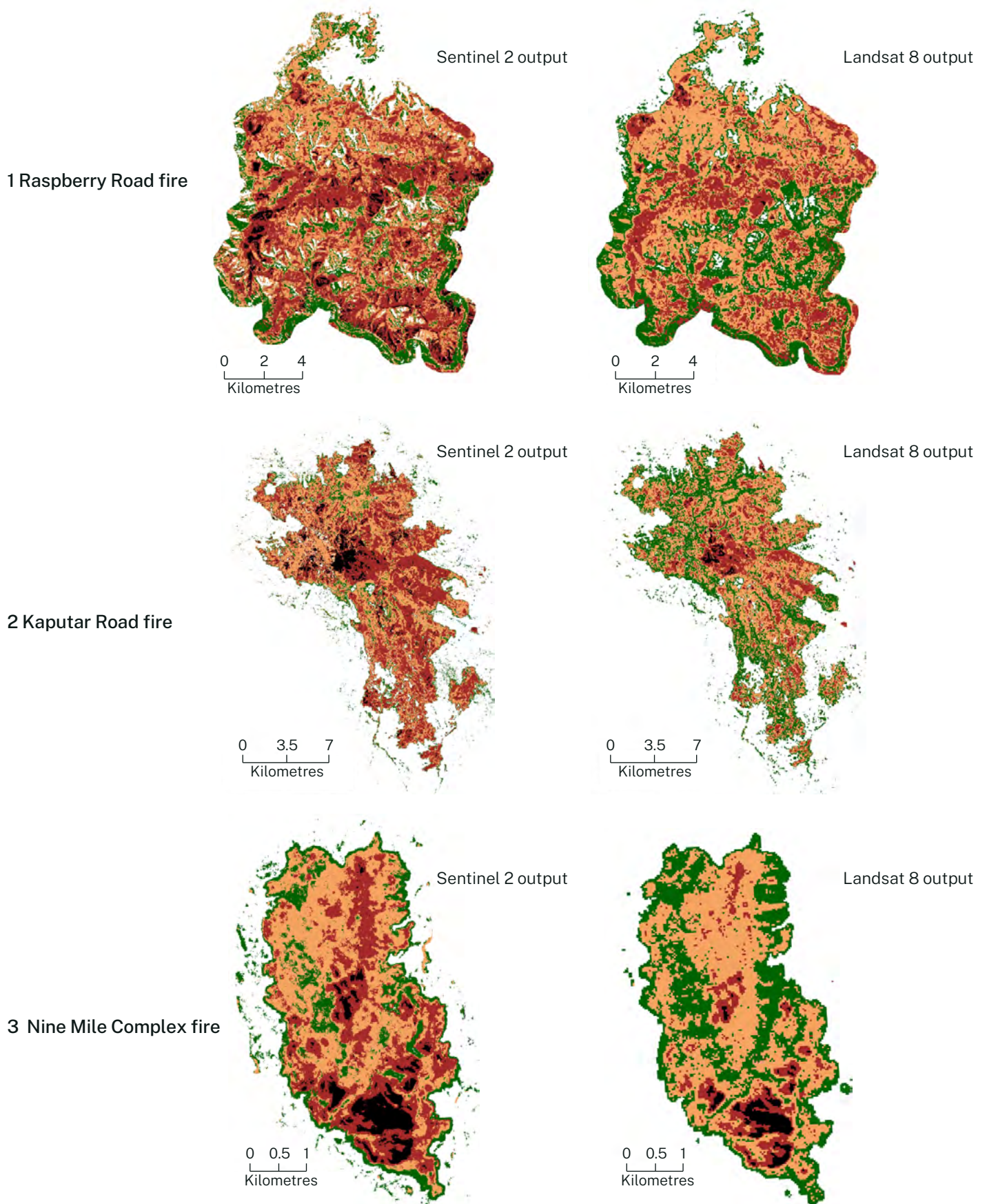


Figure A3 FESM outputs for 3 test fires mapped with both Sentinel 2 and Landsat 8 imagery. See Figure A1 to cross-reference locations of these fires in New South Wales

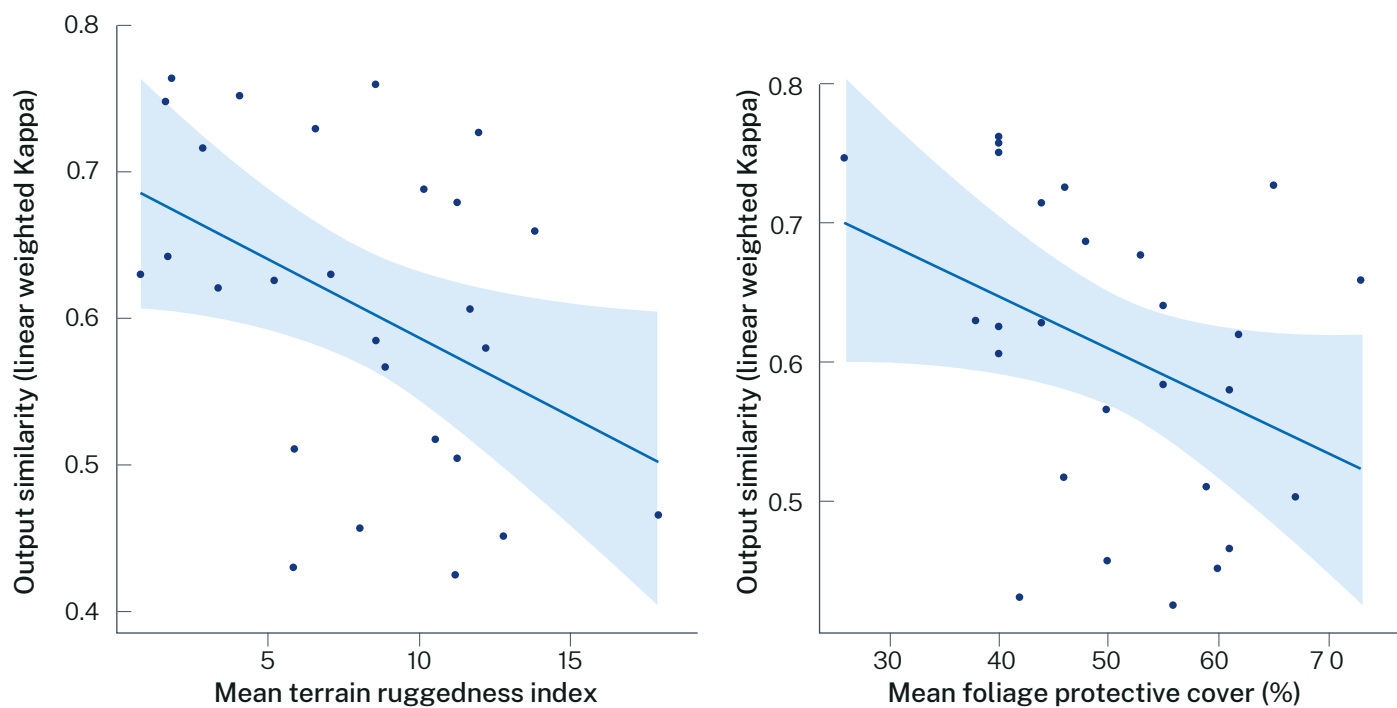


Figure A4 Relationships between FESM output similarity between sensors and explanatory factors affecting similarity

