THEME 1.1- HISTORICAL AND SEASONAL CONTEXT ANALYSES

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Subproject: Fuel dryness

Subproject lead: Rachael Nolan

OVERVIEW

1. Theme

Historical and seasonal context of the 2019/20 NSW bushfires.

2. Project question or problem statement

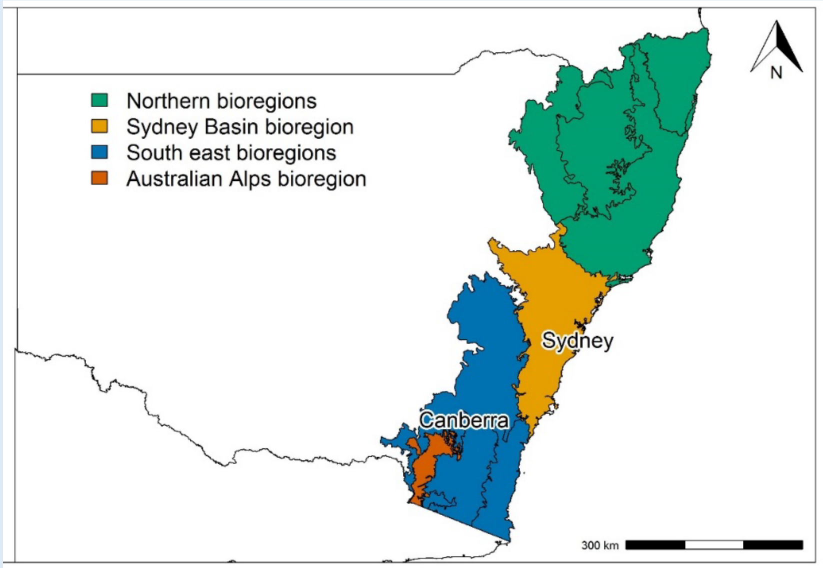
Was fuel dryness leading up to and during the 2019/20 bushfire season in NSW unprecedented?

3. Background

Large bushfires generally only occur in eastern Australia when fuels are very dry. Here, we examine three metrics which have been demonstrated to influence fire size (Nolan et al., 2016; Williams et al., 2014). The first metric is vapour pressure deficit (VPD), calculated from temperature and humidity. VPD represents atmosphere demand for water, and can be thought of as the 'drying power of the atmosphere'. The second metric, dead fuel moisture content (DFMC), is calculated from VPD, and represents the moisture content of dead fuels (e.g. dead leaves and twigs). The third metric, live fuel moisture content (LFMC) represents the moisture content of live fuels (e.g. leaves and twigs on living plants). Both VPD and DFMC can fluctuate widely at a sub-daily scale. In contrast, LFMC fluctuates more slowly and is governed by changes in soil moisture content.

4. Geographic location

All of the NSW bioregions affected by bushfires this season are shown below. The study area was divided into four main regions for analyses:



5. Key findings

- Three metrics of fuel dryness: (i) vapour pressure deficit (VPD), (ii) dead fuel moisture content (DFMC) and (iii) live fuel moisture content (LFMC) all showed that conditions were either very much drier than average, or the driest on record, in the months leading up to, and during, the fires, in particular in December 2019.
- For VPD, records were set for highest mean monthly VPD in northern NSW in October, November and December, 2019. Similar records were set in November and December in the Sydney basin, and in December for the south coast and alpine regions (Fig. 1, Table 1). Records were examined from 1950 – 2019/20.
- For estimated DFMC, mean monthly DFMC was very much below average over August-December 2019, with many regions experiencing the lowest values on record in December (Video 1). Records were examined from 1950 – 2019/20.
- The annual number of days that DFMC was in a critically dry state (<10% moisture content; Nolan et al., 2016) set records for northern NSW, the Sydney basin bioregion and the south coast (Fig. 2). These results suggest a lengthening of the fire season for these regions in 2019.
- For estimated LFMC, mean monthly values reached record breaking low levels relative to recent seasons, with many regions experiencing their lowest values on record in December 2019 (Video 1, Fig. 3). The exception to this was the Alpine bioregion. Records

were examined from 2006 – 2019/20 (representing the availability of satellite imagery).

- The duration that live fuels were in a critically dry state (below 102% moisture content; Nolan et al., 2016) was similar to previous seasons (Fig. 4).

6. Significance of findings in context of previous studies

The dry fuel conditions during the 2019/20 fire season reported here are consistent with previously reported relationships between low fuel moisture content and the occurrence of large bushfires (Nolan et al., 2016), and high vapour pressure deficit and the occurrence of large fires (Williams et al., 2014). The exceptionally low values of live fuel moisture content are consistent with the severe drought across the study area during the fire season (Bureau of Meteorology, 2019). Analyses from the western United States indicate that anthropogenic climate change has contributed to increased VPD, and a subsequent increase in forest fires, in that region (Abatzoglou and Williams, 2016).

7. Limitations and remaining knowledge gaps

These analyses were undertaken with gridded climate or satellite data sets, at a resolution of approximately 5 km x 5 km and 500 m x 500 m respectively. This coarse spatial resolution prevents analyses of fine-scale variations in fuel dryness, for example the drying of gullies, which may have played an important role in the 2019/20 fire season.

8. Implications for fire management

It is likely that the unprecedented fuel dryness across eastern NSW, particularly in December 2019, contributed to the large areas burnt in the 2019/20 fire season. There are clear links between very low fuel dryness and bushfire risk. There are indications that the 2019/20 fire season began earlier than usual, with 2019 exhibiting the most number of days where dead fuel moisture content was in a critically dry state since 1950.

9. Figures

Figure 1. Anomaly in mean monthly vapour pressure deficit (VPD), 1950 to 2019, for one of the months of peak fire activity for each of the study regions.

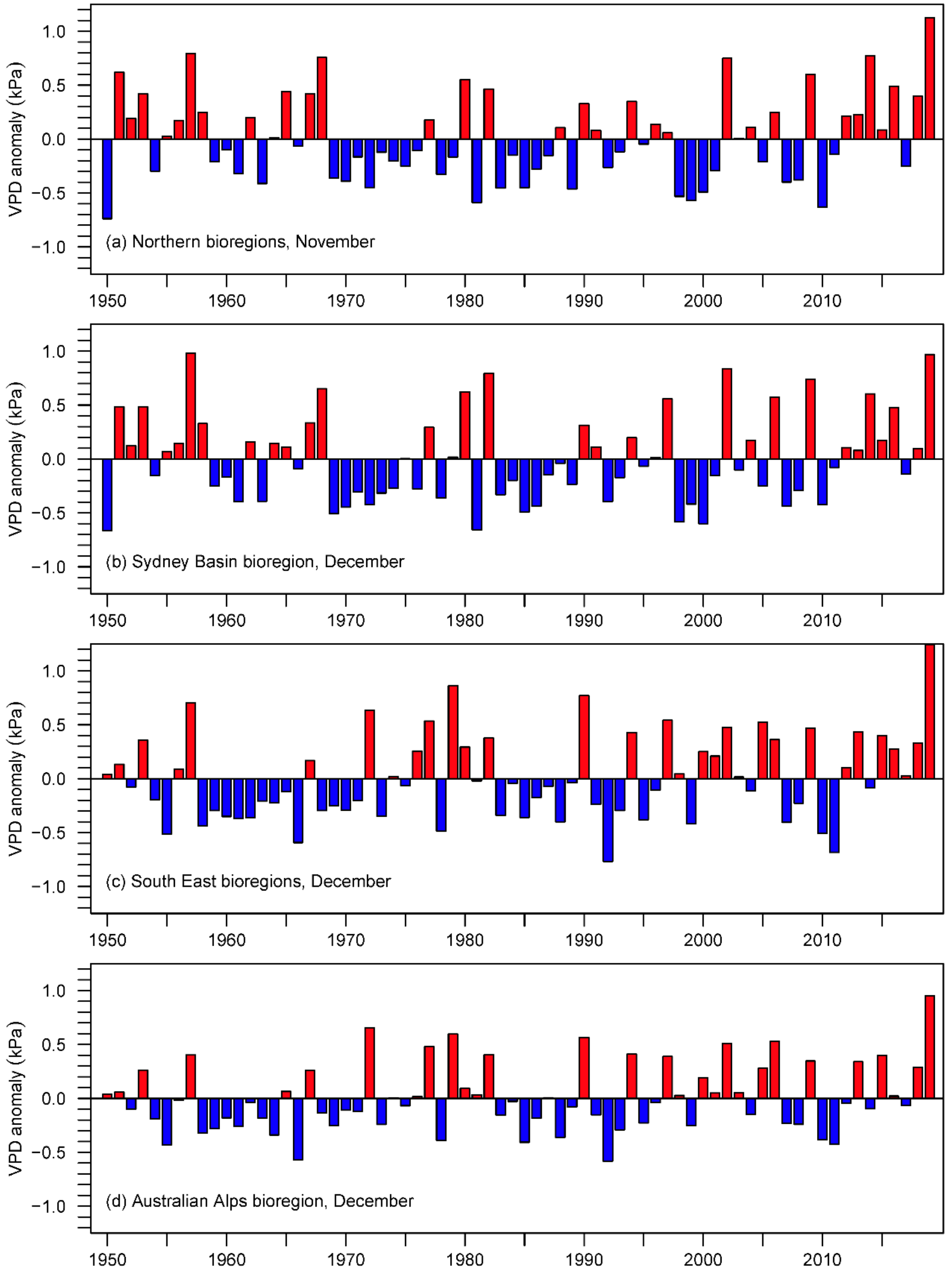


Table 1. Summary of the anomalies in mean monthly vapour pressure deficit (VPD), 1950 to 2020, for each of the study regions.

Month	VPD anomaly (kPa), Northern bioregions		
	Minimum (1950-2018/9)	Maximum (1950-2018/9)	2019/20
Aug	-0.3	0.5	0.4
Sep	-0.7	2.2	1.8
Oct	-0.6	0.8	0.8
Nov	-0.7	0.8	**1.1**
Dec	-0.8	0.9	**1.2**
Jan	-0.8	1.1	0.6
Feb	-0.7	0.9	-0.3

Bold values represent record high anomalies

Month	VPD anomaly (kPa), Sydney Basin bioregion		
	Minimum (1950-2018/9)	Maximum (1950-2018/9)	2019/20
Aug	-0.3	0.5	0.2
Sep	-0.9	2.6	1.4
Oct	-0.6	0.9	0.6
Nov	-0.7	1.0	**1.0**
Dec	-0.9	0.9	**1. 1**
Jan	-0.9	0.9	0.5
Feb	-0.7	0.8	-0.1

Month	VPD anomaly (kPa), South east bioregion		
	Minimum (1950-2018/9)	Maximum (1950-2018/9)	2019/20
Aug	-0.2	0.4	0.2
Sep	-0.6	2.2	0.9
Oct	-0.5	0.8	0.7
Nov	-0.7	1.2	0.9
Dec	-0.8	0.9	**1.2**
Jan	-0.9	0.8	0.7
Feb	-0.7	0.9	-0.1

Month	VPD anomaly (kPa), Australian Alps bioregion		
	Minimum (1950-2018/9)	Maximum (1950-2018/9)	2019/20
Aug	-0.1	0.3	0.1
Sep	-0.5	1.2	0.4
Oct	-0.4	0.7	0.4
Nov	-0.6	1.0	0.4
Dec	-0.6	0.7	**1. 0**
Jan	-0.7	0.8	0.6
Feb	-0.6	1.0	-0.2

Figure 2. Annual number of days with critically dry dead fuel moisture content conditions (below 10%). Solid line represents 1950-2019 mean.

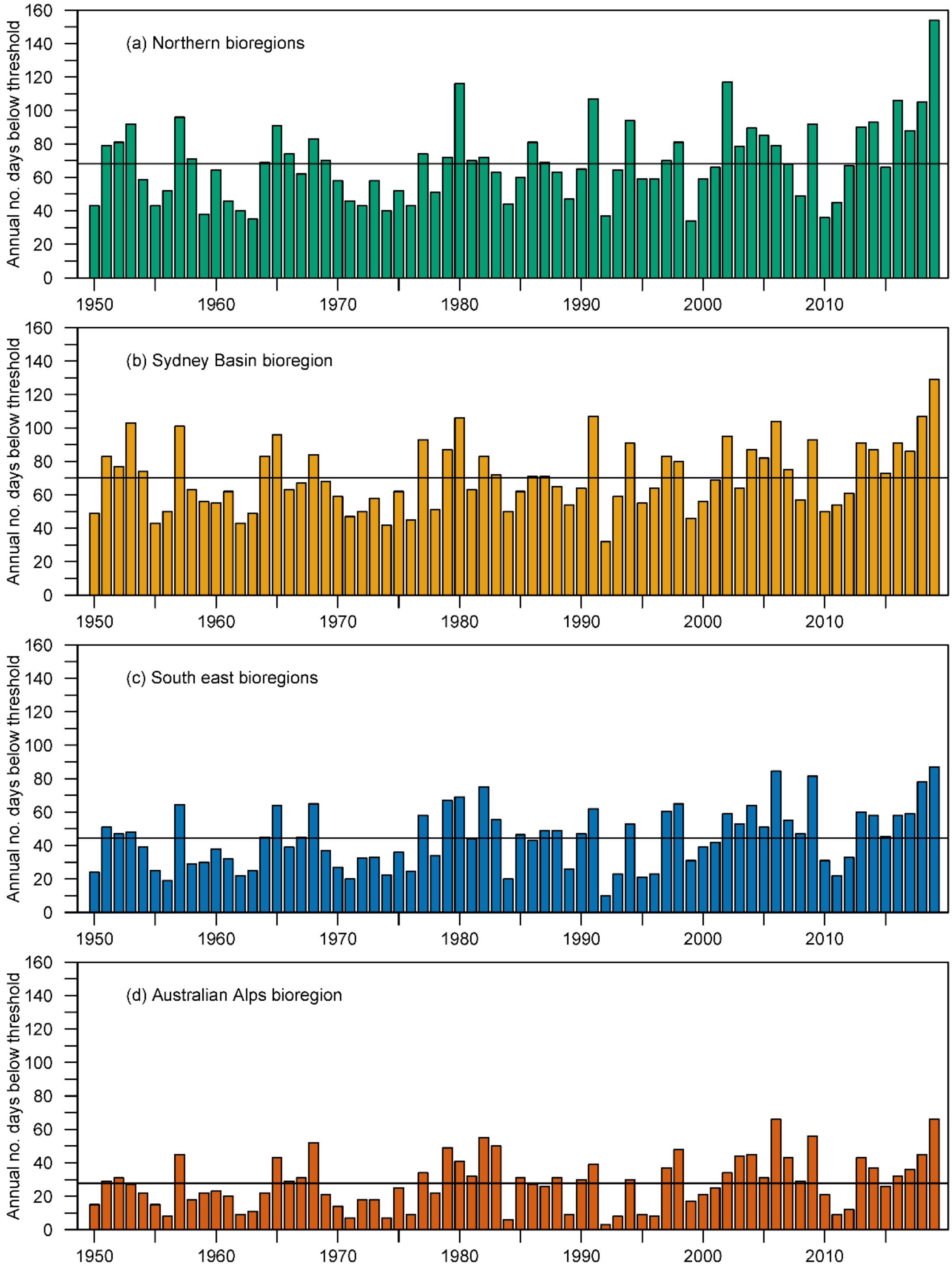


Figure. 3. Median value of mean monthly live fuel moisture content (LFMC) for November, for each of the study regions. Solid line represents 2006-2019 mean.

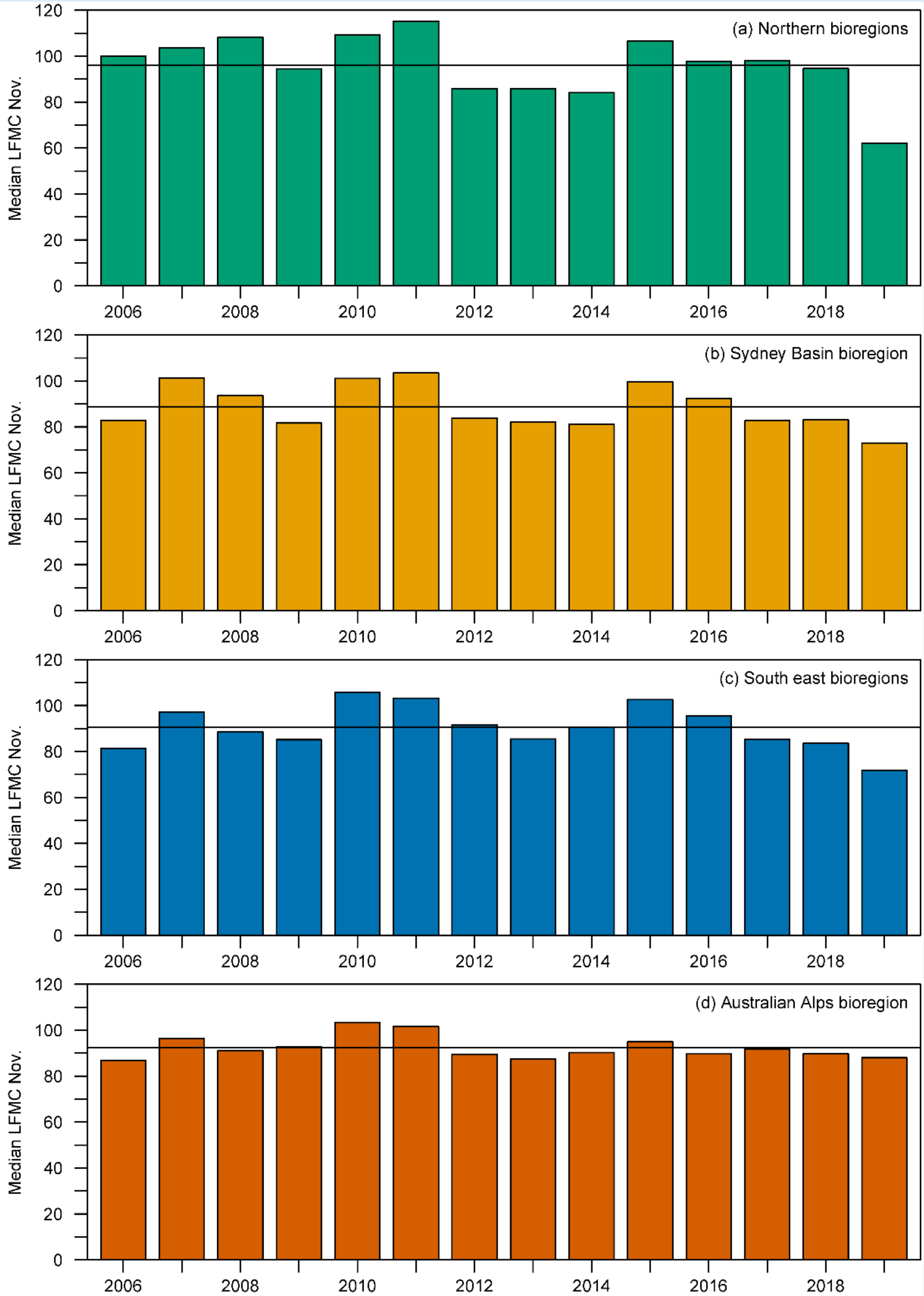
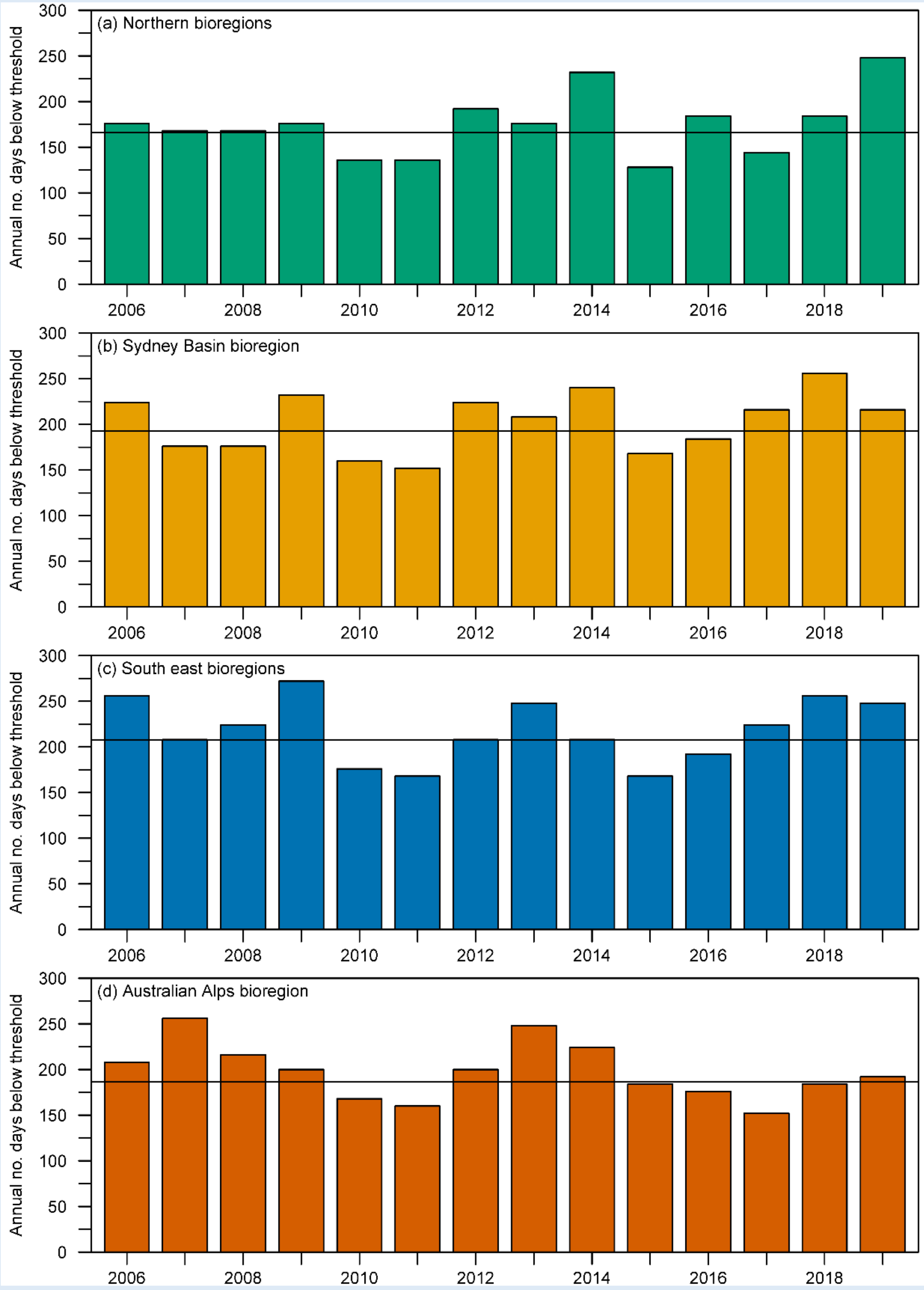


Figure 4. Annual number of days with critically dry live fuel moisture content conditions (below 102%). Solid line represents 2006-2019 mean.



Video 1. Maps of temporal trends in deciles of: (i) mean monthly VPD, (ii) mean monthly DFMC; and (iii) mean monthly LFMC. Video link here.

10. Key reference list

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11. Appendix

Methods

Vapour pressure deficit

Significant relationships have been found between vapour pressure deficit (VPD) and area burnt in Alaska (Sedano and Randerson, 2014) and the southwest United States (Williams et al., 2019; Williams et al., 2015). VPD has also been indirectly related to area burnt in south-eastern Australia, through its influence on dead fuel moisture content (Nolan et al., 2016a).

VPD was calculated following Monteith and Unsworth (1990) as:

$$\text{VPD (kPa)} = e_s - e_a \quad (1)$$

where e_s is saturation vapour pressure and e_a is actual vapour pressure. e_s is calculated as:

$$e_s = 0.6108 * \exp\left(17.27 * \frac{T_{air}}{T_{air}+237.3}\right) \quad (2)$$

where T_{air} is air temperature (°C).

Gridded maximum daily T_{air} and e_a at 3pm were sourced from the Australian Water Availability Project (AWAP), hosted by the Australian Bureau of Meteorology (Jones et al., 2009). These datasets were used to calculate maximum daily vapour pressure deficit.

Dead fuel moisture content

Fuel moisture (FM) content is defined as the percentage of water weight over dry fuel weight:

$$\text{FM (\%)} = \left(\frac{F_w - D_w}{D_w}\right) * 100 \quad (3)$$

where F_w is the fresh weight of fuel and D_w is the dry weight of fuel.

Resco de Dios et al. (2015) developed a semi-mechanistic model of dead fuel moisture content (FM_D). This model predicts moisture content of suspended fuels in the 10 hour fuel class (6.35–25mm diameter), although the moisture content of 1 hour fuels (<6.35 mm) are also strongly correlated with those of 10 hour fuels (Nolan et al., 2016b). The spatial application of this model for south-eastern Australian forests and woodlands was developed in Nolan et al. (2016b), and is applied here. The model is:

$$FM_D = 6.79 + 27.43e^{(-1.05\ VPD)} \quad (4)$$

where FM_D is dead fuel moisture content (%) and VPD is vapour pressure deficit (kPa).

Calculation of VPD and source of datasets are described above. Minimum daily gridded FM_D was estimated here.

Live fuel moisture content

An empirical model of live fuel moisture content (LFMC, in %) was developed for south-eastern Australian forests and woodlands, and is described in Nolan et al. (2016a). This model uses the Visible Atmospherically Resistant Index (VARI; Gitelson et al., 2002) calculated from the MODIS Terra satellite:

$$LFMC = 52.51\ e^{1.36\ VARI_{max-min}} \quad (5)$$

where $VARI_{max-min}$ is the relative variation of the VARI recorded for a pixel at a given time compared to the minimum and maximum value observed for that pixel over the image time series.

The empirical model was developed using the MODIS 8-day composite data set MOD09A1, from collection 5. The current MODIS collection, collection 6, has a number of changes implemented that correct for sensor degradation and also improve vegetation index retrieval algorithms (Didan et al., 2015). These changes have resulted in some discordance in time-series of vegetation indices calculated from collection 6 compared to collection 5 (Heck et al., 2019). Thus, the LFMC model was re-validated using collection 6, prior to application of the model here. The root mean square error (RMSE) of the model validation was 17.0 and the r^2 was 0.33.

MODIS data products were courtesy of the online Data Pool at the NASA Land Processed Distributed Archive Centre, USGS/Earth Resources Observation and Science Center, Sioux Falls, SD (https://lpdaac.usgs.gov/data_access).

Google Earth Engine (Gorelick et al., 2017) was used to access and process 8-day composite imagery from the MODIS Terra satellite, 500 m resolution.

Note, this model cannot be applied to recently burnt vegetation (within the previous 5 years), and so these areas are masked from analyses.

References

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Gitelson, A.A. et al., 2002. Vegetation and soil lines in visible spectral space: a concept and technique for remote estimation of vegetation fraction. Int. J. Remote Sens., 23(13): 2537-2562, 10.1080/01431160110107806.

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