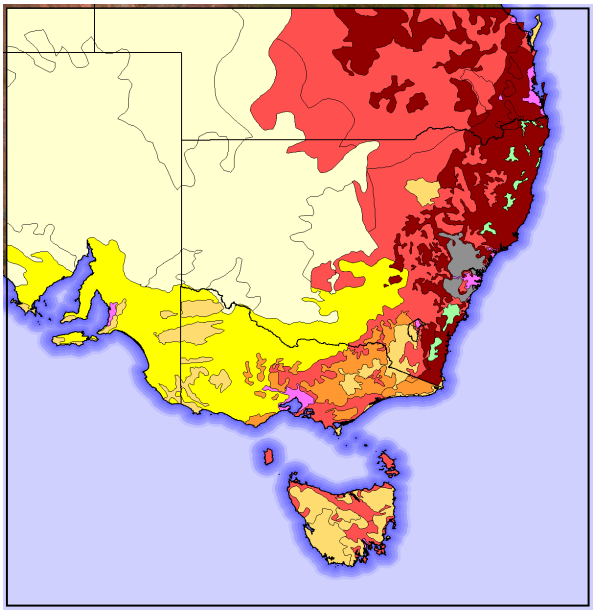
-THE LEGACY OF BLACK SUMMER-

**The context of, and lessons from,
Australia's Black Summer bushfires in 2019-2020.**

AUSTRALIAN FIRE PATTERN ANALYSES USING MODIS HOTSPOTS



Part 6: A SYNTHESIS OF FIRE REGIMES OF SOUTH-EAST AUSTRALIA

UNSW CANBERRA

Adj Prof Rick McRae
UNSW Canberra Bushfire Research Group
[e] r.mcrae@adfa.edu.au

TABLE OF CONTENTS

INTRODUCTION

For decades there has been extensive discussion about Australia's fire regimes. These are the patterns of fire on the local landscape, in both space and time. They reflect the vegetation type, the landform, the climate, natural ignition frequencies, and the goals and activities of land-managers.

There are currently three key issues for fire regimes:

1. Climate change is having massive impacts on our ecosystems. The Black Summer wildfires were so far beyond what had occurred before that we still do not fully understand what happened.
2. We are having major discussions around switching from "modern industrialised" agriculture to approaches based on traditional indigenous practices.
3. We do not have any rigorous descriptions of what the fire regimes actually are.

This report is an attempt to address issue number three, by using the complete multi-decadal time series of MODIS hotspots. Being a time-series, it gives insights into the other issues.

There are two satellites gathering global imagery every day from near-polar orbits. Typically, they fly over eastern Australia in the early afternoon and soon after midnight. Stakeholders such as NASA classify the imagery pixels to see if they might include fire heat. If so, they are put into the hotspot database. Launched initially with six-year missions, the TERRA and AQUA satellites have now provided data for over two decades.

This provides a unique opportunity to map out and analyse the fire regimes of south-east Australia.

There is no single unique way to identify a fire regime. No doubt there will be issues with the material presented here. The blending of wildfire and prescribed burning hotspots will be one source of uncertainty. This has been partially addressed by using three ranges of hotspot intensity – measured by Fire Radiative Power, in Megawatts. There will be others. My desire is that if further discussion must be had, then this might initiate it.

MODIS data does bring up some potentially controversial findings. The fact that fire regimes showing changes in onset or duration are all clustered around where key decision-makers work is one. Another is the way that forestry activity is often an outlier is another. Another is that the focus of burning in wheatbelts seems to reflect protection of adjacent land-uses (also true in south-west Australia). Any discussion on these that might be generated is worthwhile.

The bottom line is that our continent is a diverse and complex place, and any view of it must reflect that complexity. Given the urgency of mitigating or adapting to climate change we must recognise this.

One final thought for bushfire researchers… While it may be tempting to analyse complete sets of data from large databases to test hypotheses about fire dynamics, a failure to recognise the diversity of fire regimes may cause unnecessary errors in your findings. For example, an identified relationship between grassfire activity and dew point temperature might be something that is already included in the grasslands' response to seasonal climate patterns. That might be included in the basis for that fire regime. An *a priori* focus on the regime might allow attention to be placed on other, perhaps more relevant, patterns.

METHOD

Almost all fire activity globally is captured by the MODIS sensors flown on the TERRA and AQUA near-polar orbiting earth observation satellites. Launched near the turn of the century on six-year missions, they have now captured over two decades of data.

Algorithms scan all pixels in the imagery recorded, and those that meet certain thresholds produce a spatial point in a database of fire hotspots. These can be freely downloaded from NASA or partner agencies. While many use these in near real-time, they have significant value in analysis of spatial and temporal patterns.

In this report, MODIS hotspots are used to assess the variability of fire regimes across south-east Australia. This includes all of New South Wales (NSW), Victoria (Vic), the Australian Capital Territory (ACT) and Tasmania (Tas), and parts of South Australia (SA) and Queensland (Qld).

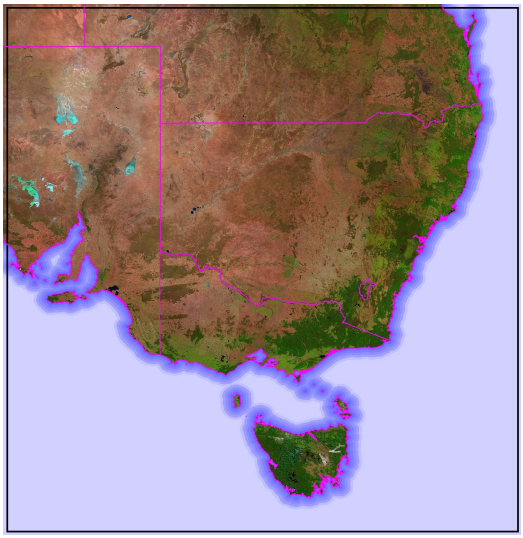


Figure 1. Study area.

The method used to do this is:

1. Regions of similar land-use and hotspot patterns are mapped and attributed.

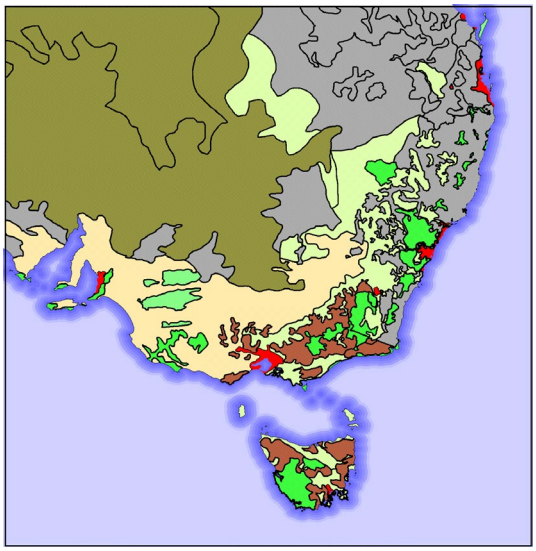


Figure 2. Land-use types. Dk green = reserve; Lt green = rural; Brown = forestry; Beige = wheatbelt; Grey = mixed ridge and rural valley floor; Khaki = rangeland; Red = urban

2. All hotspots are tagged with the ID for the region that they lie within. Hotspots also carry data on acquisition date and on Fire Radiative Power (FRP) in Megawatts.
3. These are grouped hierarchically by year, day-of-the-year, and region. Year refers to fire year – from July 1 to June 30. The year tag refers to the year of July 1.
4. For each region and year, the accumulation of hotspots from July 1 is compared to the final annual tally. The days on which the 10th percentile, 50th percentile and 90th percentile is crossed is noted.
5. Step 4 is repeated for all hotspots, only those with FRP over 100 MW (beyond a cool prescribed burn), and only those with FRP over 500 MW (a hot fire, and likely a Blow-Up fire Event).
6. Graphs of the annual dates for these thresholds are prepared, along with the matching annual hotspots counts.
7. Conclusions are drawn from these on the timing and severity of fire years.

For each region, a set of graphs of hotspot parameters is presented. These cover (from left to right) all hotspots, hot hotspots (those over 100 MW FRP) and severe hotspots (those over 500 MW FRP).

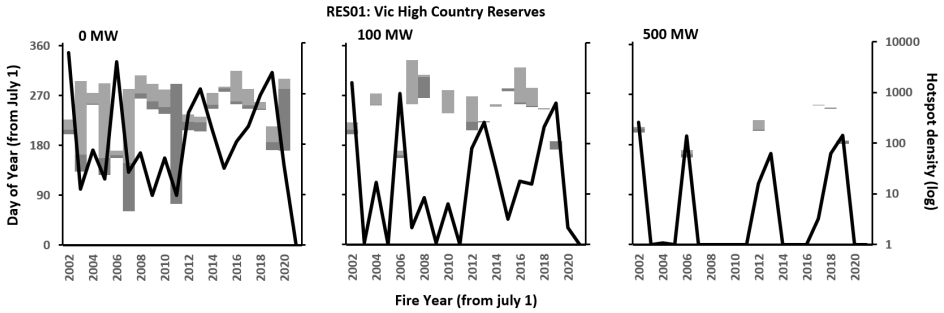


Figure 3 .Inter- and intra-annual hotspot occurrence patterns.

The X-axis is fire year (July to June), and the left-hand Y-axis is day of the year (1 to 365, with no adjustment for leap year). For each:

- Each year has a set of overlapping columns. Dark grey spans from the day when 10% of the annual total have occurred to the day when 50% have occurred. Light grey spans from the day when 50% of the annual total have occurred to the day when 90% have occurred.
- There is a black line showing the annual density of hotspots, on a logarithmic scale (right-hand Y-axis). The density is the annual count divided by the region's area, in units of 100 square kilometres (chosen for scaling purposes).

A stylised example of the interpretation is shown below:

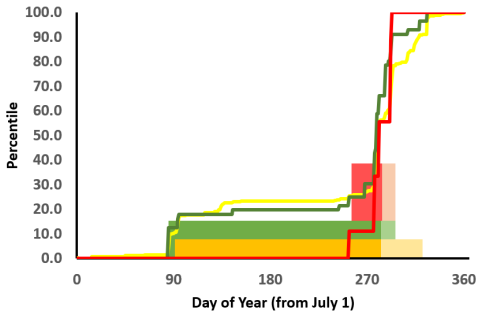


Figure 4. Example showing 10th, 50th and 90th percentile values for the three intensity classes, separately. Orange = all hotspots, Green = hotspots above 100MW, Red = hotspots above 500MW. Dark colours show 10th to 50th percentiles, light colours show 50th to 90th percentiles. The lines with related colours show the actual accumulation curves.

It is important to note the use of a logarithmic right-hand Y-axis for hotspot density in the graphs in Figure 3. The relative scale of the spikes from bad fire seasons is downplayed to allow better inter-annual comparisons.

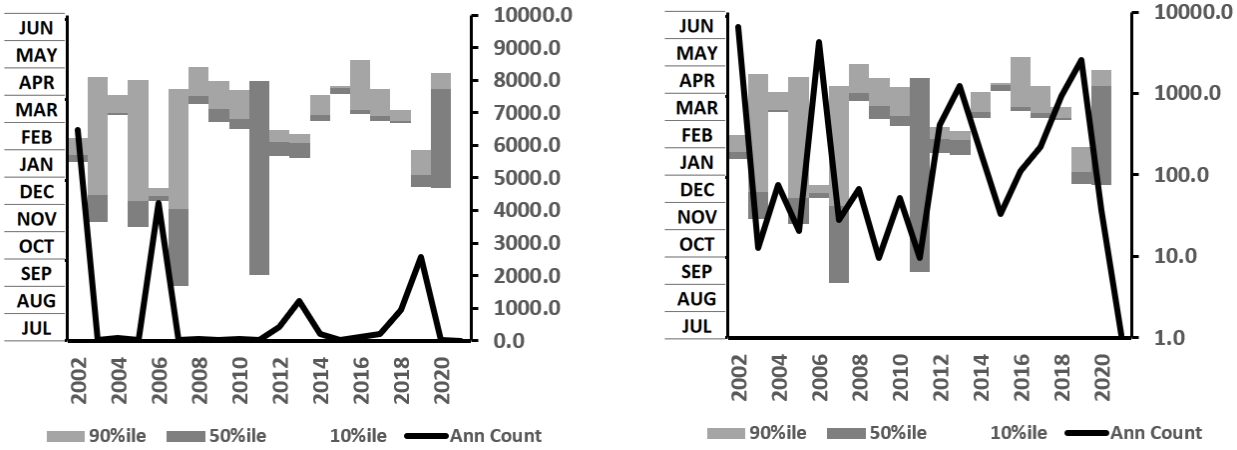


Figure 5. Comparison of linear and logarithmic hotspot density scales.

The use of the 10, 50 and 90 percentiles values reflects the typical logistic curve accumulation of hotspots over a year in most regions – see the example below. The values chosen aim to highlight the period of maximum rate of accumulation, which is when fire managers are most busy and when wildfire is risk is at its peak.

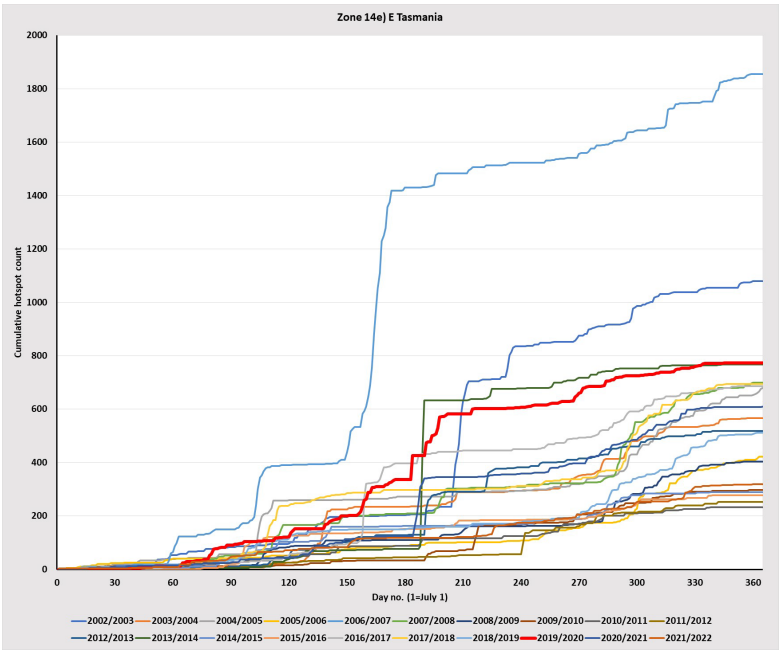


Figure 6. Annual hotspots accumulation graphs for eastern Tasmania. The 10%ile value is typically reached after October, while the 90%ile is reached around April. This graph uses fire years – from July to June.

Also shown for each region is a stylised model of landscape impact model for a sample of the region. The sample is a 20km by 20 km square, and every hotspot inside it is sampled. The squares are placed to be representative and may not capture all of the key fire events in that region. With FRP set into classes, the annual impact is tallied up based on accumulated FRP. A stylised Inverse Olsen fuel accumulation model is applied, with the annual reduction in impact set to 50% for forests, 90% for grasslands and 70% for shrublands. Impacts are further accumulated where new fires occur before the previous one's impact has

abated. All of the graphs have the same Y-axis (even though its values are from an index and technically not of direct real-world meaning).

Note also that decay of black bars does not mean that forest regeneration has finished – ecological regeneration may take decades in some regions. It simply says that the landscape covered up the primary scars of the fires.

In the example below, there are two major BUFE clusters that produce many severe FRP hotspots.

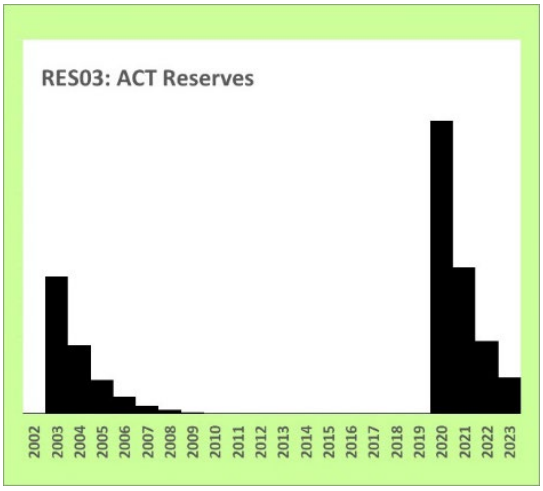


Figure 7. Example of analysis of landscape-scale impacts of major fires on a landscape. Here large forest fire events culumatively carry on 50% of their values into the next year.

As a final step, the regions were grouped by similarity of their assessed fire regimes.

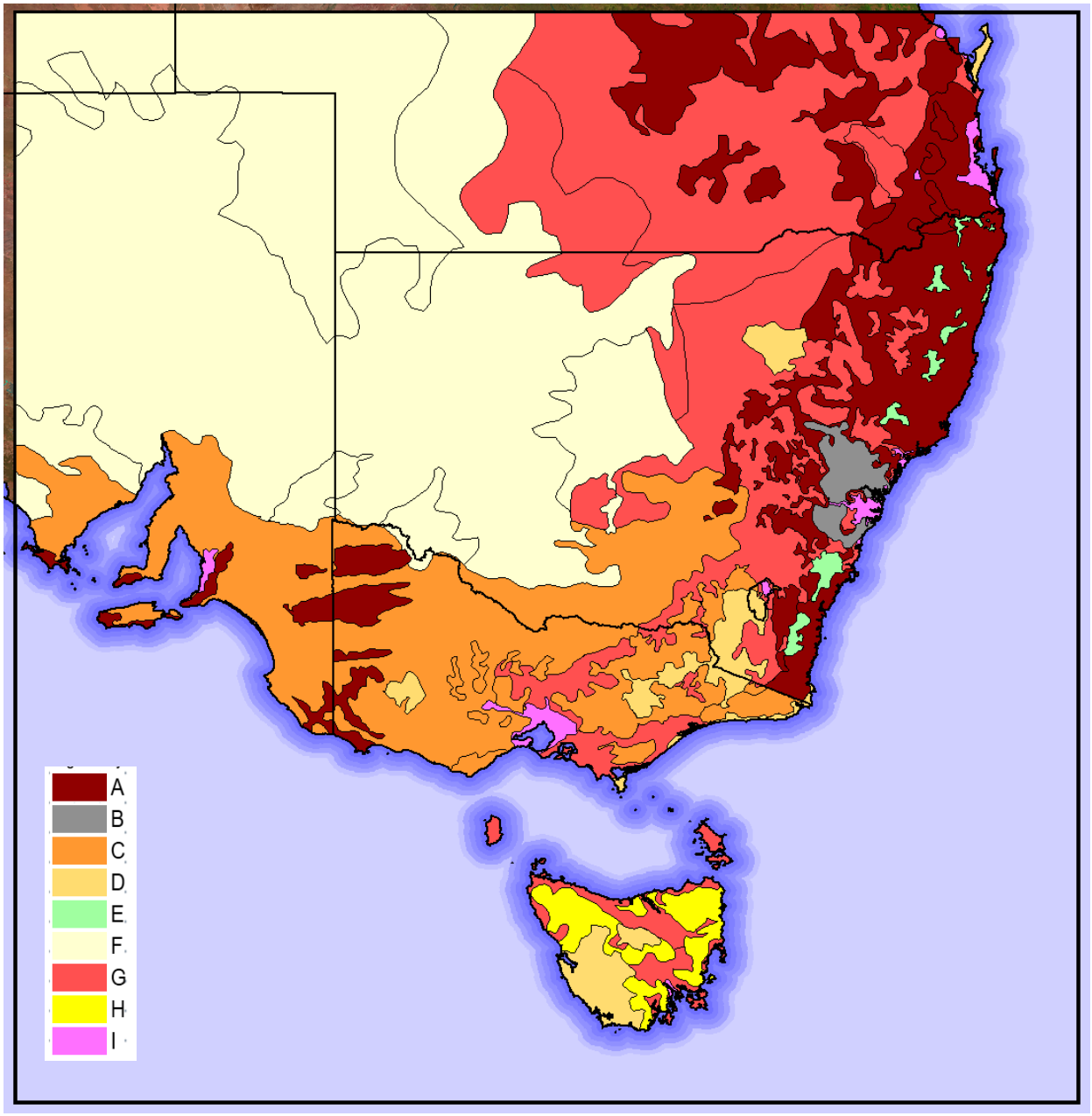


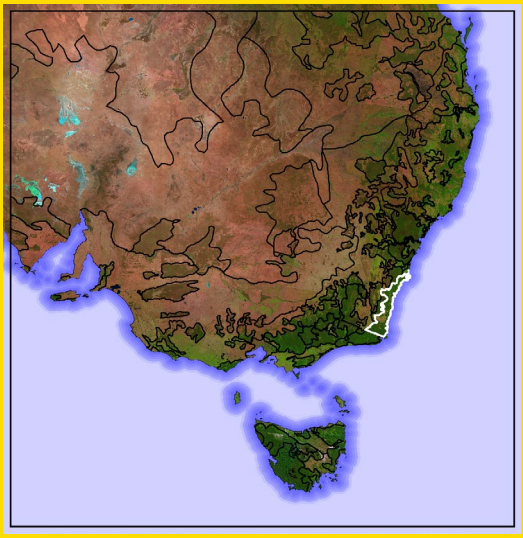
Figure 8. Map of fire regime groups. Group codes are explained below.

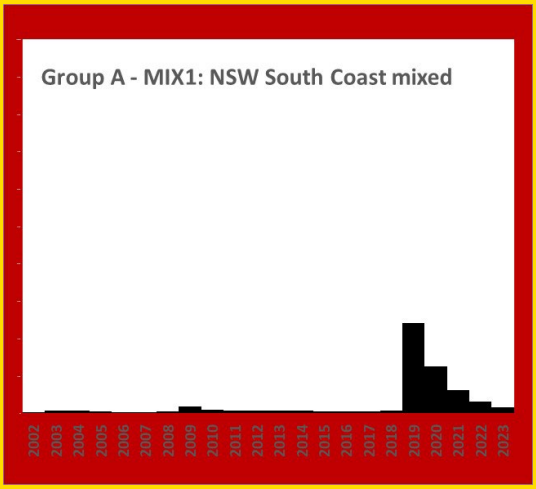
Group	Description	Includes
A	Protracted hot burning	Mixed land-use; western reserves
B	Extended variable seasons	Reserves near Sydney
C	Extensive autumn burning	Southern forestry; wheatbelt
D	Variable summer & autumn burning	Most reserves; inland forestry
E	Variable spring & summer burning	NSW Coastal reserves
F	Protracted low-frequency burning	Rangelands
G	Protracted mid-frequency burning	Rural land
H	Protracted summer & autumn burning	Tasmania forestry
I	Protracted limited-intensity burning	Urban land

Note: The colours used here are used in other places, as graph background colours.

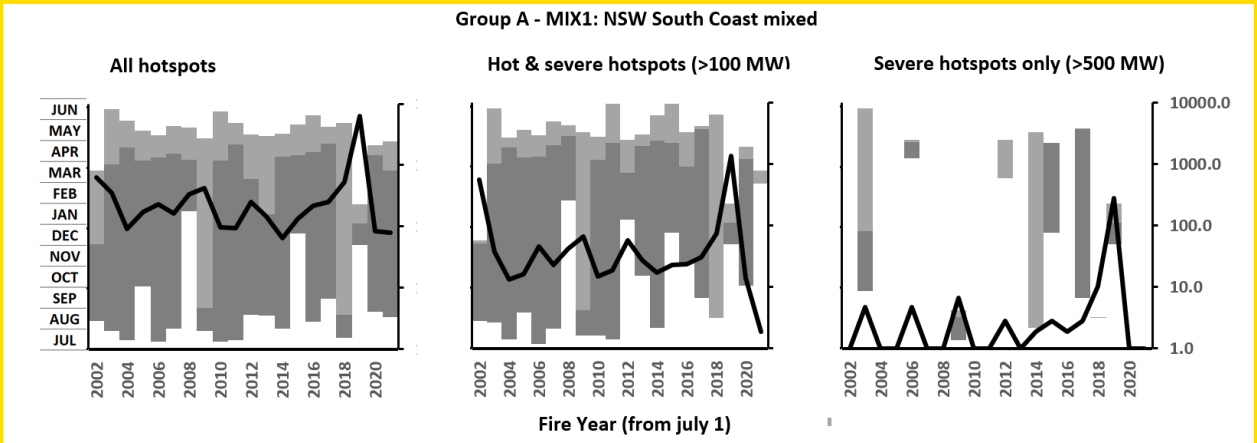
GROUP A: PROTRACTED HOT BURNING

GROUP A, MIX1: NSW SOUTH COAST MIXED





SAMPLE: Clyde River, NSW.
988 hotspots



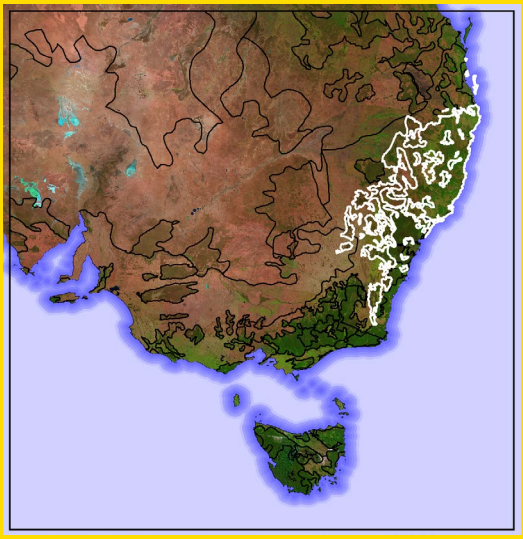
Hotspots common, severe hotspots rare (10 years).

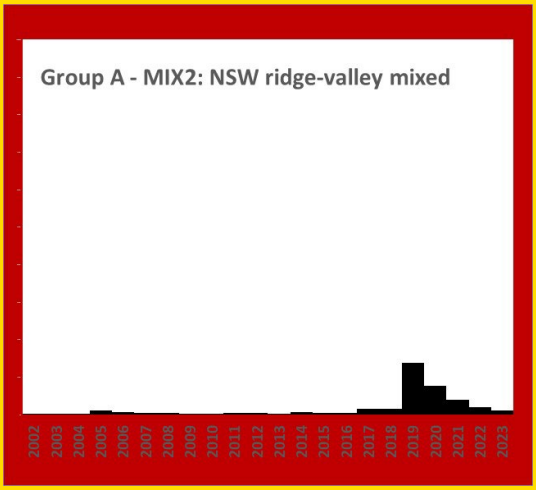
This 10,630 km^2 region of forest and grassland was hit hard by Black Summer. It has an autumn activity core and no trend towards earlier or longer extents.

Recorded pyroCbs: 2

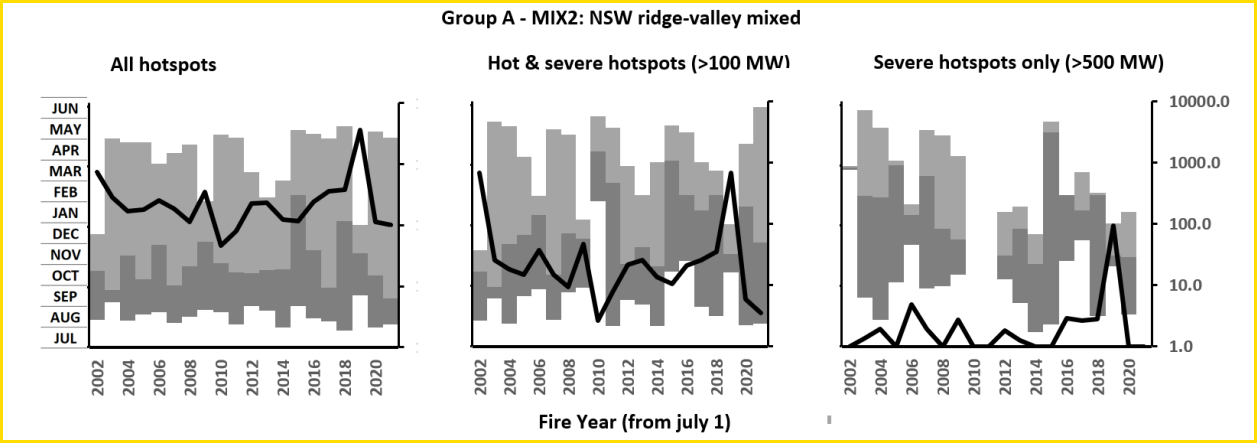
2019af (28 Dec) NSW: Ulladulla area
2019ak (30 Dec) NSW: E of Cooma

GROUP A, MIX2: NSW RIDGE-VALLEY MIXED





SAMPLE: Nundle SF, NSW.
820 hotspots



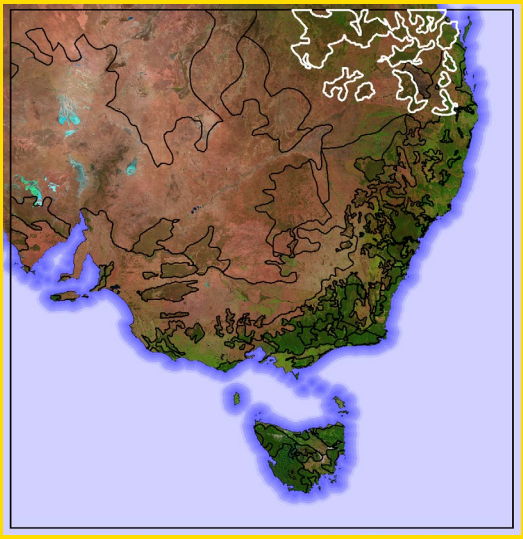
Hotspots frequent, severe hotspots rare (17 years).

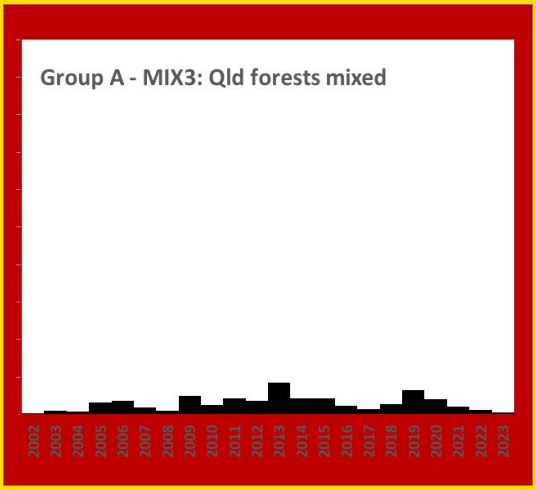
This 126,400 km^2 region has a mix of woodland and ridges and grassland in the valley floors. Activity mostly peaks in spring (later in the south), with more intense activity into summer. There is no trend towards earlier or longer extents.

Recorded pyroCbs: 8

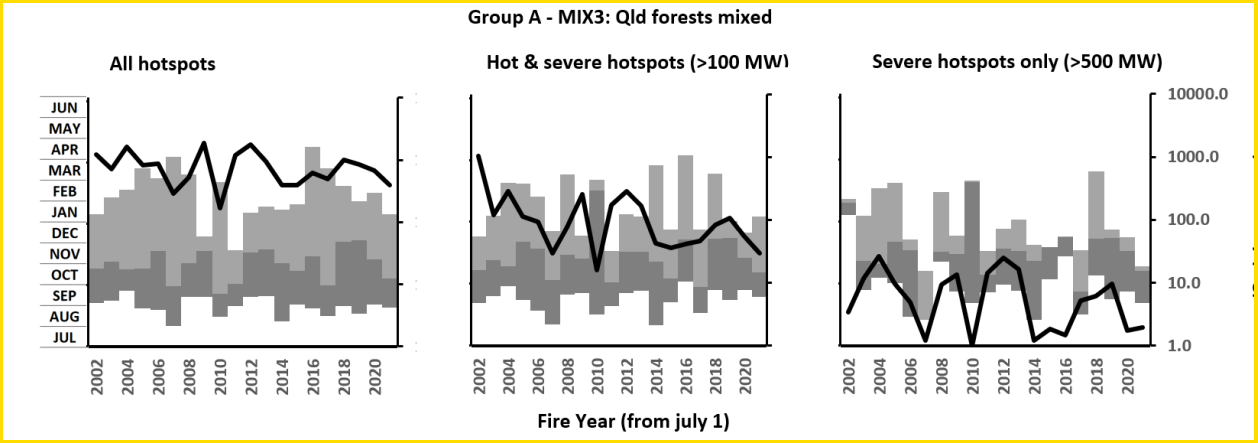
2019w (10 Dec) NSW: Mt Werong
2019at (10 Dec) NSW: Gibraltar Range
2019aw (10 Dec) NSW: Mt Carrington
2019ax (10 Dec) NSW: Paddys Flat
2019z (19 Dec) NSW: West of Sydney
2019ab (21 Dec) NSW: Ilford
2019ae (28 Dec) NSW: Badja area
2019ah (29 Dec) NSW: Wombeyan Caves area

GROUP A, MIX3: QLD FORESTS MIXED





SAMPLE: NW of Taroom, Qld.
1107 hotspots



Hotspots very frequent, severe hotspots common (all years).

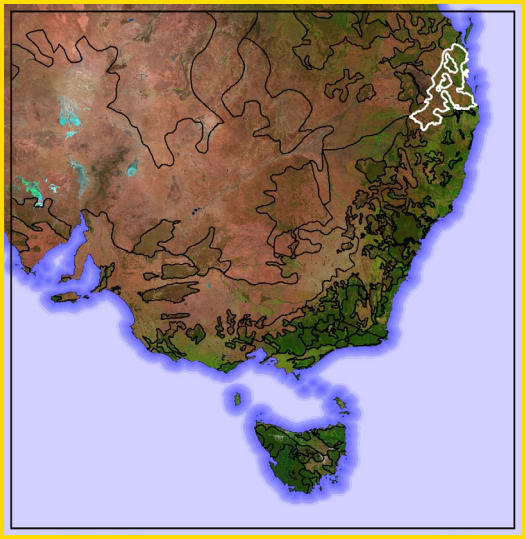
This region of 109,100 km^2 is mainly a woodland / grassland mix.

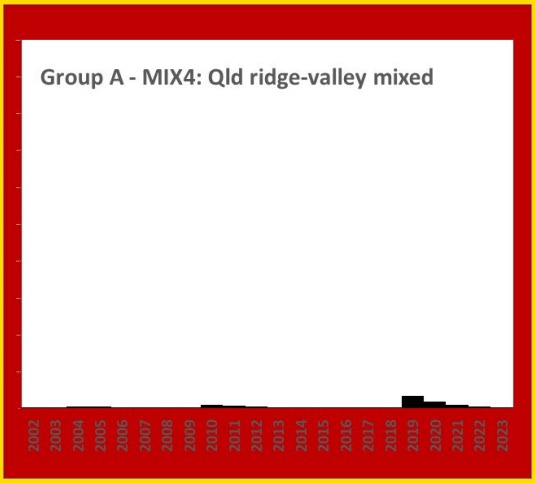
It has a spring core often continuing into summer. It has no trend towards earlier or longer activity seasons.

Recorded pyroCbs: 2

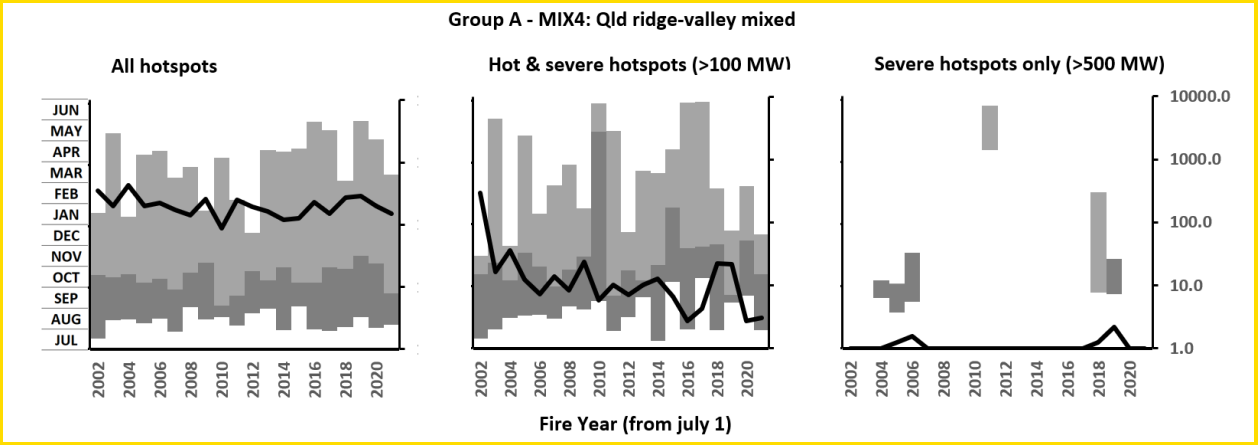
2016d (05 Dec) Qld: Cecil Plains*
2016e(06 Dec) Qld: Cecil Plains*

GROUP A, MIX4: QLD RIDGE - VALLEY MIXED





SAMPLE: Boonah, Qld.
229 hotspots

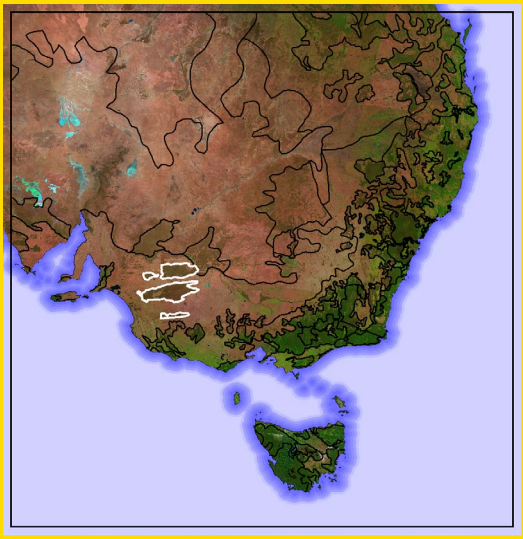


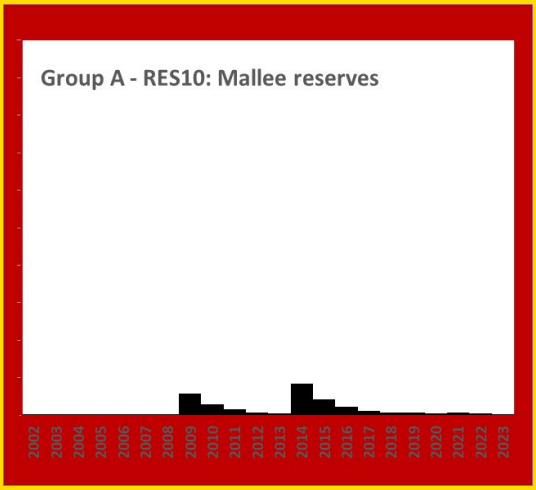
Hotspots common, severe hotspots rare (6 years).

This region of 32,590 km^2 is mainly a grassland / woodland mix.

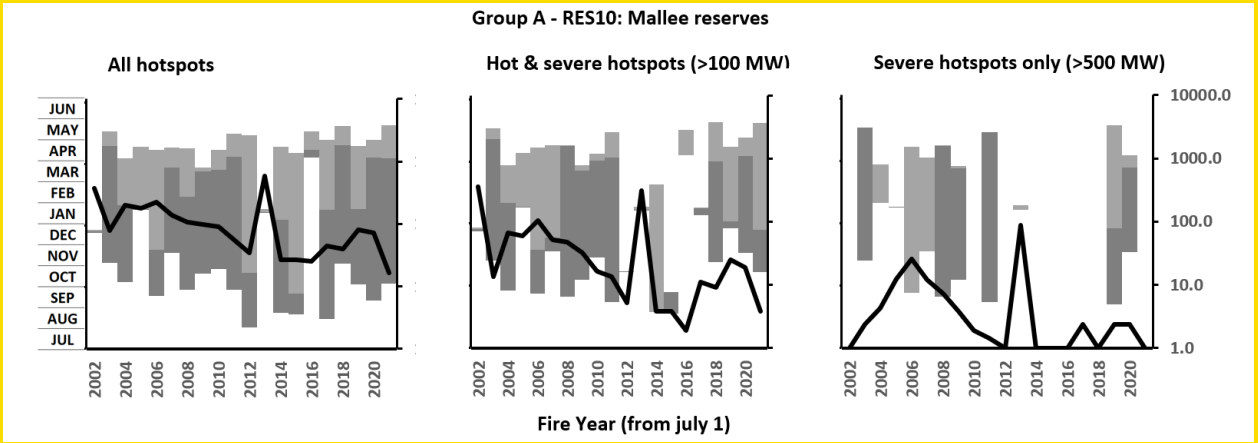
It has a late winter - spring activity core. After 2011 it has shown a pronounced trend towards more autumn activity.

GROUP A, RES10: MALLEE RESERVES





SAMPLE: Wyperfeld NP. Vic.
218 hotspots



Hotspots common, severe hotspots uncommon (12 years).

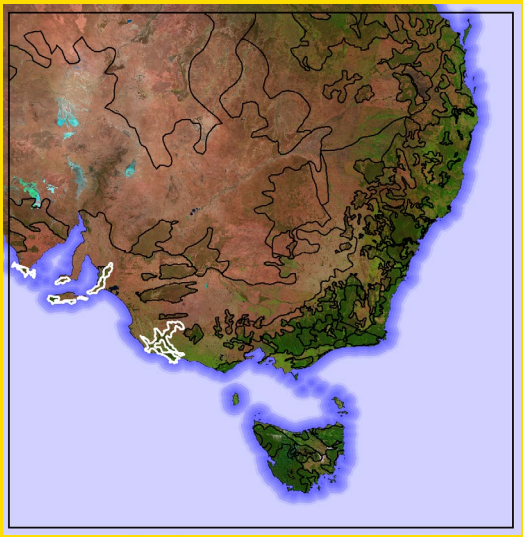
This region spans 20,870 km^2 of mallee shrubland. Peak activity is variable, ranging from spring to autumn.

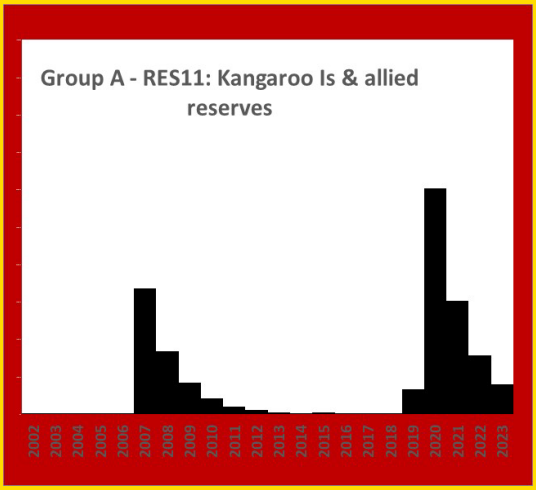
Its fire activity patterns show three phases: (1) up to 2012 late summer, trending earlier with peaks in autumn; (2) then variable for five years; (3) then later with summer peaks.

Recorded pyroCbs:

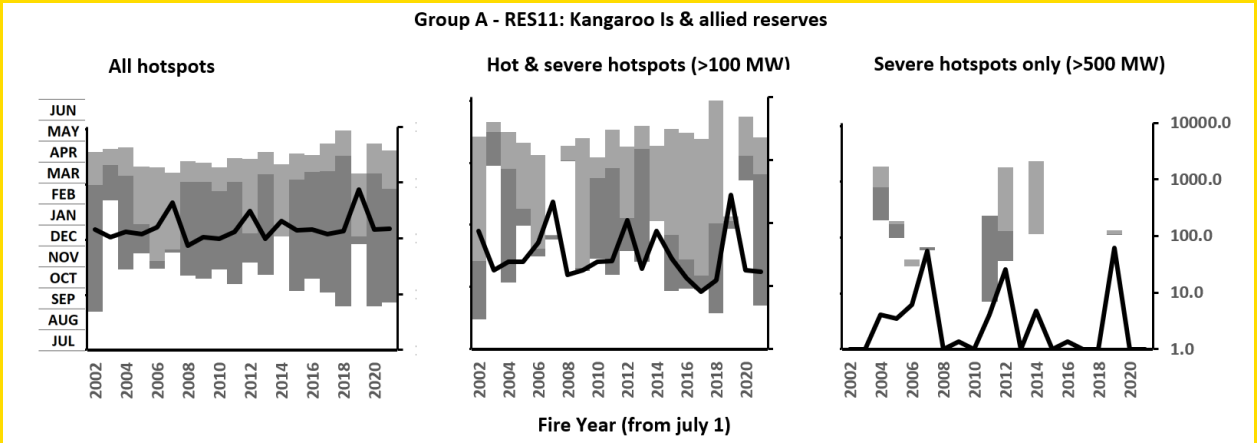
2002a (17 Dec) Vic: Big Desert

GROUP A, RES11: KANGAROO IS & ALLIED RESERVES





SAMPLE: Western Kangaroo Island, SA.
751 hotspots

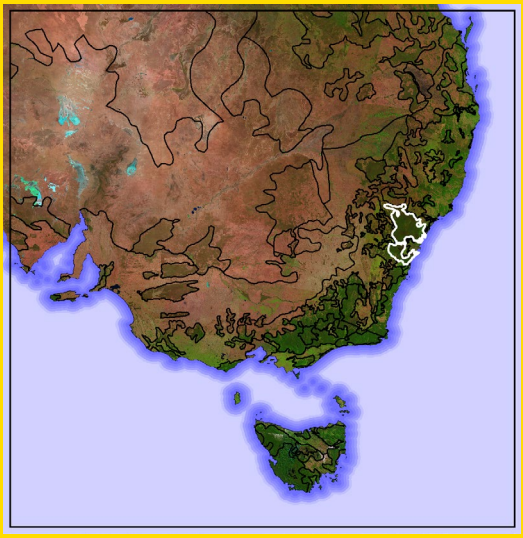


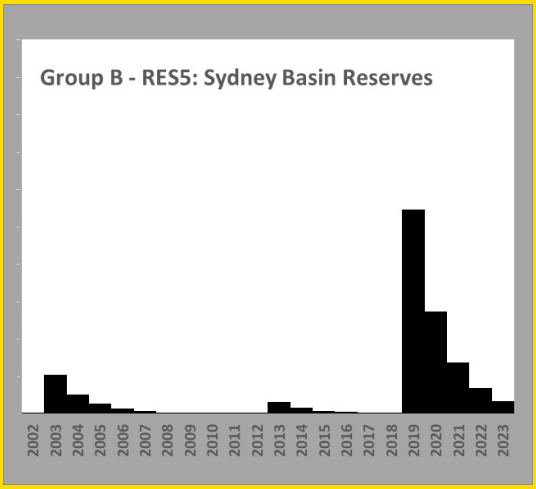
Hotspots common, severe hotspots rare (8 years).

Covering 14,650 km^2 this region includes major coastal reserves exposed to the Great Australian Bight, with a forest / grassland mix. Activity has an autumn core, with a clear trend to earlier and longer seasons.

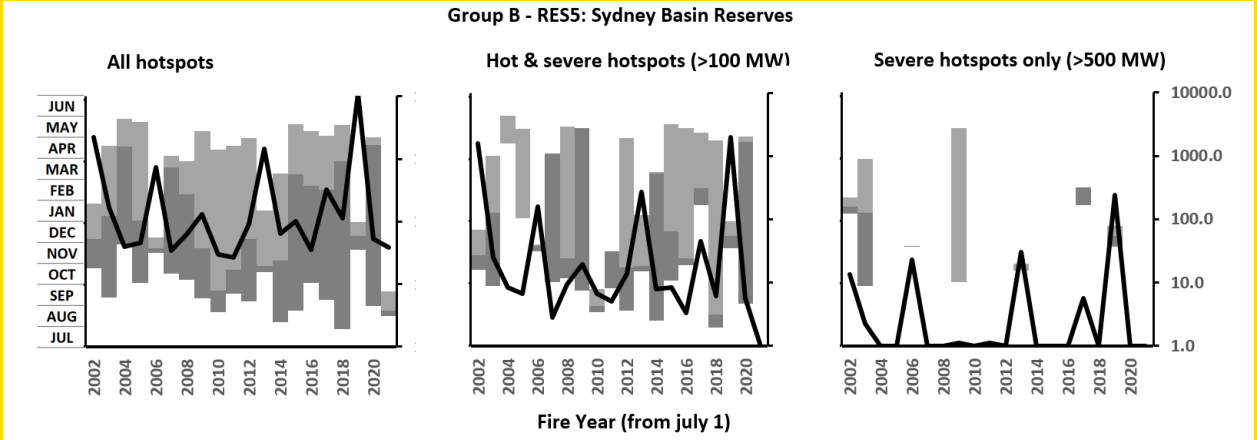
GROUP B: EXTENDED VARIABLE SEASONS

GROUP B, RES5: SYDNEY BASIN RESERVES





SAMPLE: NE of Newnes Junction, NSW.
951 hotspots



Hotspots common, severe hotspots rare (7 years).

This region has 17,900 km^2 of mainly forest and shrubland. Its fire regime has a variable core, with hot FRPs mainly in spring, and severe FRPS in summer.

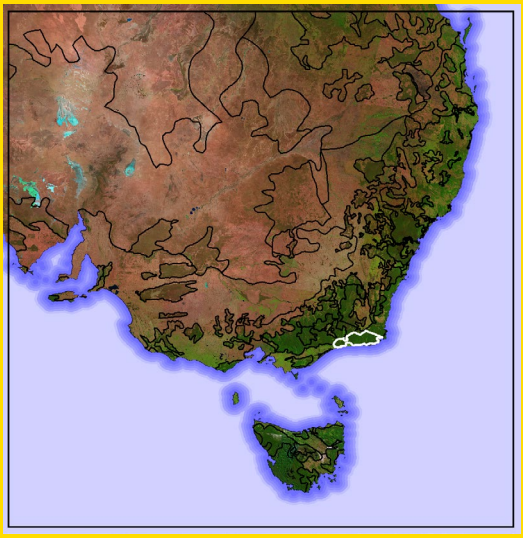
There is a clear trend towards earlier onset and longer duration seen in the graphs. This may reflect the requirement for these reserves to be burnt to protect neighbouring property and land-uses. The high prevalence of hot FRPs may reflect the rugged landforms involved in most HRBs.

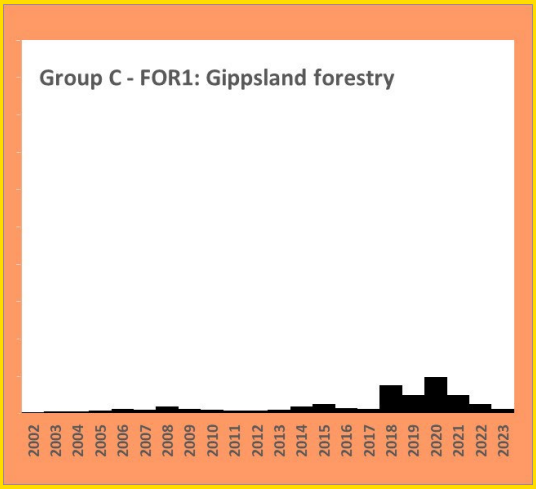
Recorded pyroCbs: 7

2006b (22 Nov) NSW: Wollemi
2006c (22 Nov) NSW: Grose Valley
2019u (22 Nov) NSW: Grose Valley
2019au (10 Dec) NSW: Nullo Mtn
2019av (10 Dec) NSW: Cockatoo Hill*
2019ac (21 Dec) NSW: Mt Irvine
2020a (01 Jan) NSW: Nullo Mtn

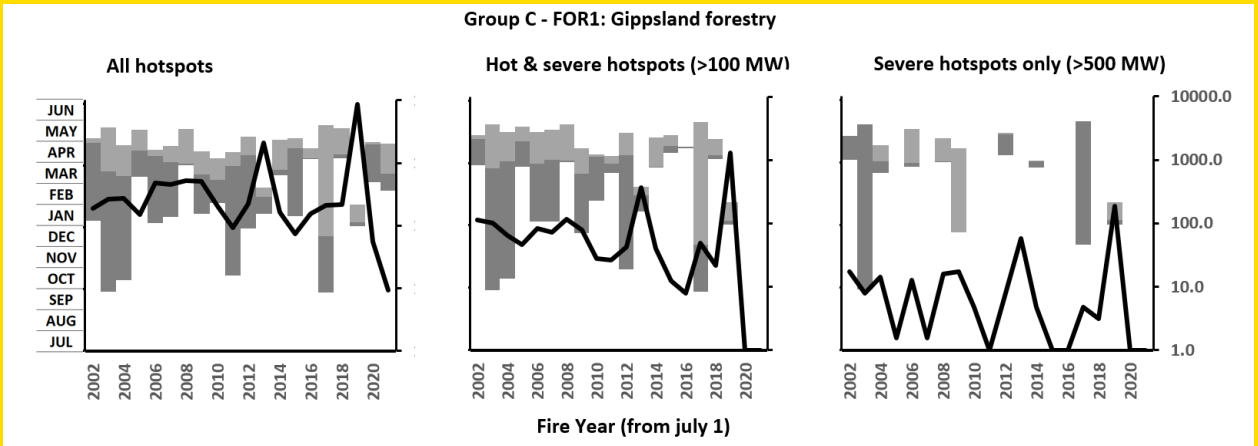
GROUP C: EXTENSIVE AUTUMN BURNING

GROUP C, FOR1: GIPPSLAND FORESTRY





SAMPLE: NE of Orbost, Vic.
522 hotspots



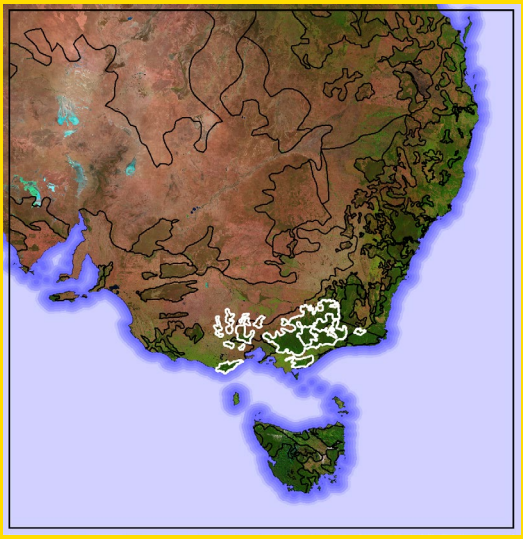
Hotspots frequent, severe hotspots uncommon (10 years).

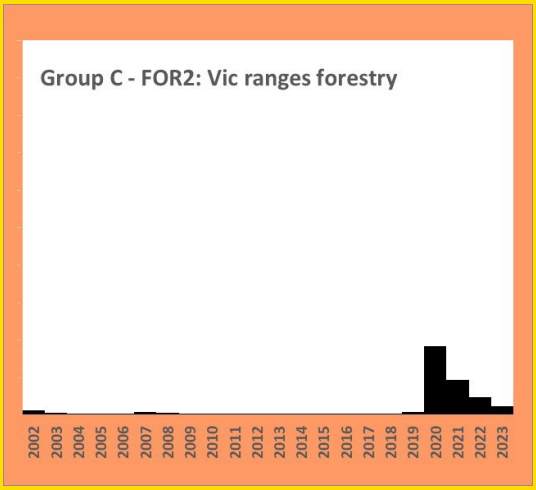
This 6,377 km^2 region is mainly forests. Hotspot activity has a strong autumn core, with no trend to an earlier or longer extent.

Recorded pyroCbs: 5

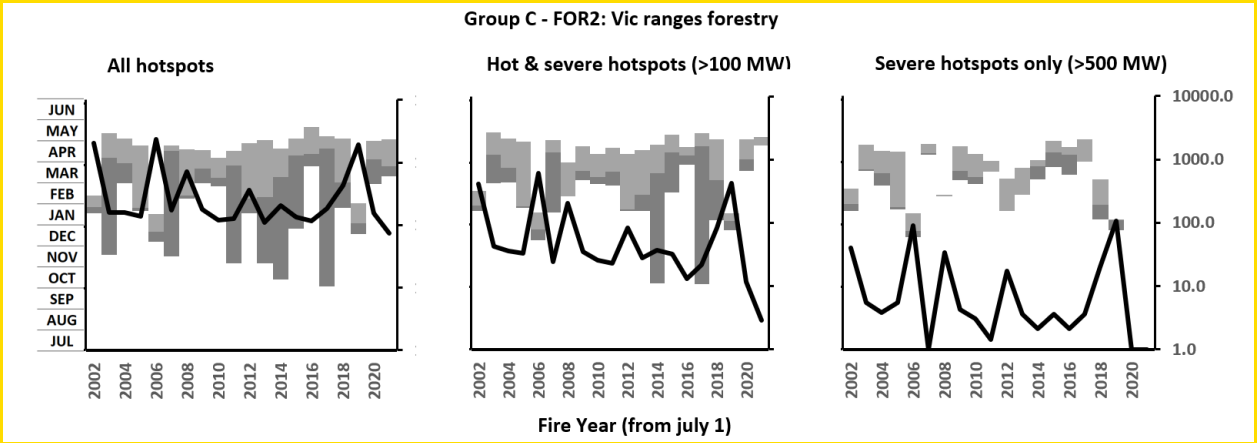
2019aa (20 Dec) Vic: Tambo Crossing
2019ah (30 Dec) Vic: Goonjerah
2019an (30 Dec) Vic: Ensay
2019ap (30 Dec) Vic: Bullumwaal
2019aj (30 Dec) Vic: Wulgulmerang

GROUP C, FOR2: VIC RANGES FORESTRY





SAMPLE: S of Colac, Vic.
987 hotspots



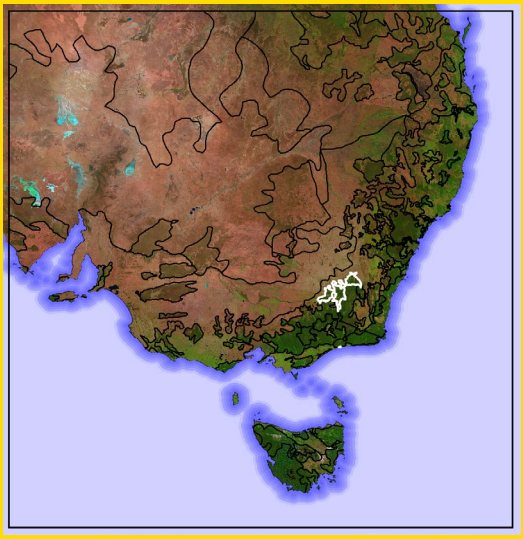
Hotspots common, severe hotspots uncommon (18 years).

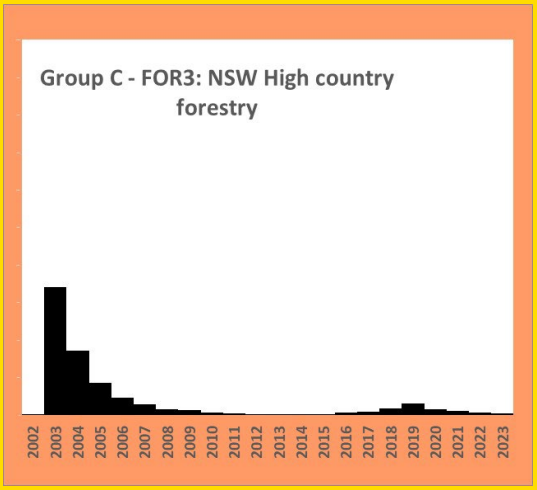
This 42,180 km^2 region is mainly forests. Hotspot activity has a strong autumn core. There is a trend to an earlier and longer extent after 2008 which may reflect the occurrence of multiple blow-up fire events in December.

Recorded pyroCbs: 18

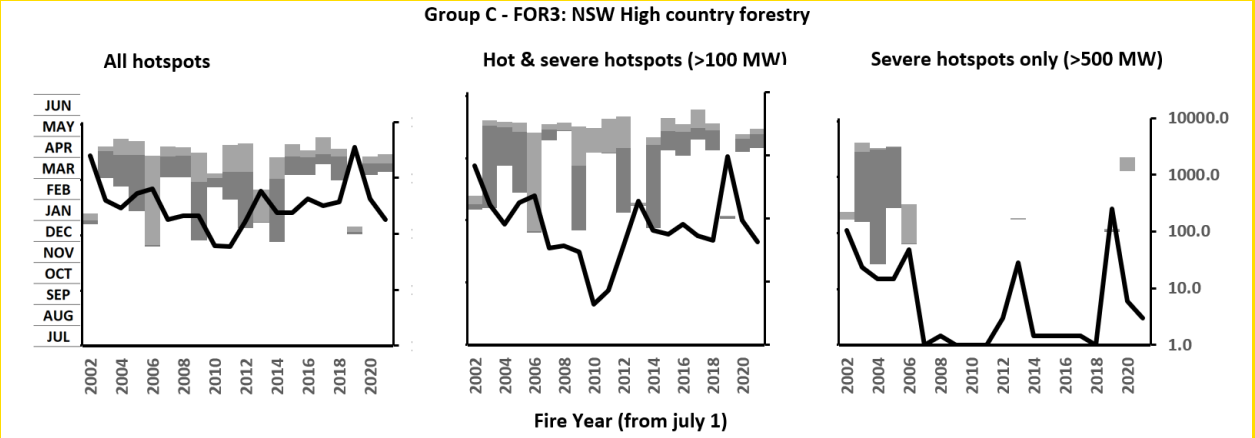
2006e (06 Dec) Vic: Dandongadale*
2006h (10 Dec) Vic: Black Range*
2006j (10 Dec) Vic: Turton river*
2006l (14 Dec) Vic: Thomson River*
2006m (14 Dec) Vic: Gaffneys Creek*
2007a (16 Jan) Vic: Mount Buller
2009c (07 Feb) Vic: Bunyip
2009d (07 Feb) Vic: Dargo
2009e (07 Feb) Vic: Beechworth
2019 (03 Feb) Vic: Walhalla
2019j (02 Mar) Vic: Bunyip
2019i (03 Mar) Vic: Bunyip
2019o (04 Mar) Vic: Dargo
2019r (05 Mar) Vic: Dargo
2019t (05 Mar) Vic: Dargo
2019v (10 Dec) Vic: Mt Skene*
2019x (14 Dec) Vic: Grant Junction*
2019aa (20 Dec) Vic: Tambo Crossing

GROUP C, FOR3: NSW HIGH COUNTRY FORESTRY





SAMPLE: S of Wee Jasper, NSW.
777 hotspots



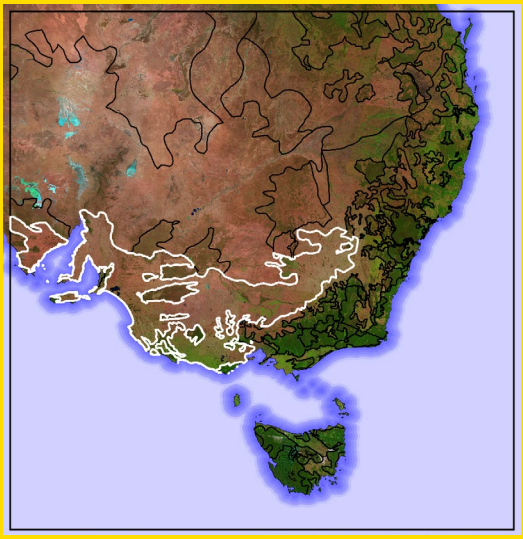
Hotspots frequent, severe hotspots uncommon (9 years).

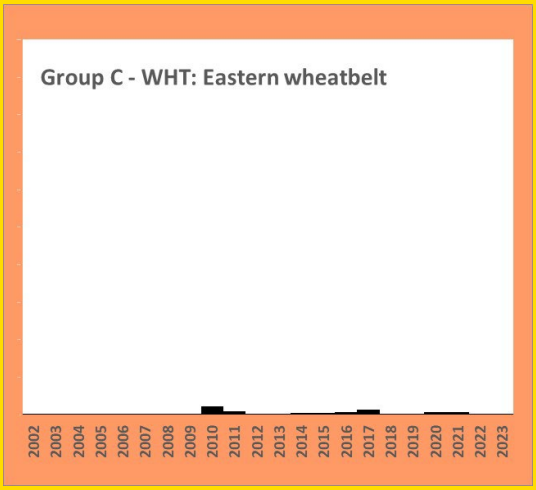
This 6,824 km^2 region is mainly forest. It has its core activity in autumn, with no trend toward earlier or longer periods of activity.

Recorded pyroCbs: 2

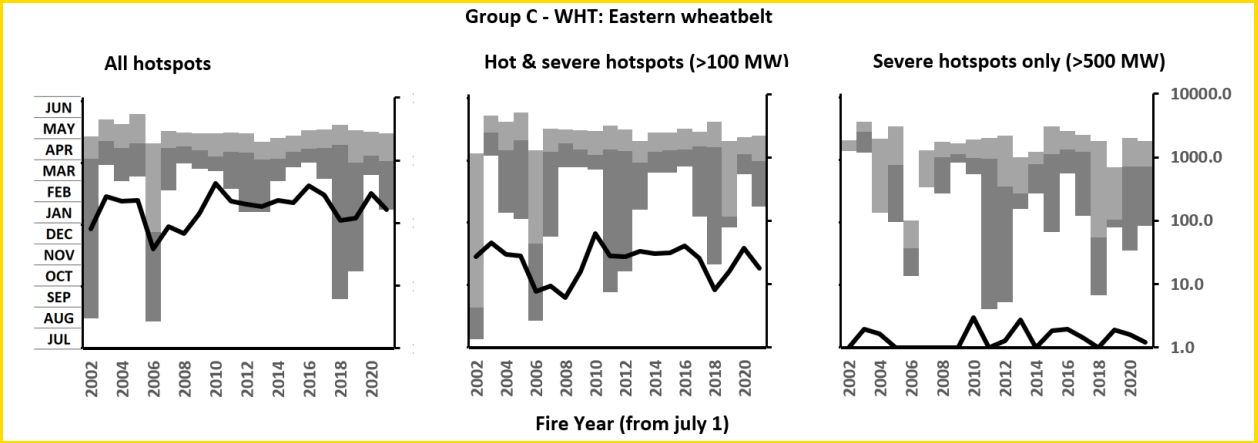
2003h (18 Jan) NSW: McIntyres Hut Fire
2019aq (31 Dec) NSW: Yarrangobilly

GROUP C, WHT: EASTERN WHEATBELT





SAMPLE: S of Cobram, Vic
246 hotspots

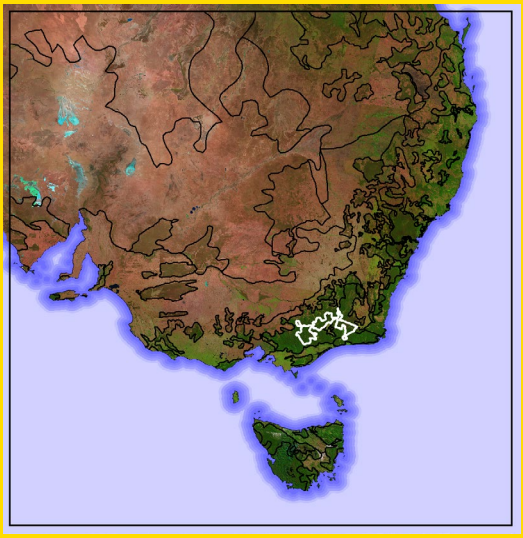


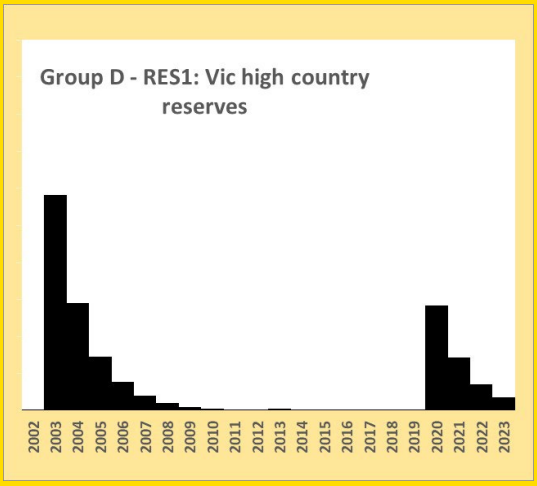
Hotspots common, severe hotspots rare (all years).

This region covers 280,900 km^2 of mainly actively managed grassland. Activity has an autumn peak and is quite stable with no trends evident.

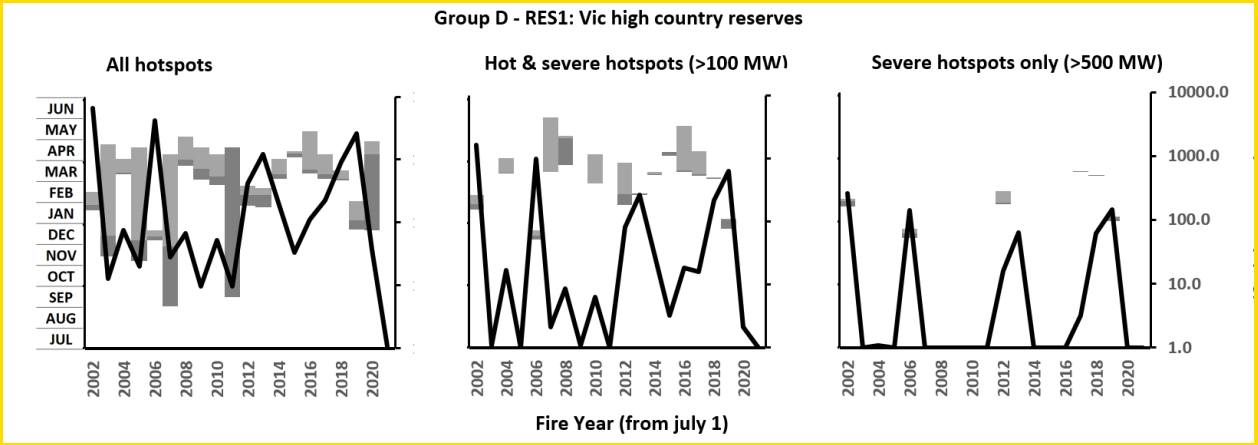
GROUP D: VARIABLE SUMMER & AUTUMN BURNING

GROUP D, RES1: VIC HIGH COUNTRY RESERVES





SAMPLE: Bogong High Plains, Vic.
1043 hotspots



Hotspots common, severe hotspots rare overall (7 years).

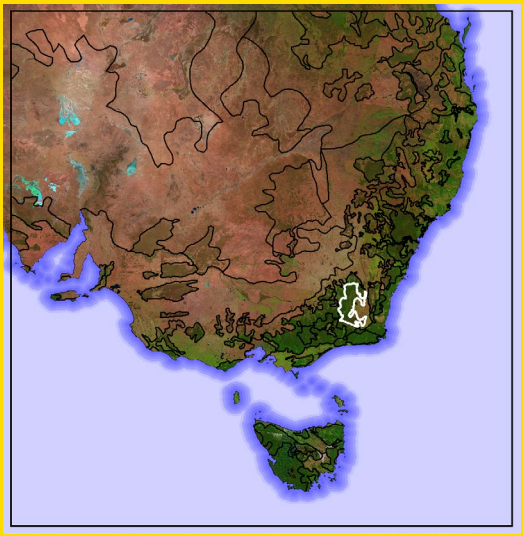
This region has 9,400 km^2 of mainly forest and heathland. Its fire regime is mainly an autumn core of HRBs, sometimes swamped by summer BUFE events (about 30-fold). Most hot FRP hotspots are from autumn HRBs. There are infrequent, severe BUFE FRPs in summer: in 2002/2003; 2006/2007; 2012/2013; 2018-2020.

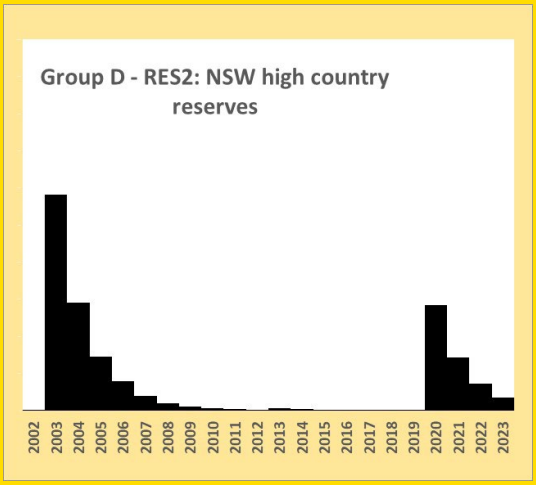
No trend towards earlier onset or longer duration is seen in the graphs.

Recorded pyroCbs: 17

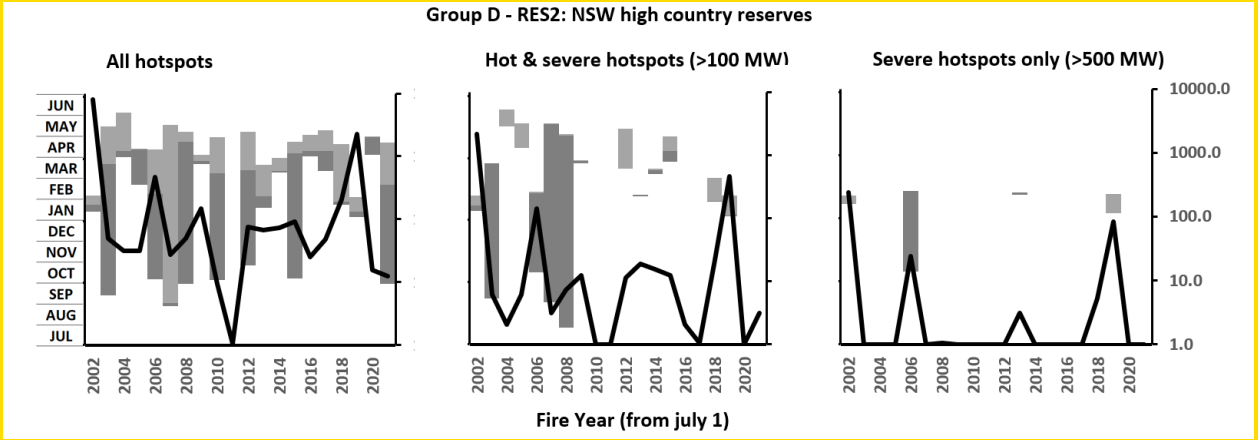
1998a (02 Feb) Vic: Caledonia River
2003j (26 Jan) NSW: Alpine Complex
2003k (30 Jan) NSW: Alpine Complex
2006f (06 Dec) Vic: Basalt Knob #1*
2006g (06 Dec) Vic: Licola*
2006i (10 Dec) Vic: Basalt Knob #2*
2006k (14 Dec) Vic: East Licola*
2014c (09 Feb) Vic: East Gippsland
2019a (25 Jan) Vic: Timbarra
2019b (03 Feb) Vic: Timbarra
2019i (02 Mar) Vic: Licola
2019k (03 Mar) Vic: Licola
2019m (04 Mar) Vic: Licola
2019 n (04 Mar) Vic: High Plains
2019 p (04 Mar) Vic: Mt Wellington
2019q (05 Mar) Vic: Tea TreeRange
2019s (05 Mar) Vic: Licola
2019ao (30 Dec) Vic: Diggers Hole
2020d (04 Jan) NSW: W of Mt Kosciuszko

GROUP D, RES2: NSW HIGH COUNTRY RESERVES





SAMPLE: Toolong Range, NSW.
780 hotspots



Hotspots common, severe hotspots rare overall (4 years).

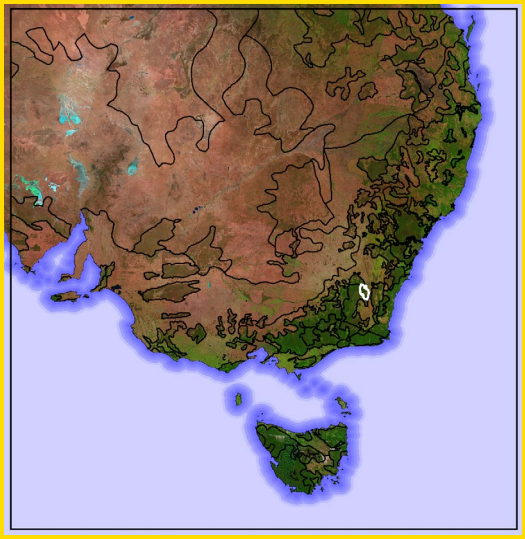
This region has 9,600 km^2 of mainly forest and heathland. Its fire regime is mainly an autumn core of HRBs, sometimes swamped by summer BUFE events (about 30-fold). Most hot FRP hotspots are from autumn HRBs. There are infrequent, severe BUFE FRPs in summer: in 2002/2003; 2006/2007; 2018-2020.

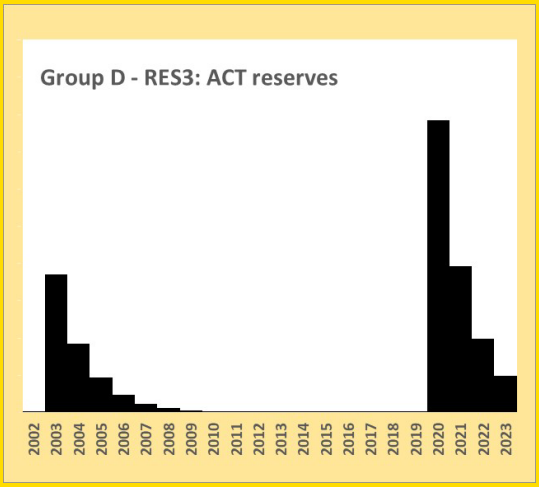
No trend towards earlier onset or longer duration is seen in the graphs.

Recorded pyroCbs: 6

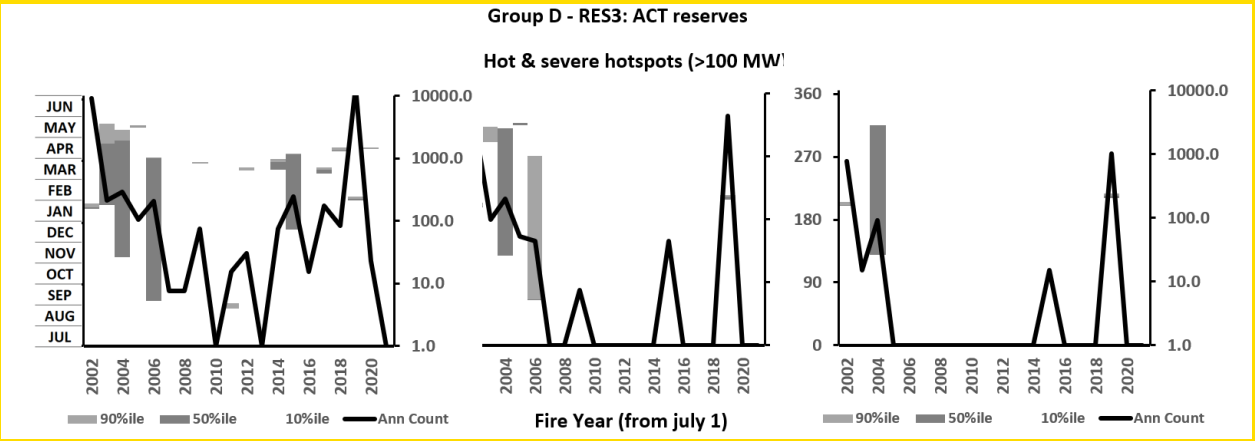
2003c (17 Jan) NSW: Cabramurra
2003d (17 Jan) NSW: Thredbo
2003e (18 Jan) NSW: Broken Cart Fire
2003i (18 Jan) NSW: Tumut River
2020c (04 Jan) NSW: Cabramurra
2020e (04 Jan) NSW: Cabramurra

GROUP D, RES3: ACT RESERVES





SAMPLE: Orroral Valley, ACT.
1126 hotspots



Hotspots common, severe hotspots rare (5 years).

This region has 1,300 km^2 of mainly forest. Its fire regime is mainly an autumn core of HRBs, sometimes swamped by summer BUFE events (about 30-fold). Most hot FRP hotspots are from autumn HRBs. There are infrequent, severe BUFE FRPs in summer: in 2002/2003; 2006/2007; 2012/2013; 2018-2020.

While severe hotspots are underrepresented (as MODIS often does not pick them up when it next overflies), the lack of hot hotspots reflects the landscape impact of extreme wildfires repeating every two decades, leaving very few optimal burning windows.

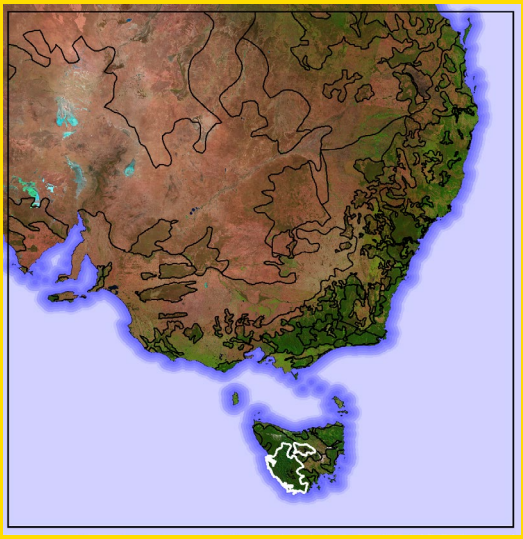
No trend towards earlier onset or longer duration is seen in the graphs.

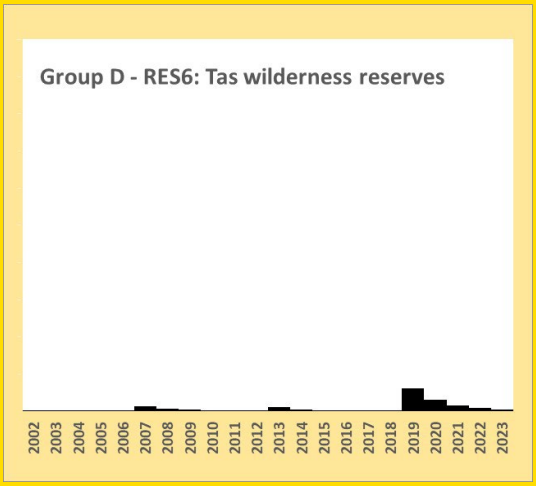
Despite its small size, this region was created to allow comparison with the other signatories to the Alpine Agreement.

Recorded pyroCbs: 3

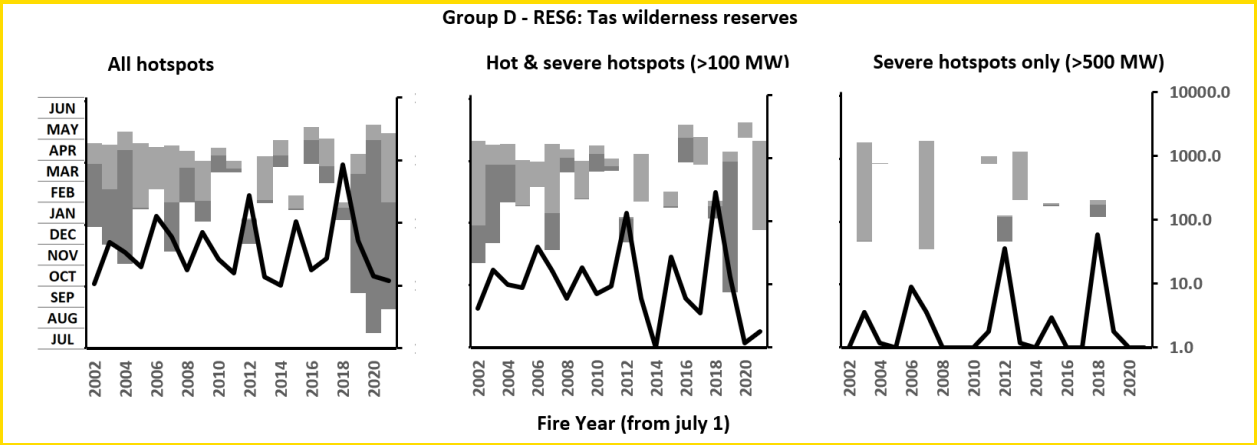
2003b (17 Jan) ACT: Stockyard Spur
2003f (18 Jan) ACT: Stockyard Complex
2003g (18 Jan) ACT: Stockyard Complex
2020k (01 Feb) ACT MT Clear (Orroral fire)

GROUP D, RES6: TAS WILDERNESS RESERVES





SAMPLE: Scotts Peak Dam, Tas.
127 hotspots

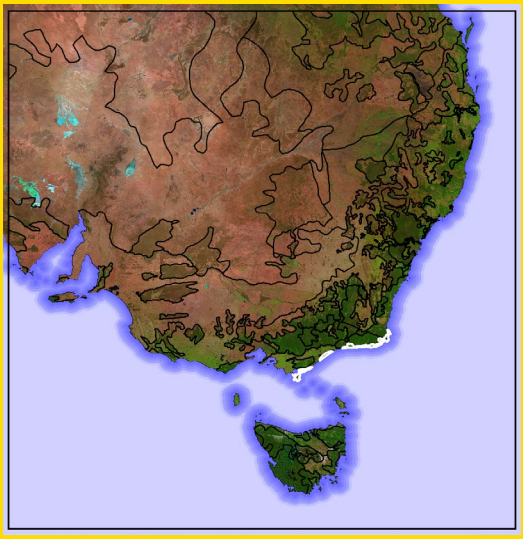


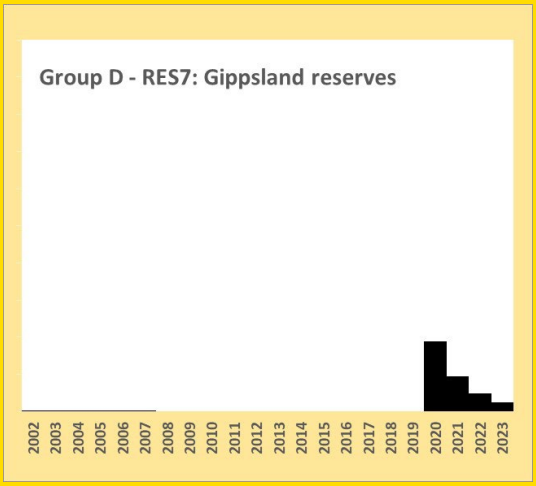
Hotspots common, severe hotspots rare (8 years).

This region has 17,000 km^2 of mainly forest, but with many wet types and many with Gondwanan origins. Its fire regime has a stable core, with most activity in late summer into autumn.

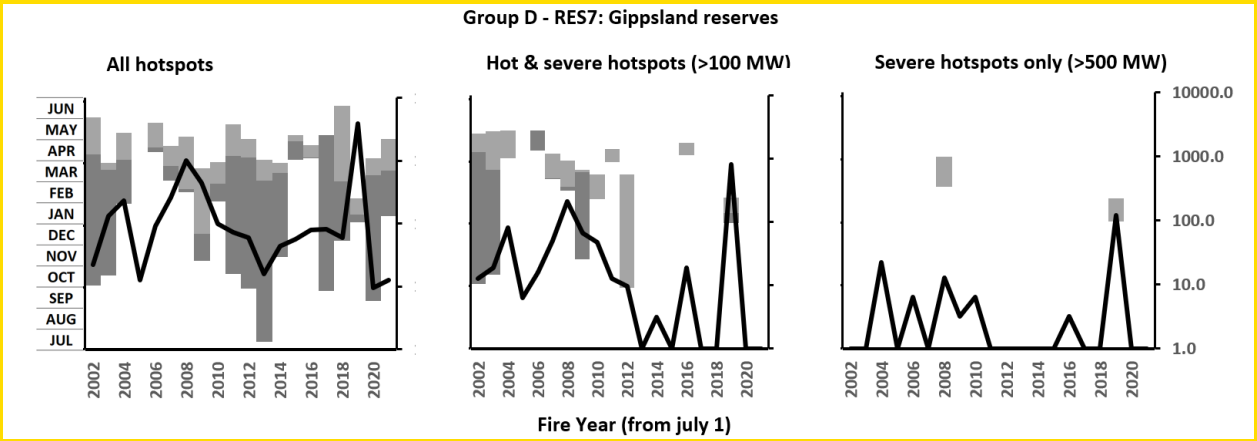
A major surge in activity after the major fires in early 2019, primarily with low FRP, is likely due to increased risk mitigation for local communities and land-uses.

GROUP D, RES7: GIPPSLAND RESERVES





SAMPLE: Cape Howe, NSW/Vic.
279 hotspots



Hotspots common, severe hotspots rare (7 years).

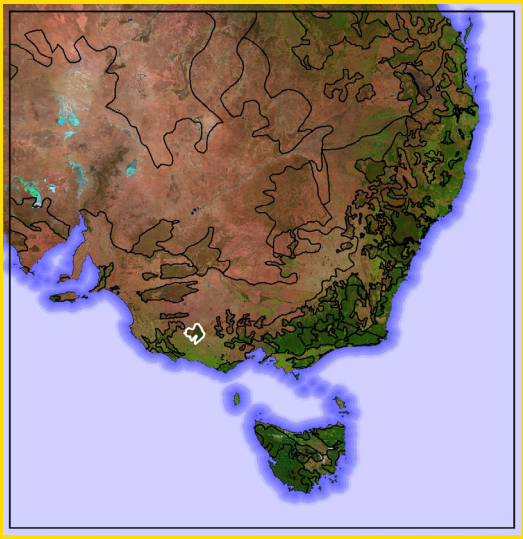
This region has 3,100 km^2 of mainly coastal shrubland and forest. Its fire regime has a variable core, with hot FRPs mainly in summer and autumn. There is no clear trend towards earlier onset or longer duration.

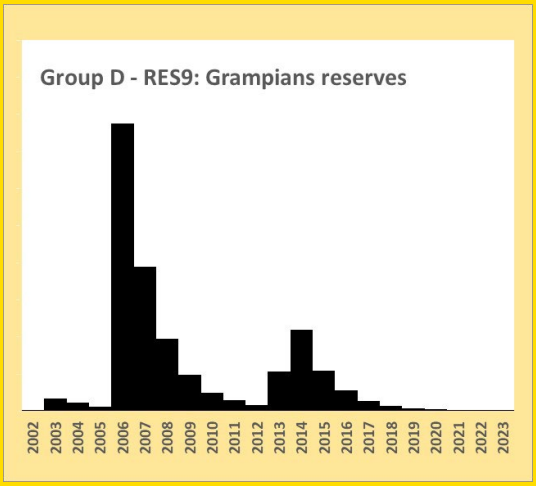
During Black Summer, some major BUFEs occurred here.

Recorded pyroCbs: 3

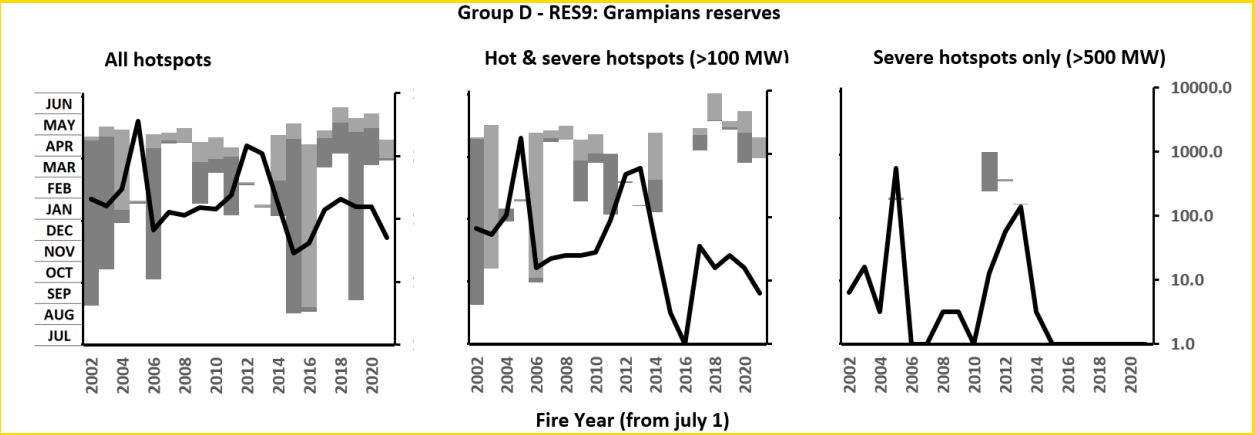
2019ai (29 Dec) Vic: Cann River
2019al (30 Dec) Vic: Cann River
2019am (30 Dec) Vic: Cann River

GROUP D, RES9: GRAMPIANS RESERVE





SAMPLE: Glenista Crossing, Vic.
684 hotspots



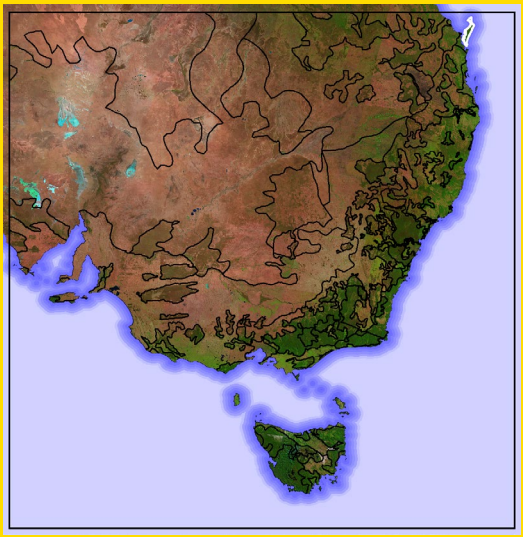
Hotspots common, severe hotspots rare (8 years).

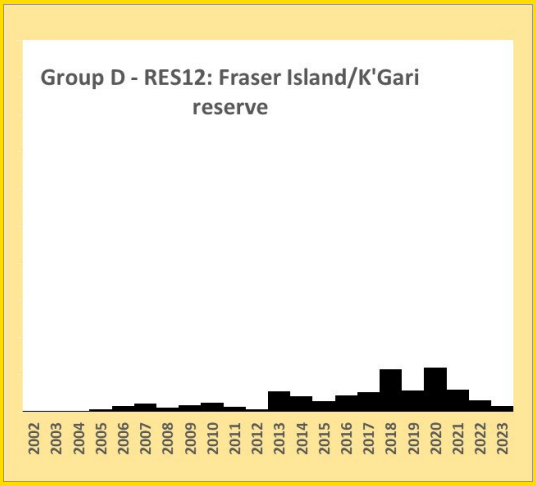
This region has 3,168 km^2 of woodland, grassland, and heathland. Most activity is in the autumn. There is no clear trend towards earlier or longer activity periods, however since 2015 the core has become later in autumn.

Recorded pyroCbs: 5

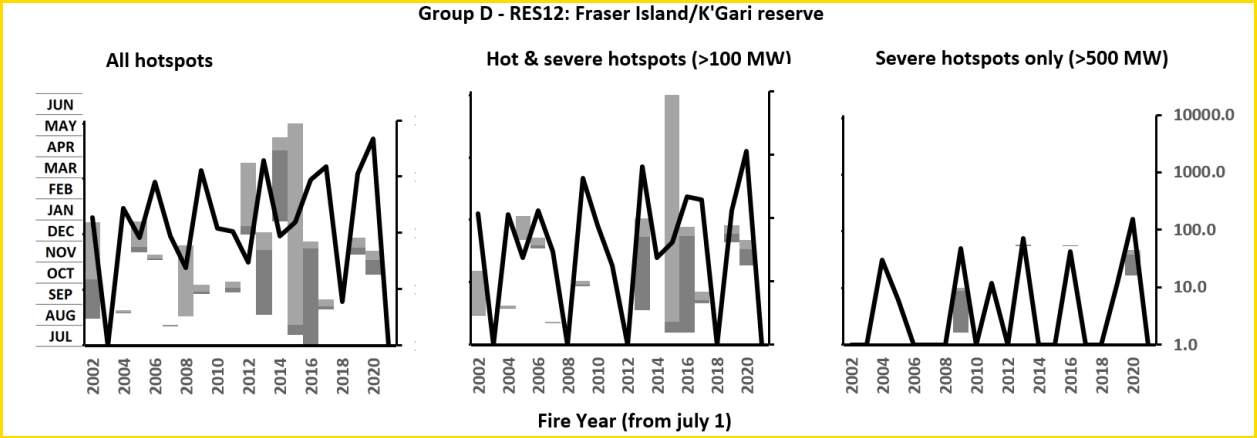
2006a (19 Jan) Vic: Grampians
2013c (21 Feb) Vic: Grampians
2014a (16 Jan) Vic: Grampians
2014b (17 Jan) Vic: Grampians
2015b (07 Jan) Vic: Black Range

GROUP D, RES12: FRASER ISLAND/K'GARI RESERVE





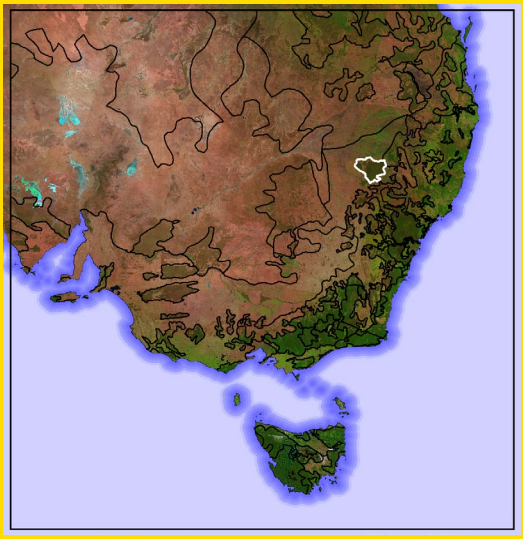
SAMPLE: Central Fraser Island, Qld.
554 hotspots

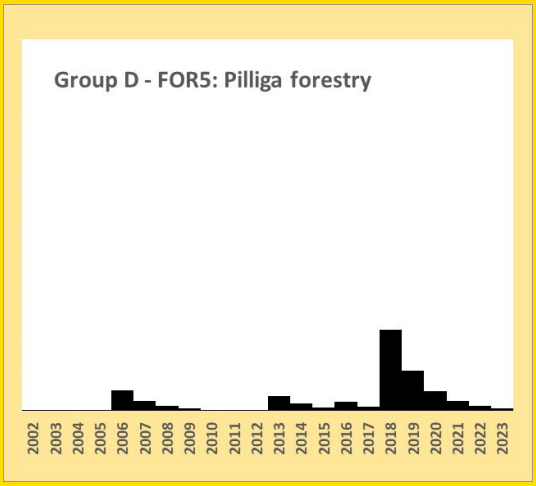


Hotspots common, severe hotspots rare (6 years).

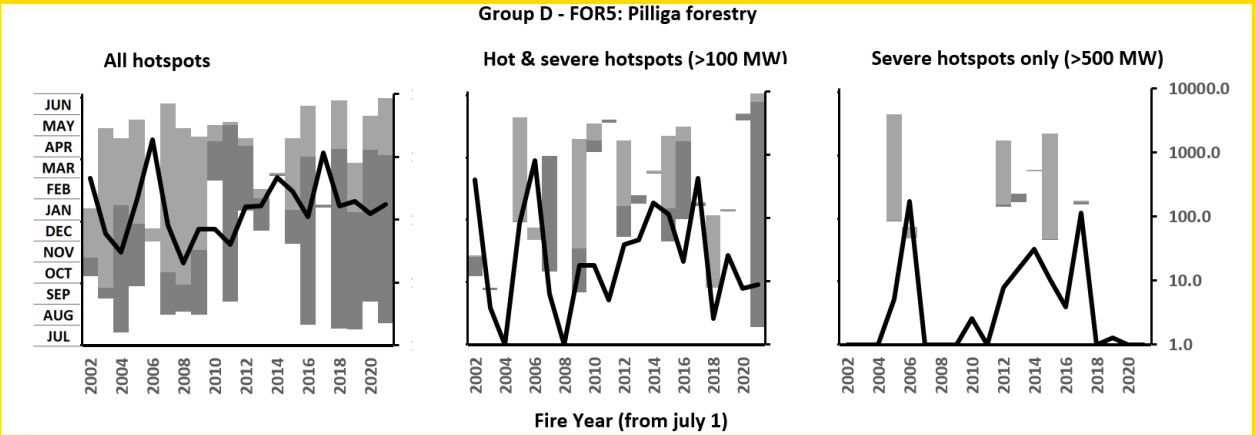
This 1,700 km^2 region is mainly coastal forest and heathland without major outliers. It has highly variable activity patterns.

GROUP D, FOR5: PILLIGA FORESTRY





SAMPLE: N of Coonabarabran, NSW.
453 hotspots



Hotspots common, severe hotspots rare (7 years).

This region has 7,800 km^2 of mainly woodland. Its fire regime is mainly a summer core of HRBs, sometimes swamped by summer BUFE events. Many hot FRP hotspots are from HRBs. There are infrequent, severe BUFE FRPs in summer: in 2005/2006; 2012/2013; .2017/2018.

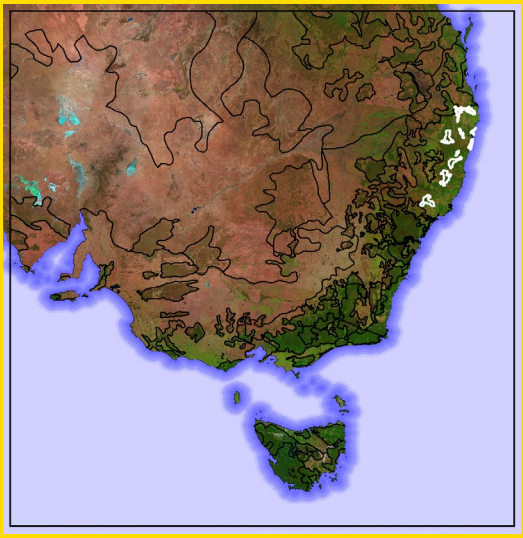
A slight trend towards earlier onset and longer duration is seen in the graphs.

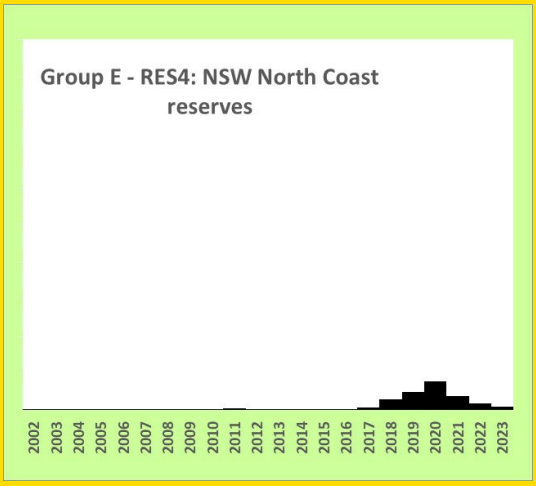
Recorded pyroCbs: 1

2006d (29 Nov) NSW: Pilliga

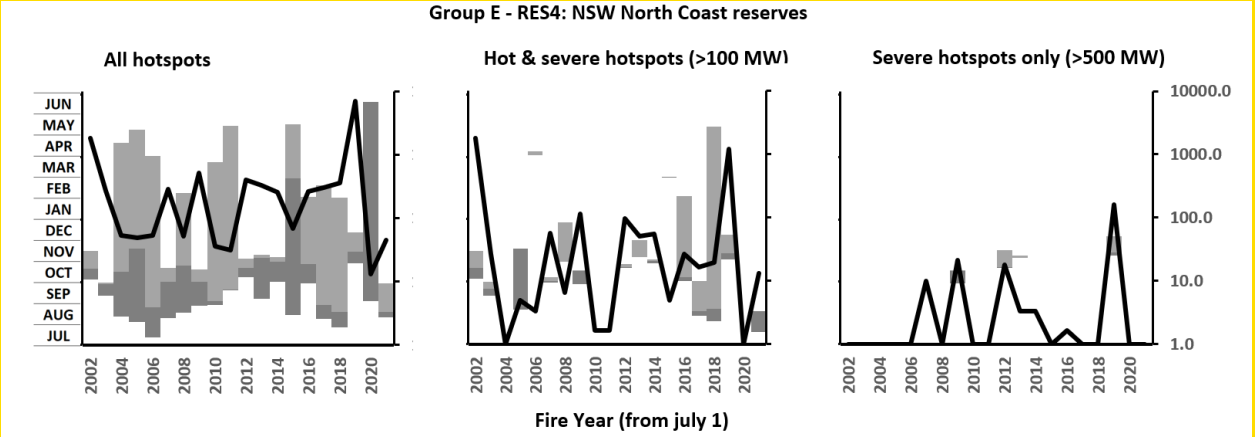
GROUP E: VARIABLE SPRING & SUMMER BURNING

GROUP E, RES4: NSW NORTH COAST RESERVES





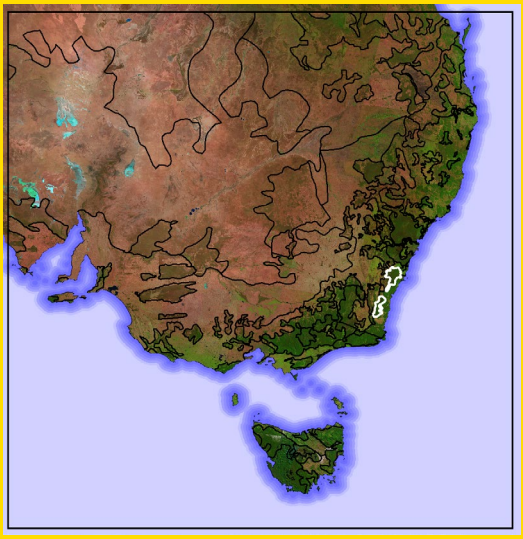
SAMPLE: Careys Peak, NSW.
143 hotspots

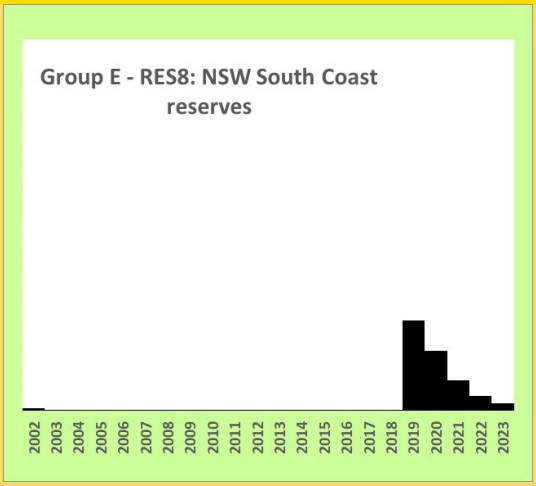


Hotspots common, severe hotspots rare (5 years).

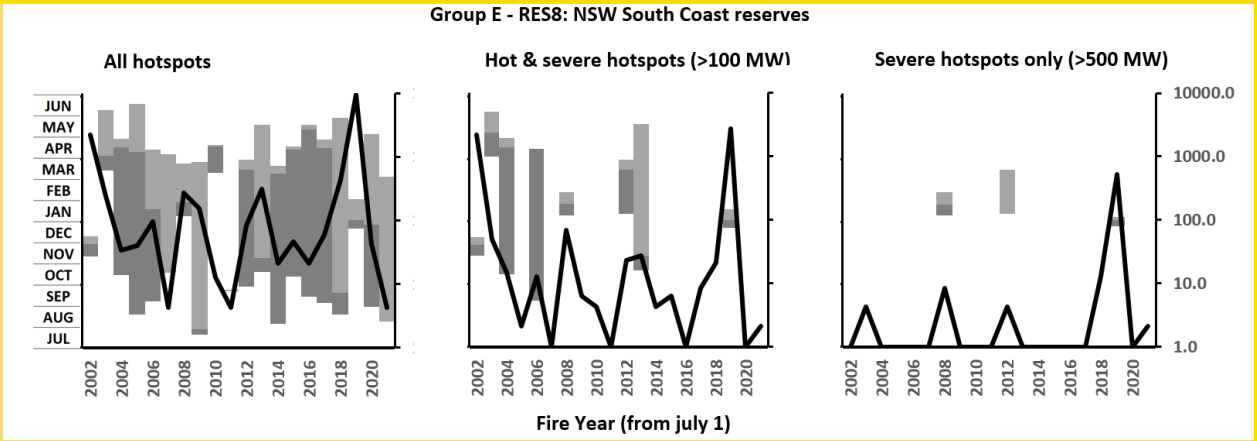
This region has 6,100 km^2 of mainly forest and shrubland. Its fire regime is mainly a spring core when FRPs are raised over the year, otherwise spanning spring, summer, and autumn. No clear trend towards earlier onset or longer duration is seen in the graphs.

GROUP E, RES8: NSW SOUTH COAST RESERVES





SAMPLE: Morton NP. NSW.
860 hotspots



Hotspots common, severe hotspots rare (4 years).

This region has 4,700 km^2 of mainly forest. Its fire regime has a variable core, with hot and severe FPRs mainly in summer, especially after 2007. Years with less activity are dominated by autumn HRBs.

There is a slight trend towards earlier onset, although why is not evident from this analysis.

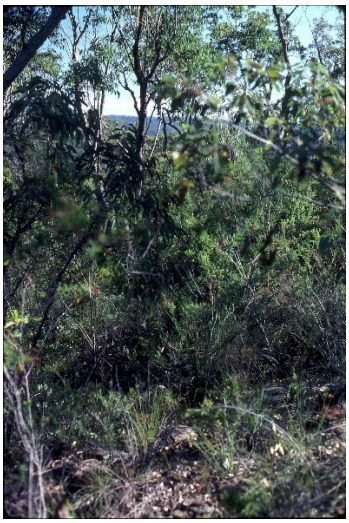
Recorded pyroCbs: 5

2019 (21 Dec) NSW: Ulladulla
2019 (28 Dec) NSW: Nowra area
2019ag (28 Dec) NSW: Mt Tianjara
2019ar (31 Dec) NSW: Nowra
2020b (04 Jan) NSW: Nowra
2020l (01 Feb) NSW: Tantawangalo

Nothofagus forest, NE Tasmania, region FOR4. Not fire tolerant,

Wet sclerophyll forest, Barrington Tops, NSW, region RES04. Fire tolerant.

Rainforest understorey, Taree, NSW, region MIX2. Not fire tolerant.



Woodland and heath, Yengo NP, NSW, region RES05. Very fire tolerant.

Old fire scars, Grey Mare Range, Kosciuszko NP, NSW, region RES02. The fire was 40 years prior.

Woodland with open understorey, St Albans, NSW, region RES05. Fire tolerant.

Woodland, Mutawintji NP, NSW, region RNG1. Fires are rare.

Sparse shrubland, Sturt NP, NSW, region RNG3. Fires after wet years,

Semi-arid rangeland, near Flinders Ranges, SA, region RNG3. Fires rare.

Woodland, near Bacchus Marsh, Vic, region FOR2. Fire tolerant.

Much planned burning aims to prevent structural loss.

Gondawanan forest, Mt Field NP, Tas, region RES06. Fire intolerant.

Wallum heath and woodland, Fraser Island/K'gari, Qld, region RES12.

Many of the hotspots arise from planned burns.

The Pilliga Scrub, NSW, region RES08. Large fires are wind-driven.

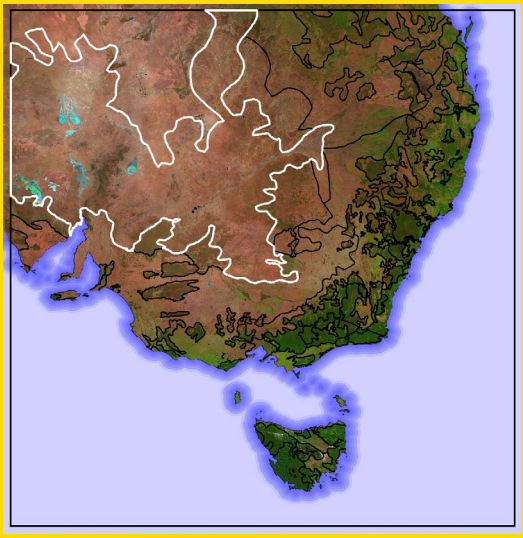
Fire impact on the fringe of Hobart, 1967. (ACT Bush Fire Council photo), region URB.

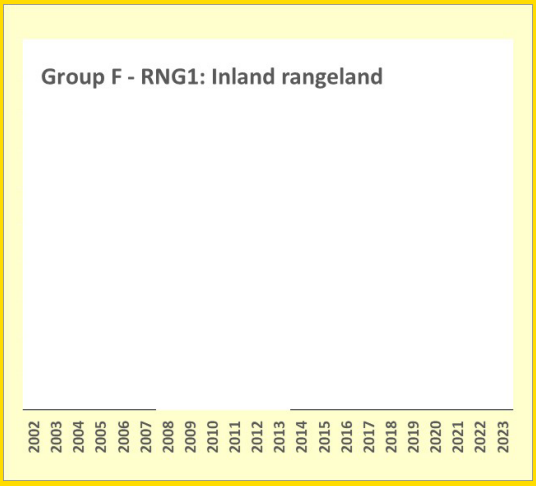
Burning-off silvicultural slash. Stromlo Pine Plantation, ACT, FOR3.

(All photos by author unless otherwise cited.)

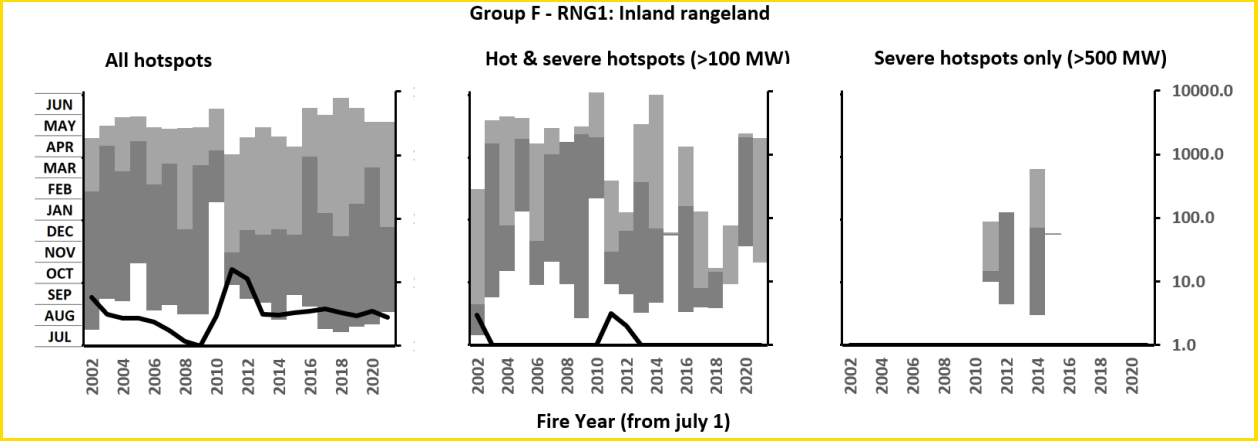
GROUP F: PROTRACTED LOW-FREQUENCY BURNING

GROUP F, RNG1: INLAND RANGELAND





SAMPLE: SE of Menindee, NSW
15 hotspots

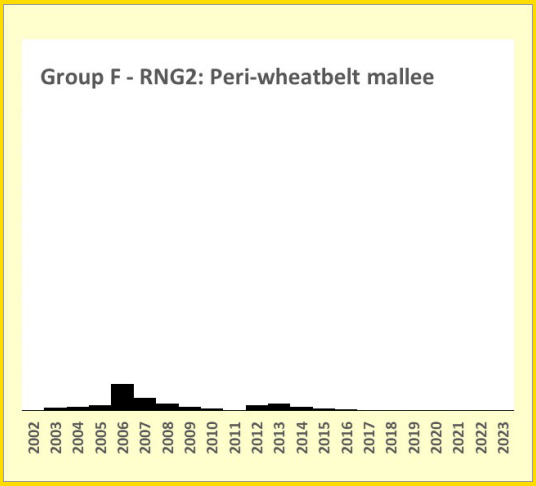


Hotspots rare, severe hotspots rare (4 years).

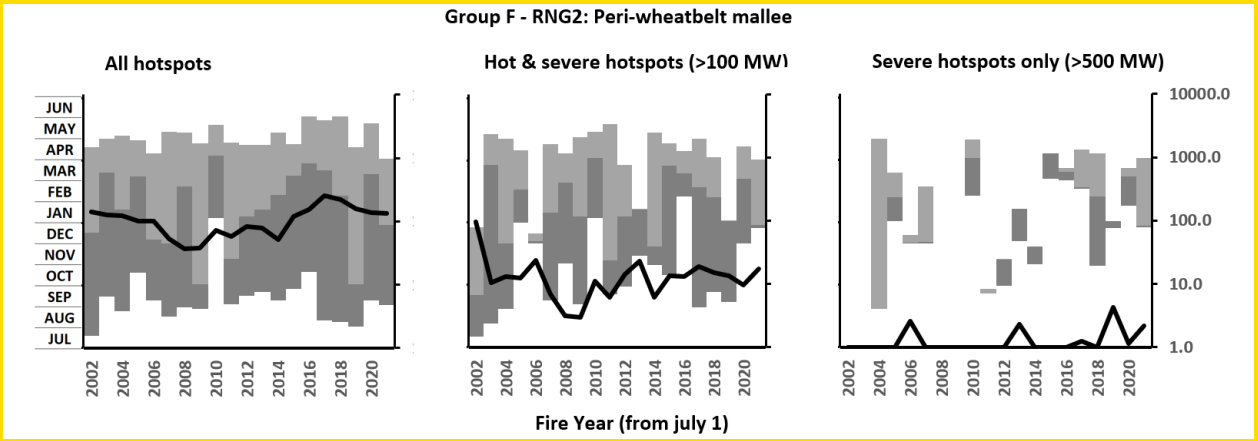
This region, the largest, covers 710,500 km^2 of shrubland and grassland.

There was a shift, in 2010, from summer core to spring core, with less hot FRP as a result. Activity, at a relatively quite low level, spans most of the year.

GROUP F, RNG2: PERI-WHEATBELT MALLEE



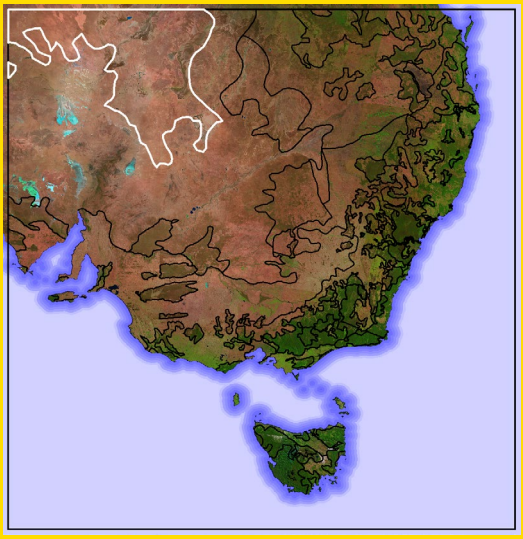
SAMPLE: NE of Mildura, NSW
339 hotspots

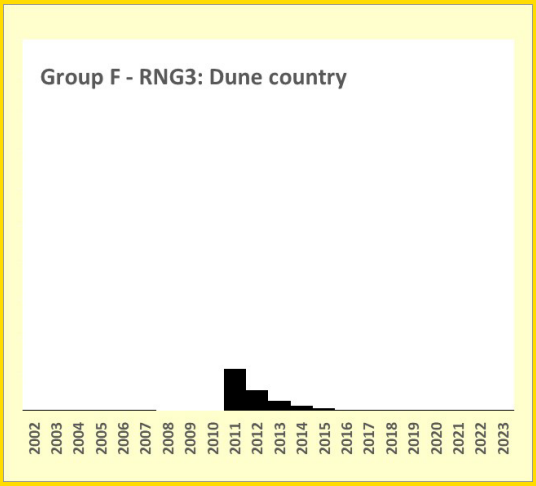


Hotspots common, severe hotspots rare (16 years).

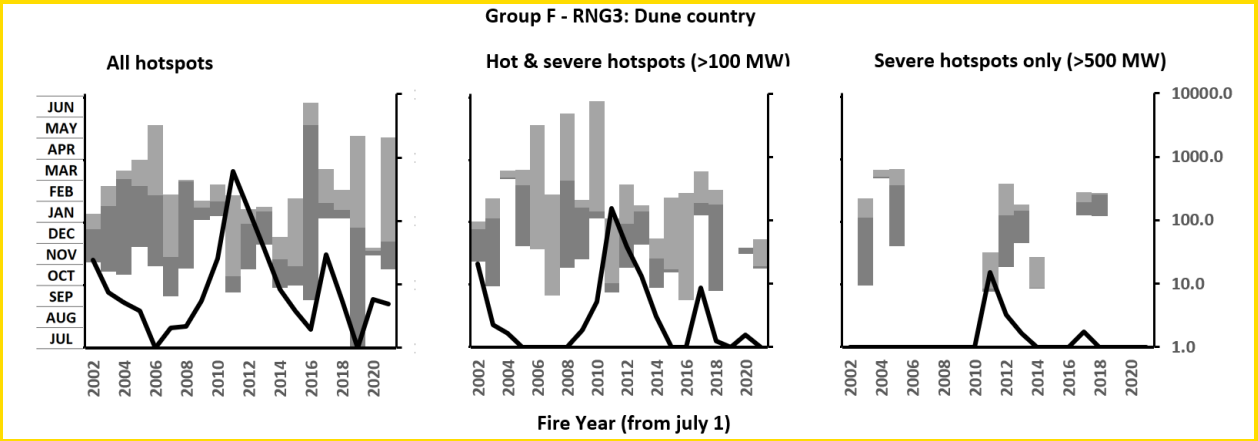
This region, covering 104,400 km^2, is mainly shrubland. Activity is variable with a summer core. There is no trend to earlier of longer activity seasons.

GROUP F, RNG3: DUNE COUNTRY





SAMPLE: Strzelecki Desert, N of Broken Hill
172 hotspots

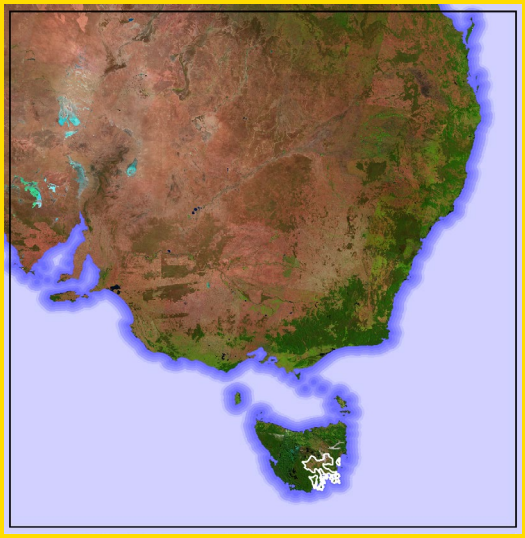


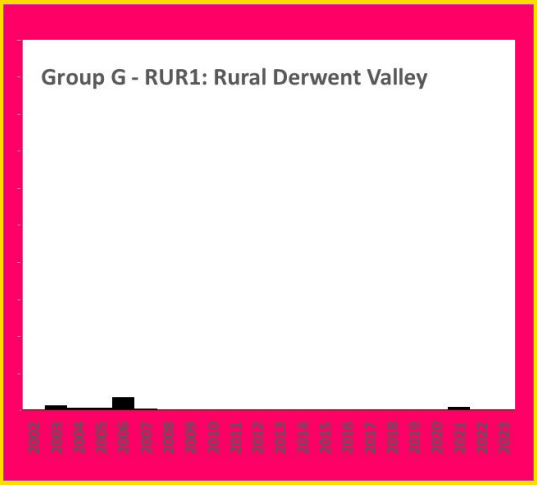
Hotspots uncommon, severe hotspots rare (9 years).

This region of 258,700 km^2 is mainly shrubland and grassland. Core activity is variable, but mainly in summer, and dependent on wet years. There is no clear trend towards earlier or longer periods of activity.

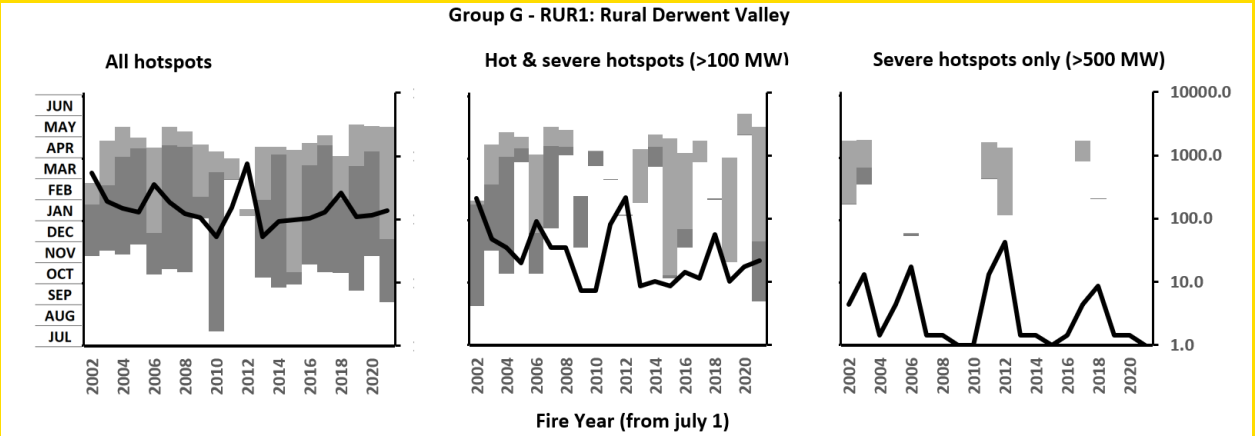
GROUP G: PROTRACTED MID-FREQUENCY BURNING

GROUP G, RUR1: RURAL DERWENT VALLEY





SAMPLE: N of New Norfolk, Tas.
116 hotspots



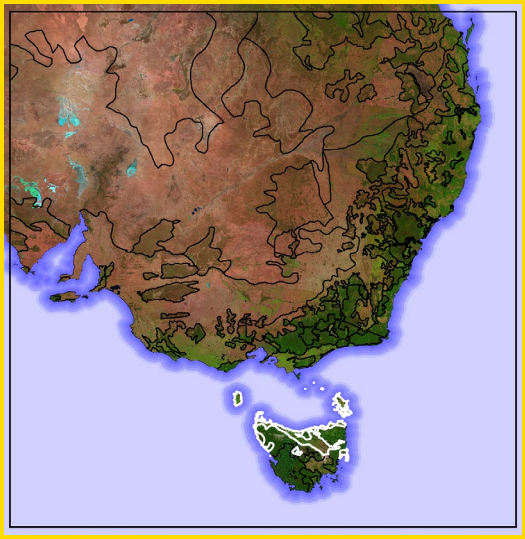
Hotspots common, severe hotspots rare (8 years).

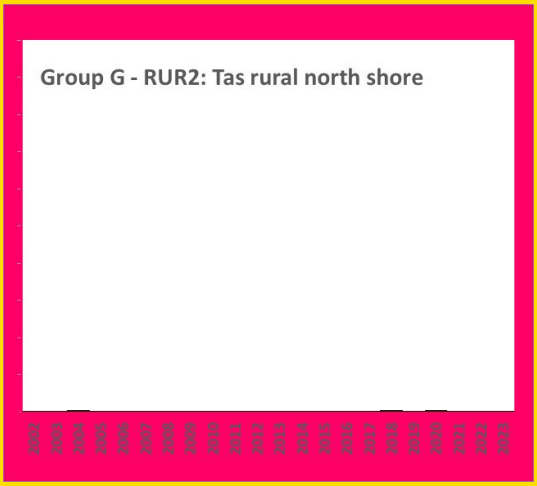
This region of 6,926 km^2 is mainly a grassland and forest mix. It ihas a late summer to aerly autumn activity core. There is a pronounced trend towards early and longer activity, which may reflect HRB patterns.

Recorded pyroCbs: 1

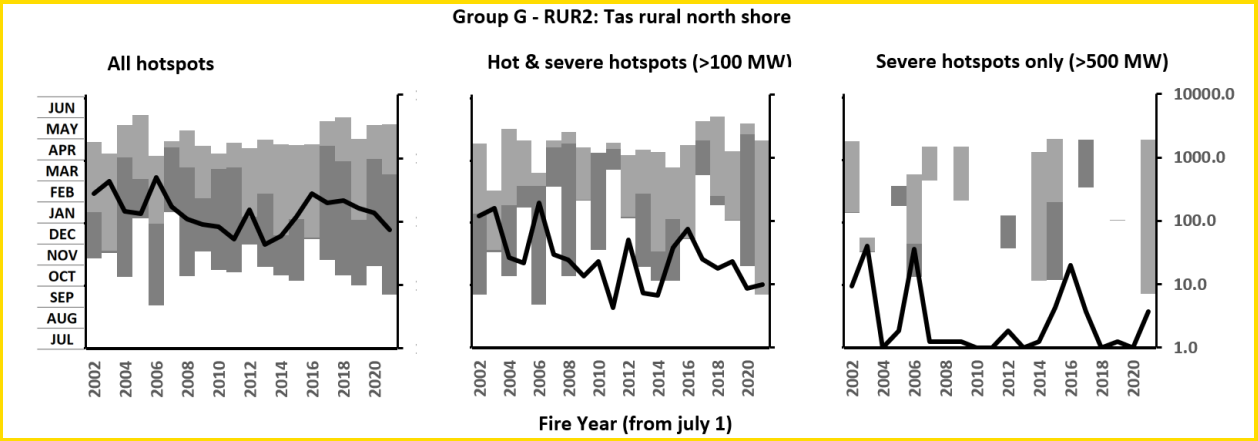
2013a (04 Jan) Tas: Dunalley

GROUP G, RUR2: TAS RURAL NORTH SHORE





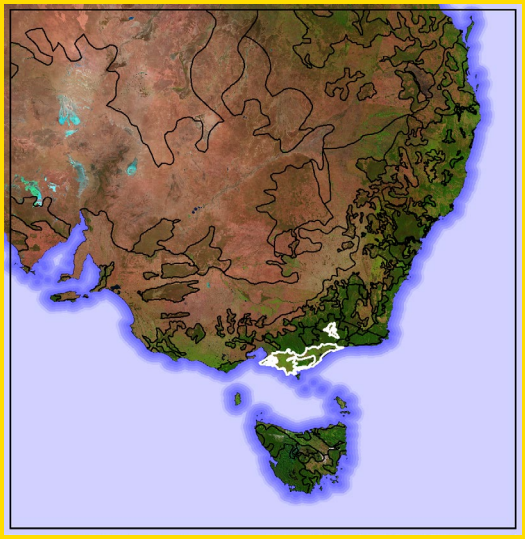
SAMPLE: SW of Launceston, Tas.
70 hotspots

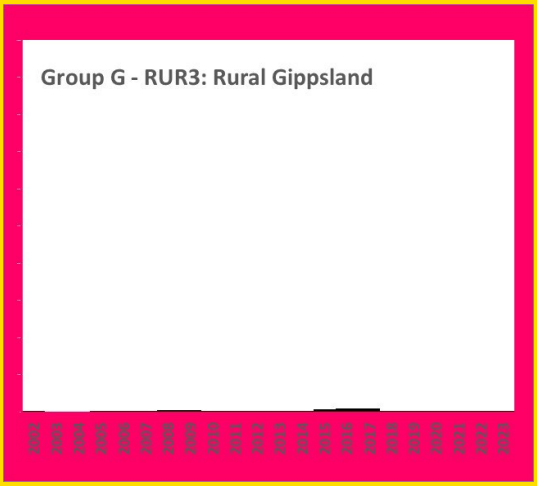


Hotspots common, severe hotspots rare (12 years).

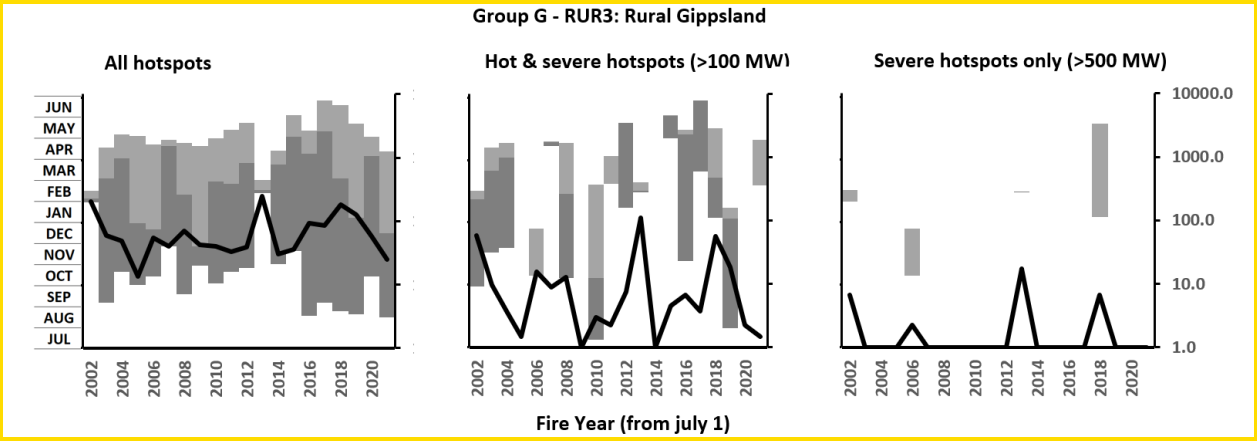
This region of 16,270 km^2 is mainly grassland. It has peak activity in late summer or early autumn. There is a slight trend towards earlier and longer activity in the lower FRP data, suggesting that it is mainly planned burning.

GROUP G, RUR3: RURAL GIPPSLAND





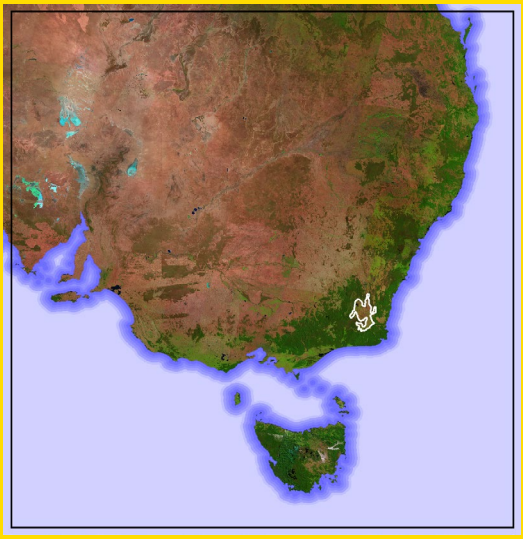
SAMPLE: Between Stratford & Bairnsdale, Vic.
81 hotspots

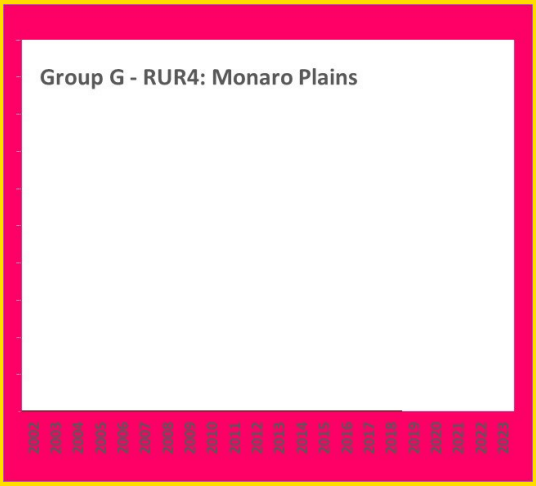


Hotspots common, severe hotspots rare (4 years).

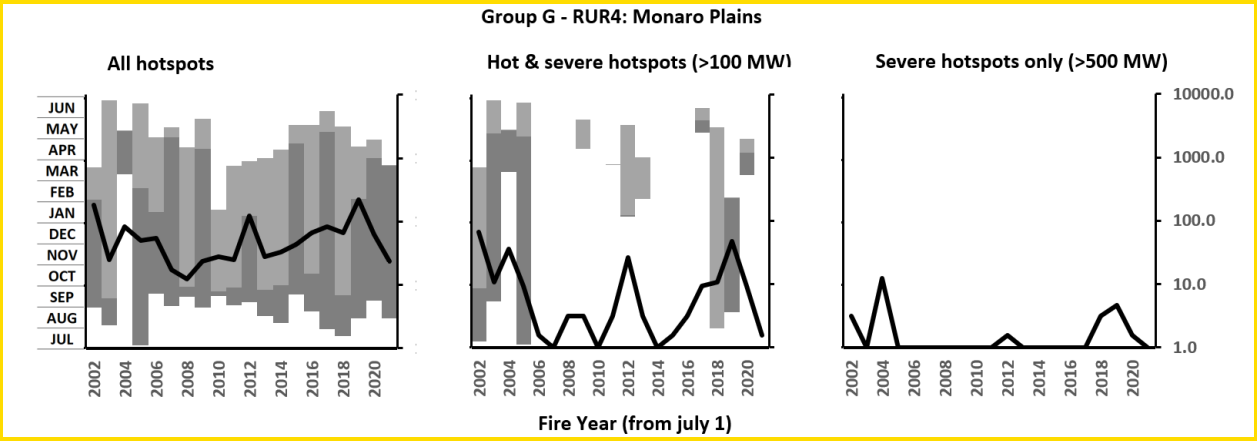
This region of 13,420 km^2 is mainly grassland. Its late summer activity core is highly variable. There is a pronounced trend to earlier and longer activity, which may reflect HRB patterns.

GROUP G, RUR4: MONARO PLAINS





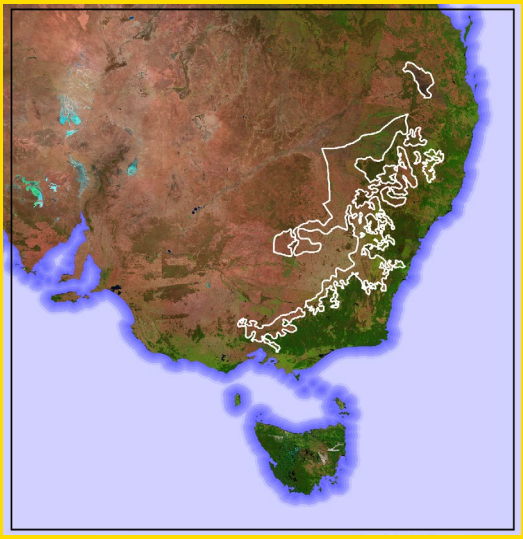
SAMPLE: Dalgety, NSW
34 hotspots

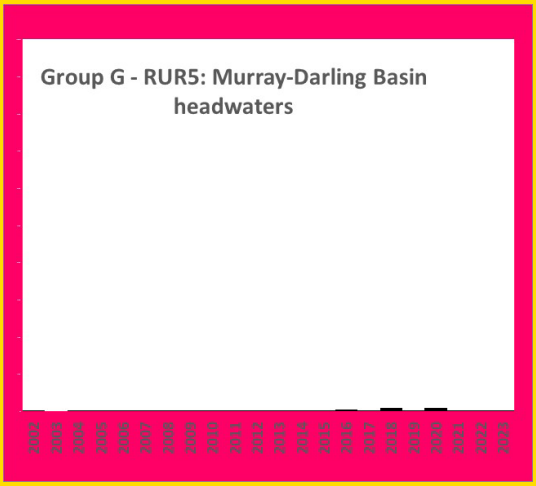


Hotspots common, severe hotspots rare (4 years).

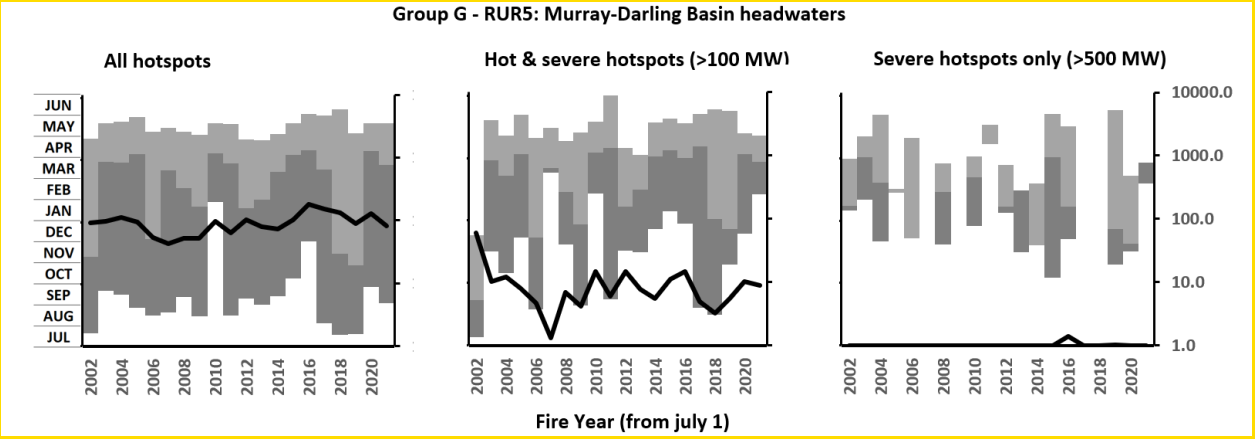
This region covers 6,500km^2 of mainly grassland, primarily used as grazing land. Most activity occurs in spring, but extends to autumn. Hot or severe hotspots are not a feature. A key feature in recent years has been management of the invasive African Love Grass. Partly as a result of this there has been a trend towards earlier and long activity seasons since 2010.

GROUP G, RUR5: MURRAY-DARLING BASIN HEADWATERS





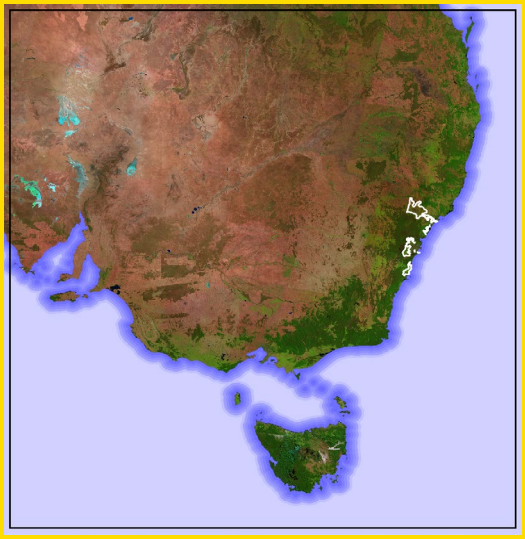
SAMPLE: NW of Narromine, NSW.
97 hotspots

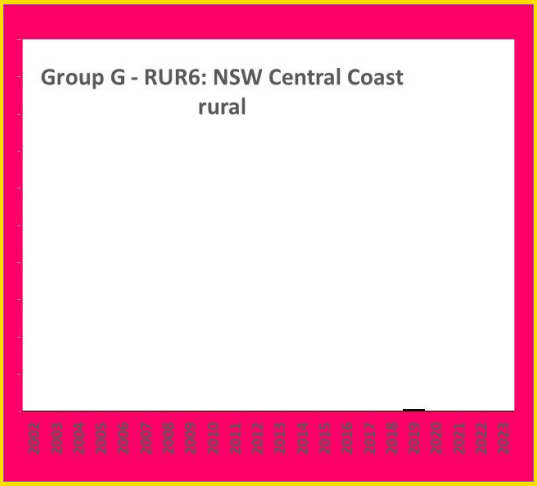


Hotspots common, severe hotspots rare (16 years).

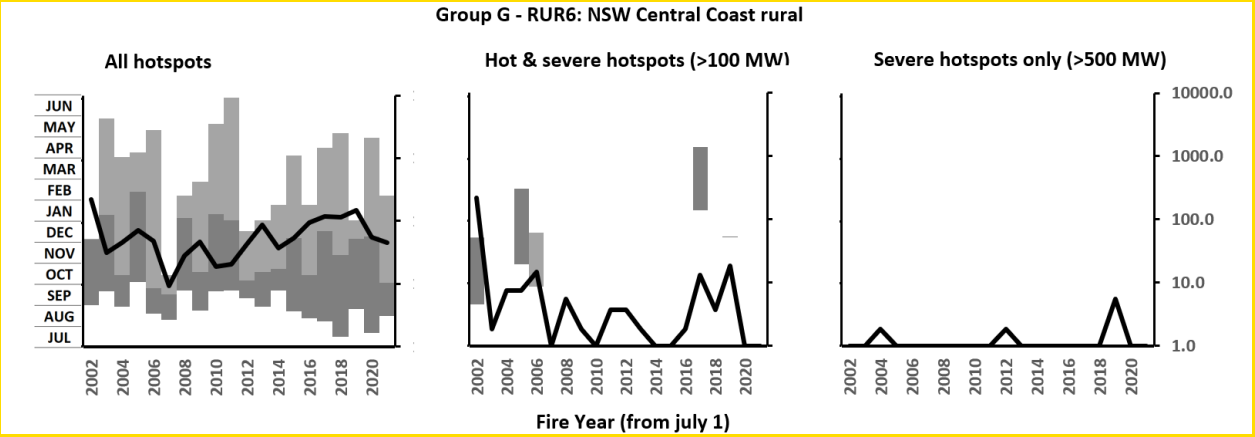
This region of 165,800 km^2 is mainly rural grassland with activity peaking in spring or autumn, but with severe activity in summer. There are no consistent trends to earlier or longer activity.

GROUP G, RUR6: NSW CENTRAL COAST RURAL





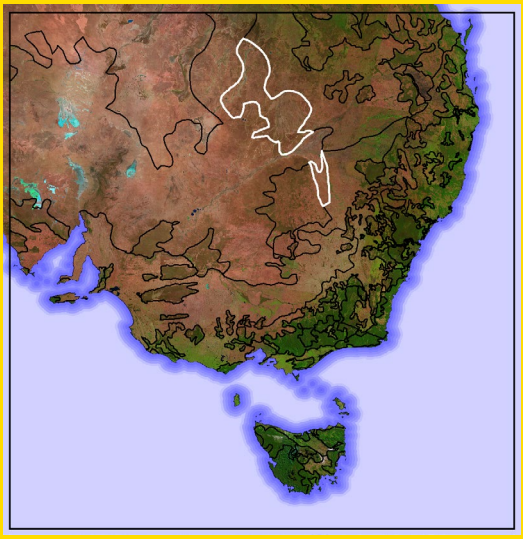
SAMPLE: Camden, SW of Sydney, NSW
58 hotspots

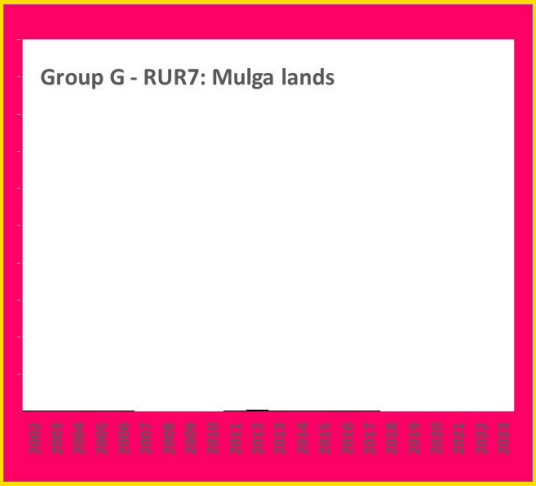


Hotspots common, severe hotspots rare.

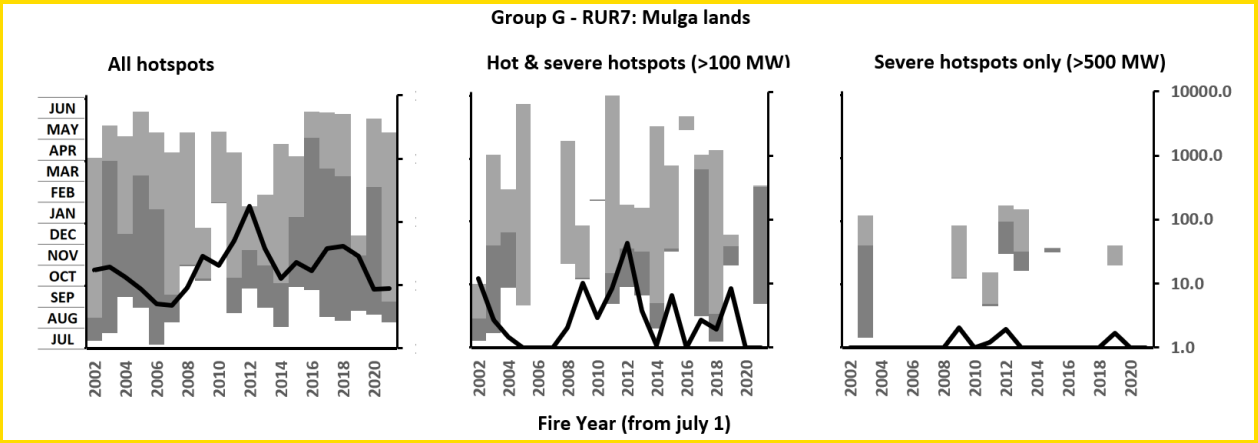
This region of 5,388 km^2 sits on the margins of the sandstone basin. It has low levels of activity but does show a trend towards earlier activity.

GROUP G, RUR7: MULGA LANDS





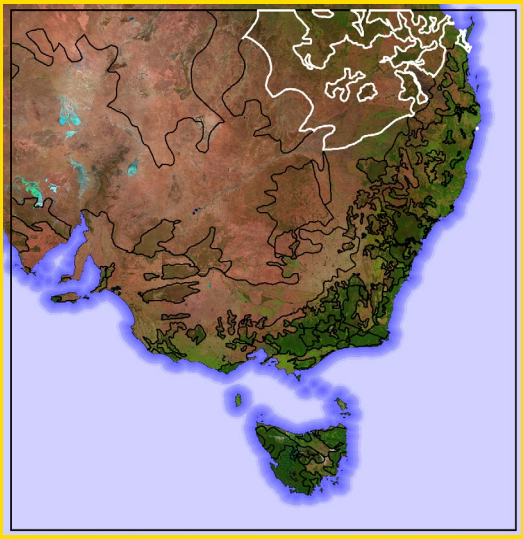
SAMPLE: SE of Cunnamulla, Qld.
30 hotspots



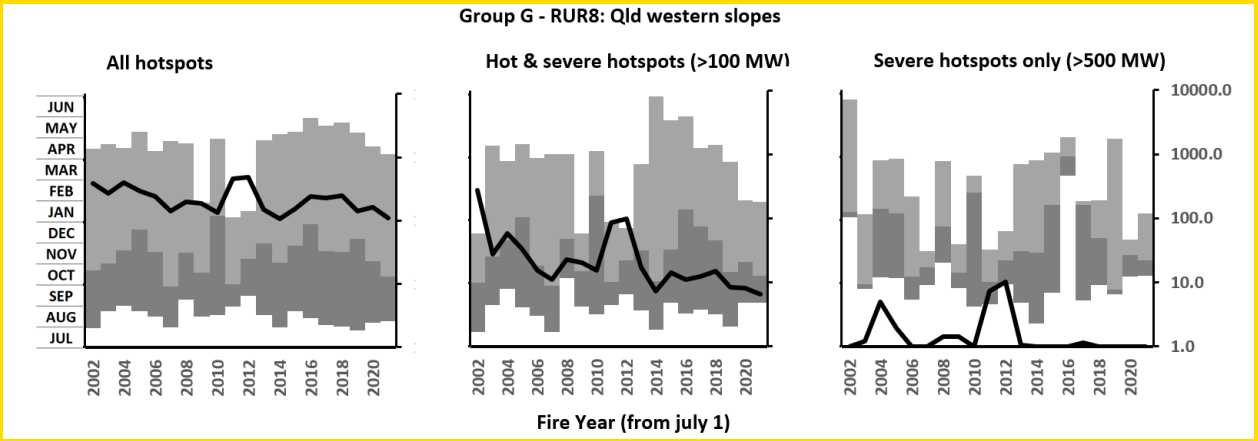
Hotspots uncommon, severe hotspots rare (7 years).

This region of 82,300 km^2 of grassland has variable activity with mainly a spring peak. There is no trend towards earlier or longer activity periods.

GROUP G, RUR8: QLD WESTERN SLOPES



SAMPLE: W of Charleville, Qld.
453 hotspots

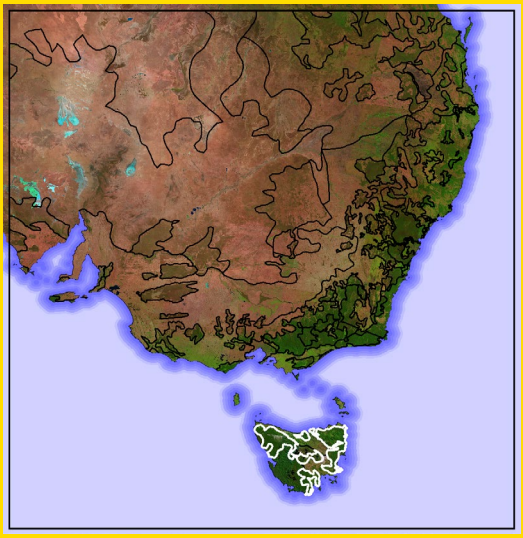


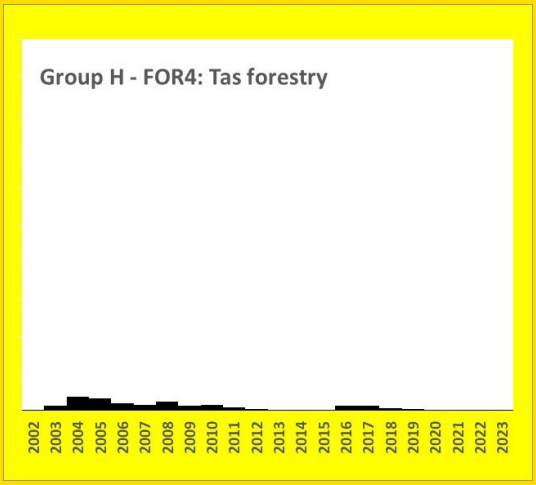
Hotspots common, severe hotspots rare (all years).

This region covers 230,800 km^2 of grassland. Activity is centred in spring, and shows no trends towards earlier of longer activity periods.

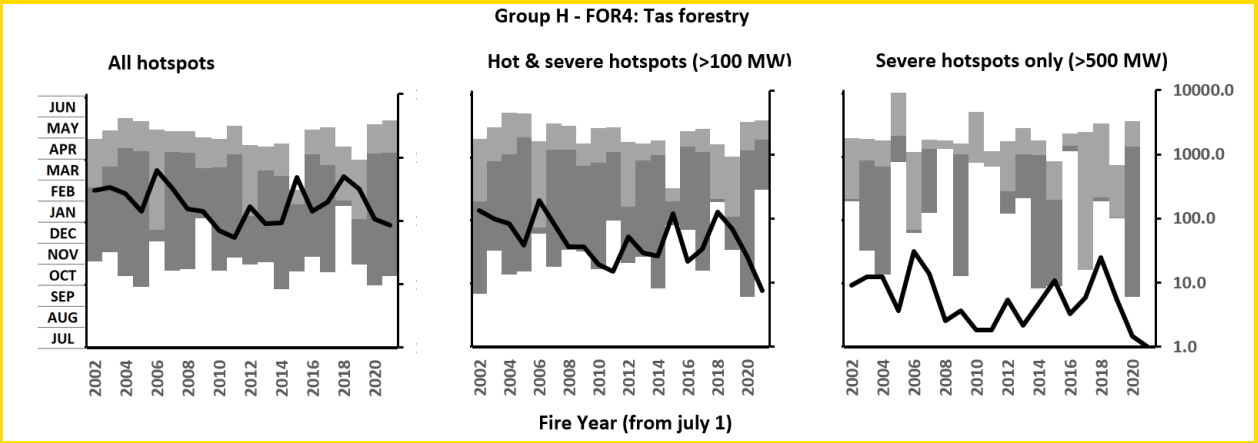
GROUP H: PROTRACTED SUMMER & AUTUMN BURNING

GROUP H, FOR4: TAS FORESTRY





SAMPLE: NE Launceston, Tas.
207 hotspots

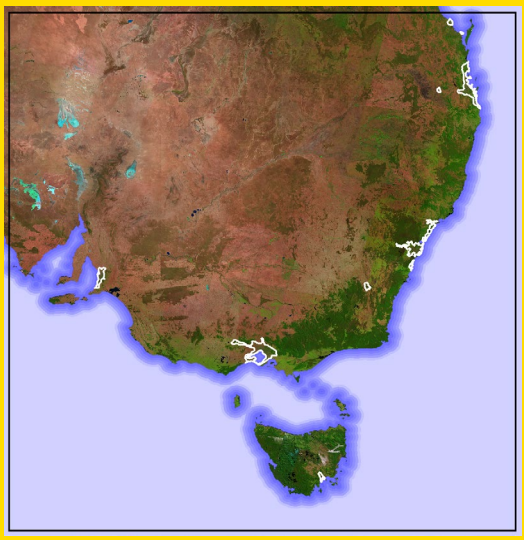


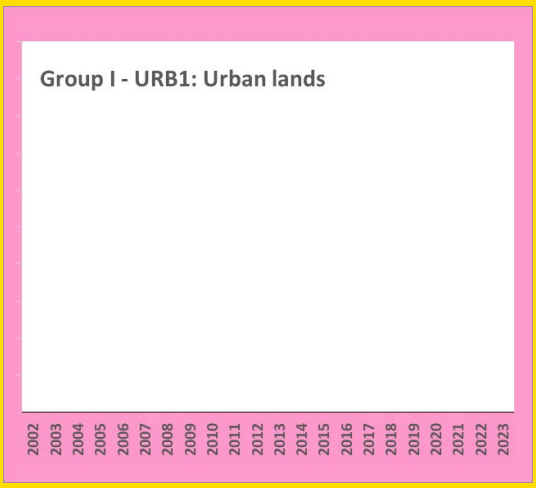
Hotspots common, severe hotspots uncommon (all years).

This 27,670 km^2 forest region has peak activity in autumn and no trend towards earlier or longer extents. Activity consistently spans late spring through autumn.

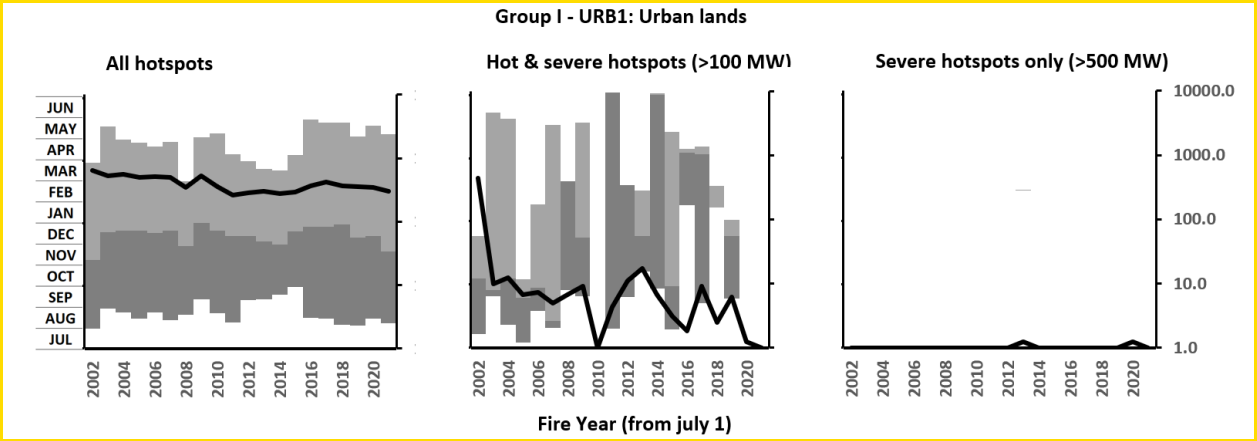
GROUP I: PROTRACTED LIMITED-INTENSITY BURNING

GROUP I, URB1: URBAN LANDS





SAMPLE: Central Sydney
204 hotspots



Hotspots frequent, severe hotspots rare.

Spanning 16,260 km^2, this region features a constant effort to protect the urban interface, burning whenever fire weather suitable. It has few Elevated FRP events.

There was a trend to shorted, later fire activity periods prior to 2015, followed by an abrupt switch to early and longer periods, with later hot FRP events.

The fire regime has little landscape-scale impact. It is however worth noting that the 2003 wildfires burnt severely into Canberra's urban areas around Weston Creek and Tuggeranong.

It must be noted that this hotspot set may contain industrial plumes, structural fires and other anomlaies that may pass the hotspot filter.

ANALYSIS

HOTSPOTS FREQUENCY

One way to classify the regions is by grouping them according to broad ranges of frequencies for both all hotspots and severe hotspots (FRP> 500 MW).

		All hotspots				
		Rare (0 – 3)	Uncommon (3 – 30)	Common (30 – 300)	Frequent (300 – 3000)	Very freq. (over 3000)
Severe hotspots	Rare	F:RNG1	F:RNG3	ALL OTHERS	I:URB1	
	Uncommon			H:FOR4, C:FOR2, A:RES10	C:FOR3, C:FOR1, A:MIX3	
	Common					
	Frequent					
	Very freq					
BUFEs		C:FOR1, C:FOR2, C:FOR3, H:FOR4, D:FOR5, D:RES01, D:RES02, D:RES03, E:RES04, B:RES05, D:RES07, D:RES09, A:RES11, A:MIX1, A:MIX2				

Most regions fall into the “Common + Rare” class. Some rangeland regions have fewer hotspots, while forestry and the Vic-SA mallee regions and MIX3 have more severe hotspots, and half of that group have more hotspots overall. URB1 has more hotspots as well, reflecting urban edge protection effort.

FIRE REGIMES

Each group of regions has similar broad properties, summarised below.

Generalised hotspot count per 100km^2 per annum	FRP class		
LAND-USE	COOL	HOT	SEVERE
A:MIX3	800	125	6
URB	500	6	1
FOR	250	50	6
MIX (other)	200	20	2
WHT	200	25	2
RES	100	13	2
RUR	80	8	1
RNG	6	3	1

As general conclusions, we can say:

- The base hotspot density is about 200 per 100km^2 per annum.
- Hot hotspots (FRP over 100 MW) have about a tenth of the frequency.
- Severe hotspots (FRP over 500 MW) have about a tenth of that frequency again.
- Urban then broad-acre land-uses have the most hotspots overall, with a focus on protecting valued land-uses (typically on valley floors) by burning on adjacent areas (typically woodlands on ridges).

- Conservation reserves have around half that number, as they need to burn on site to protect their assets and as well as manage their fire regimes.
- Fire on the wheatbelt (WHT) tends to be stubble clearing, and thus at a very specific time of year, after harvesting.
- Rural areas have few hotspots, in part reflecting the non-flammable fuel types.
- Rangelands have even lower hotspots frequencies, reflecting fuel, climate, and bushfire risk levels.

As specific conclusions we can say:

- MIX3 stands out as having the highest hotspot densities – about four times higher than average.

FIRE AGE SPECTRUM

It is important for biodiversity management reasons to maintain a balanced fire age spectrum. The synthesis presented in this report is not detailed enough, nor long enough, to resolve regional fire age spectra.

A region that has been heavily impacted by extreme wildfires is RES03, ACT Reserves. This has long been monitored for that balance. The results, below, show that it is increasingly unbalanced. Using prescribed burning to re-balance it is quite challenging, given that almost all of the area is in the youngest fire age class. That challenge is more difficult given the impact of climate change on burning windows and the potential for a repeat extreme wildfire.

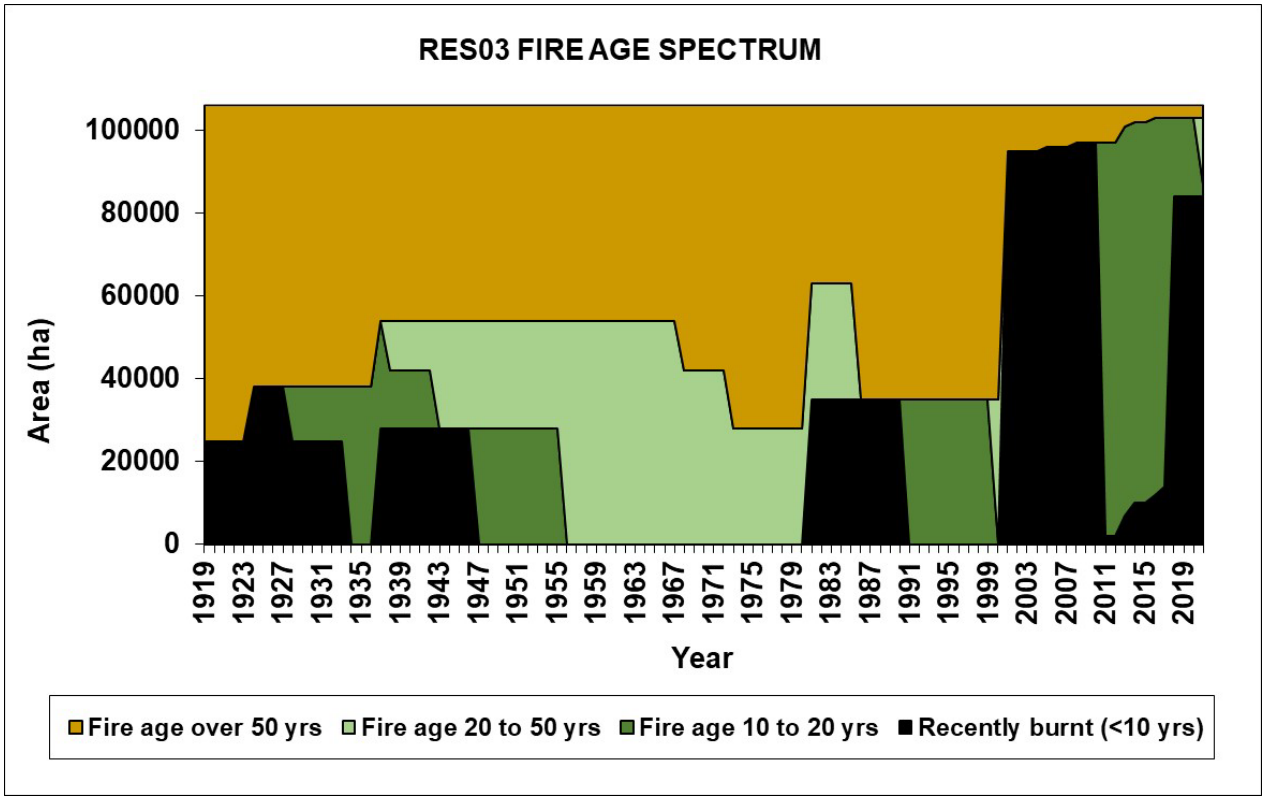


Figure 9. The distribution of fire ages classes in RES3 shows a high level of imbalance.

PYROCB OCCURENCE

Region	Area (1000 km^2)	No. pyroCbs	Hotspot frequency	Severe hotspot frequency	No. years with severe hotspots	Fuel
A:MIX2	126.4	8	Frequent	Rare	17	Woodland/grassland
A:MIX3	110	2	Very frequent	Common	20	Woodland/grassland
C:FOR2	42.2	18	Common	Uncommon	18	Forest
A:RES10	20.9	1	Common	Uncommon	12	Heathland
B:RES05	17.9	7	Common	Rare	7	Forest/shrubland
A:MIX1	10.6	2	Common	Rare	10	forest/grassland
D:RES02	9.6	6	Common	Rare	4	Forest/heathland
D:RES01	9.4	20	Common	Rare	7	Forest/heathland
D:FOR5	7.8	1	Common	Rare	7	Woodland
G:RUR1	6.9	1	Common	Rare	8	Grassland/ forest
C:FOR3	6.8	2	Frequent	Uncommon	9	Forest
C:FOR1	6.4	5	Frequent	Uncommon	10	Forest
E:RES08	4.7	6	Common	Rare	4	Forest
D:RES09	3.2	5	Common	Rare	8	Woodland/grassland /heathland
D:RES07	3.1	3	Common	Rare	6	Shrubland/forest
D:RES03	1.3	4	Common	Rare	5	Forest

The data above show no relationship between either the region's area or the number of years with severe hotspots and the number of pyroCbs, as shown in the plots below:

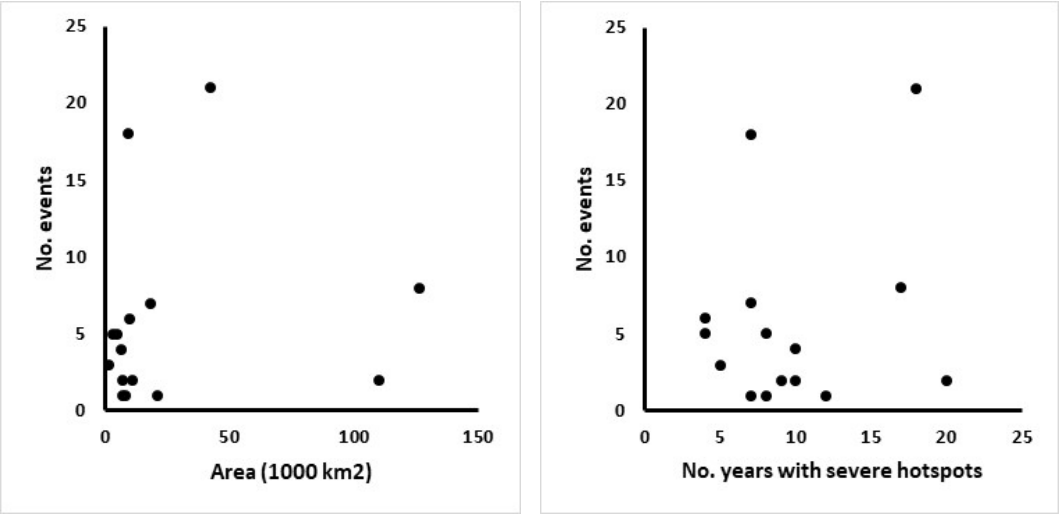


Figure 10

There is also no link to regional fuel type.

CHANGING FIRE SEASONS

Many have claimed that fire seasons are starting earlier and running longer. This is driving considerable effort into resourcing to address this operationally. Regarding this claim, a few clear conclusions arise from this study.

Firstly, fire seasons are starting earlier and running longer in urban areas (URB1).

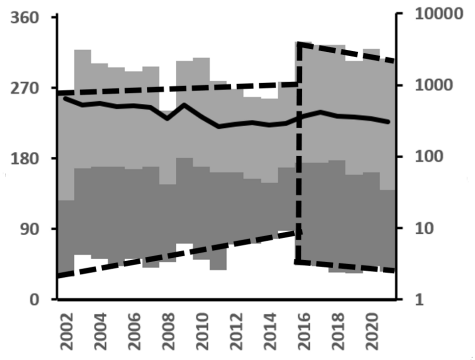


Figure 11

The dashed lines above outline an indicated shift after 2015/2016. This is driven by both a need to mitigate bushfire threats to rapidly urban edges and an increasing frequency of careless or malicious use of fire in the new peri-urban areas. Fortunately, there is not a commensurate increase in severe hotspots.

Trends towards earlier or longer fire activity periods are seen in the following regions:

- B:RES05, D:RES06, E:RES08, A:RES10, A:RES11, D:FOR5
- C:FOR 2
- A:MIX4
- G:RUR1, G:RUR3, G:RUR4, G:RUR6
- I:URB1 (see above)

Secondly, the forested areas of the southeast are experiencing Blow-Up Fire Events with an alarmingly increasing frequency. These manifest in the spikes in severe hotspot data. Those spikes are even worse than indicated due to the "hotspot hole" problem with MODIS data (see *Caveats*). This arises because all fuel elements are very flammable, and no heat is left when the satellite passes overhead next.

So, with a couple of exceptions, fire seasons are changing in the neighbourhood of political decision-makers and fire service chiefs, not elsewhere.

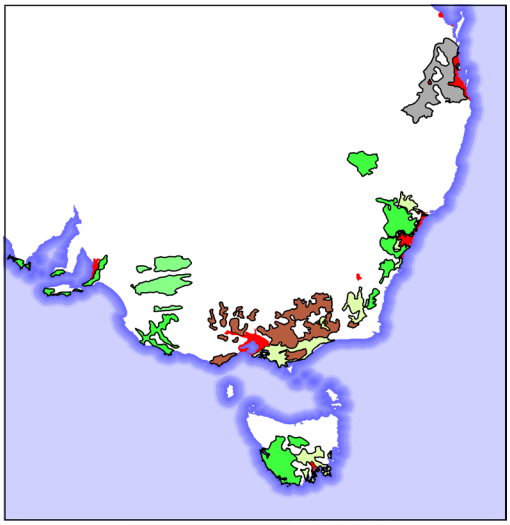


Figure 12. Regions assessed as showing a trend to earlier and/or longer activity seasons.

One metric is common in most of the graphs presented. The hotter the fire season (more high-FRP hotspots) the shorter its duration. This reflects some matters worth considering:

1. An intense operational period leaves fewer resources for HRBs.
2. The 10%ile and 90%ile can be skewed in this way by a large count of hotspots from protracted wildfires in the summer core.
3. Fire weather conducive to wildfires (especially in terms of elevated Drought Factor) do not meet prescription ideals for HRB planning.

BIOGEOGRAPHIC REGIONS

Interim Biogeographic Regionalisation for Australia (IBRA) version 7.0 represents a landscape-based approach to classifying the land surface of Australia. These are routinely used by some jurisdictions in seasonal bushfire outlooks.

https://www.environment.gov.au/fed/catalog/search/resource/details.page?uuid=%7B4A2321F0-DD57-454E-BE34-6FD4BDE64703%7D

These bioregions are only loosely aligned with the regions identified in this report, in both coverage and precision. This means that MODIS data is not usefully correlated with the IBRA regions. This reflects the anthropogenic drivers of modern fire regimes.

The IBRA regions have not been analysed in this report.

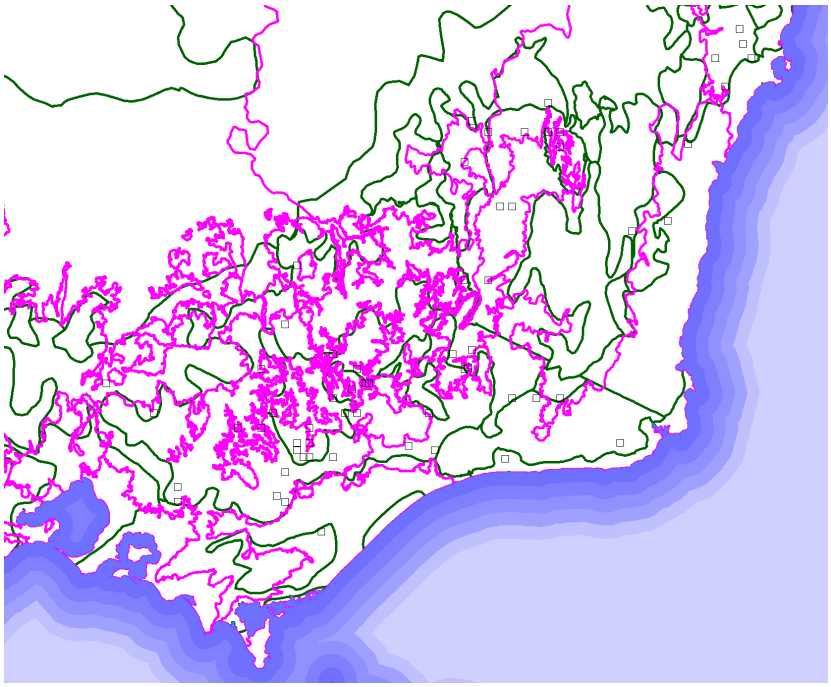
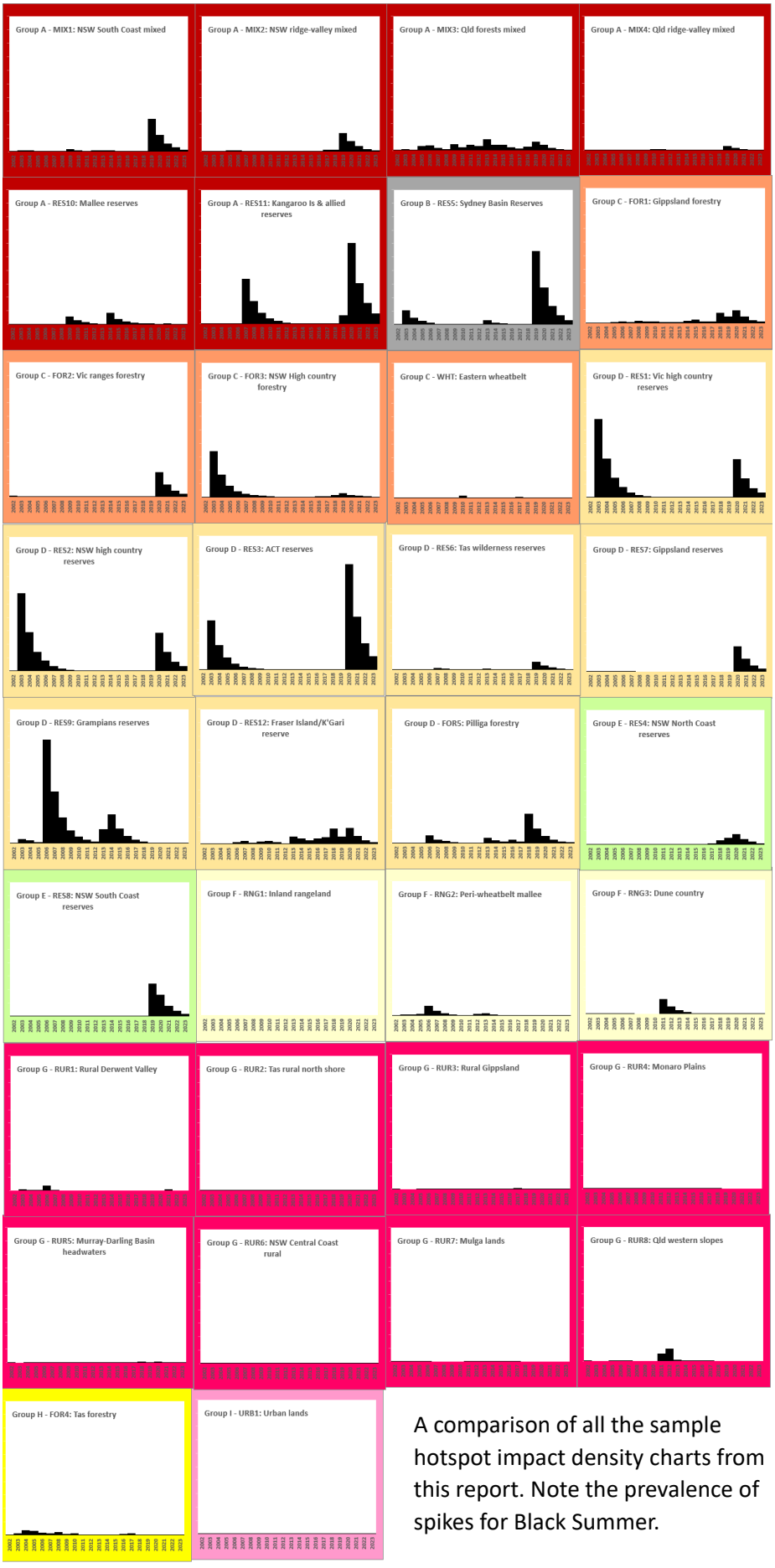


Figure 13. Fire regime regions in this report (green outlines) and IBRA bioregions (magenta outlines), showing the low level of correlation between the two sets.



A comparison of all the sample hotspot impact density charts from this report. Note the prevalence of spikes for Black Summer.

CAVEATS

The following must be considered when reading or using this report:

1. There are limits to what forms of fire are detected by MODIS imagery and its associated algorithms. Small fires are usually missed. Low intensity fires are often missed, especially if they fall on multiple image pixels. The cores of major Blow-Up Fire Events are often missed as there is little heat left when the satellite next overpass occurs. This “hotspot hole” is diagnostic of a severe blow-up event. The algorithm has filtered out other heat sources, and there can be mistakes.
2. This is a sub-continental-scale analysis and is not intended to provide information on smaller-scales. While it should guide smaller-scale analyses, there are no guarantees provided that this guidance will be reliable.
3. The data span two decades. However, the rate of climate change may quickly make the analyses based on that data inaccurate.
4. The MODIS satellites were designed for six-year missions. Both TERRA and AQUA have now passed two decades of operation. They are degrading and running out of fuel, and may soon be taken off-line. They are being replaced by a set of satellites carrying the VIIRS sensors. These typically produce between 11 and 14 times as many hotspots. It will be challenging to make the next decade’s data comparable with that of the previous two decades.
5. As this work is based only on two recent decades of data, it is difficult to discriminate information relevant to indigenous fire regimes. It is incorrect to infer any such link from this report. It is, however, hoped that this report initiates work on this topic.

ACKNOWLEDGEMENT

The MODIS data used in this analysis was retrieved from NASA’s FIRMS service:

https://firms.modaps.eosdis.nasa.gov/

We acknowledge the use of data from NASA's Fire Information for Resource Management System (FIRMS) (https://earthdata.nasa.gov/firms), part of NASA's Earth Observing System Data and Information System (EOSDIS).