Evaluating fuel and soil moisture indices as a guide to fuel availability in tall open forests

Lachlan McCaw[1] & Jennifer Hollis[2]

1. Department of Biodiversity, Conservation and Attractions, Manjimup Western Australia
2. Planning and Predictive Services, NSW Rural Fire Service, Queanbeyan New South Wales

Tall open forests:

vegetation structure & fuel characteristics

Eucalyptus diversicolor mature forest

Fuel unburnt >40 years

Partial fuel consumption

Topics

- Existing indices of fuel availability & ignition potential
- Evaluating performance of existing indices
  - fuel consumption in experimental fires
  - seasonal patterns
- Recent developments (JASMIN, AFMS)
- Where to next?

Factors accounted for in fuel availability models used operationally in WA

Model	Rainfall	Temperature	Relative humidity	Relative humidity
Surface (SMC)	wetting	daytime drying	daytime drying	o/night wetting
Profile (PMC)	wetting	daytime drying	daytime drying	-
Soil Dryness Index	wetting, minus canopy interception	daytime drying	-	-

Available Fuel Factor (AFF) represents a ratio of SMC and PMC; 0 (none) to 1 (complete) consumption

Experimental fire data – karri forest

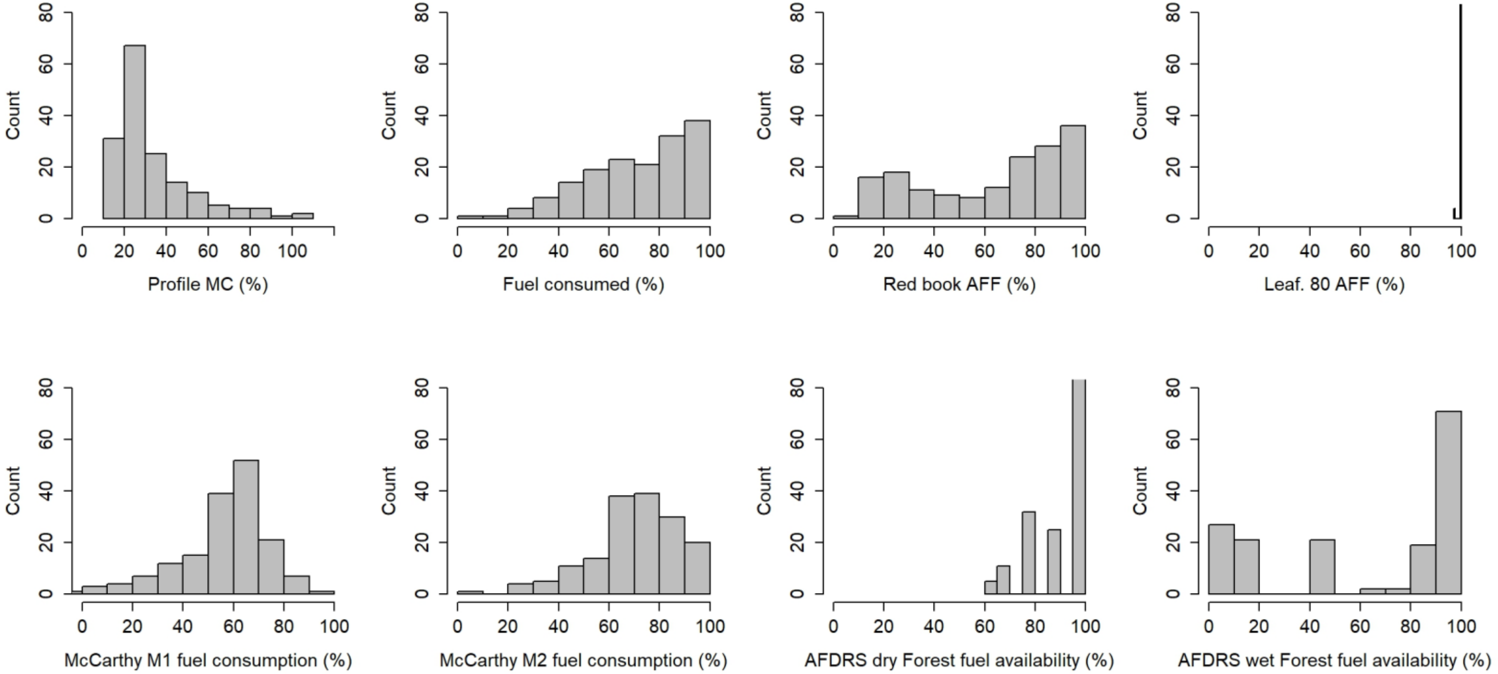
WA Forests Department - Rick Sneeuwjagt et al.

Experimental fire data – karri forest

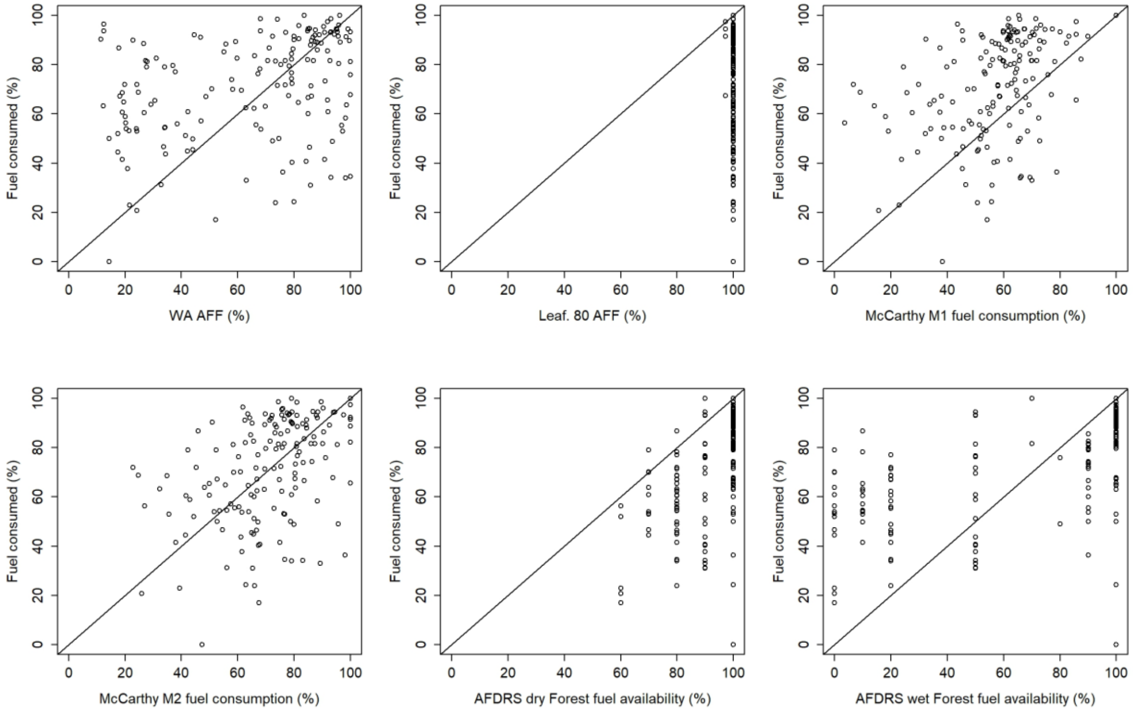
163 experimental fires October 1969-March 1970

Variable	Range	Average
Surface Moisture Content	9-28 %	16
Profile Moisture Content	13-109 %	34
Fine fuel load	7-24 t/ha	14
Wind speed	1-17 k/hr	8
Temperature	19-35 °C	25
Relative Humidity	28-79 %	56
KBDI	28-183	123
FFDI	1-15	5
Drought Factor	5.5-10	9.1
Rate of Spread	0-170 m/hr	30

Experimental data distribution: fuel availability indices



Performance of fuel availability indices



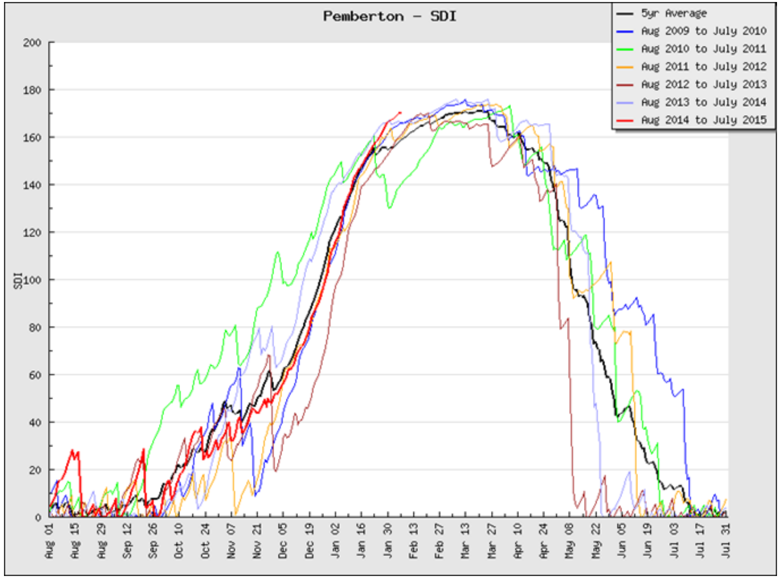
O’Sullivan bushfire

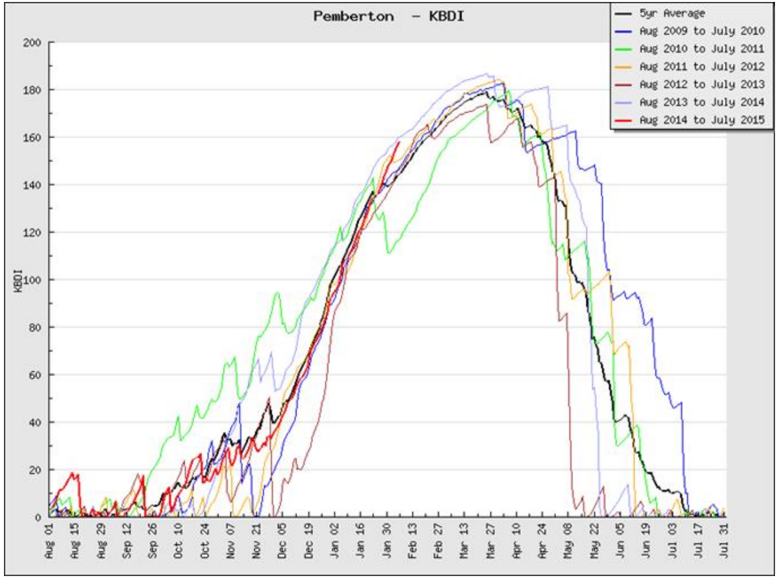
Active 30 Jan – 20 Feb 2015
98 600 ha burnt

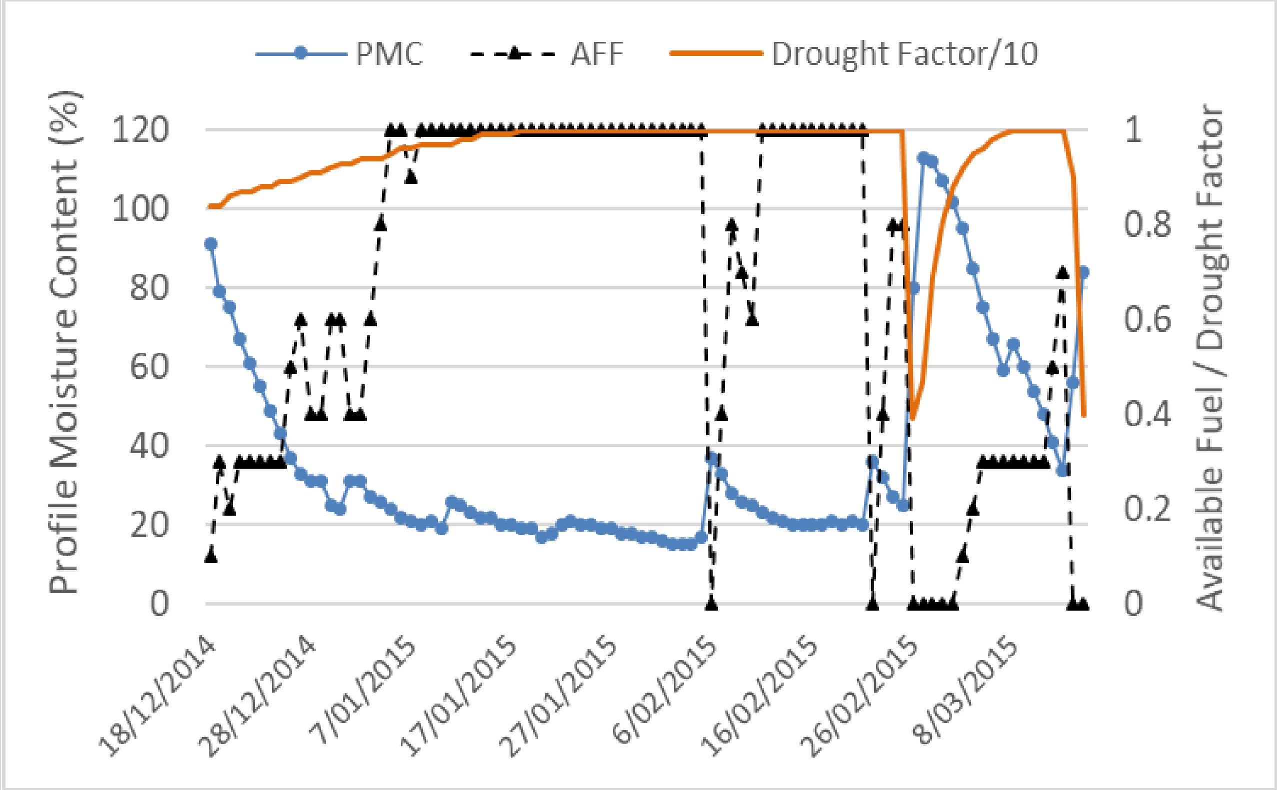
Light rain 3-6mm on 5 Feb played a transient but critical role in reducing fuel availability and fire spread

Seasonal patterns of SDI and KBDI at Pemberton

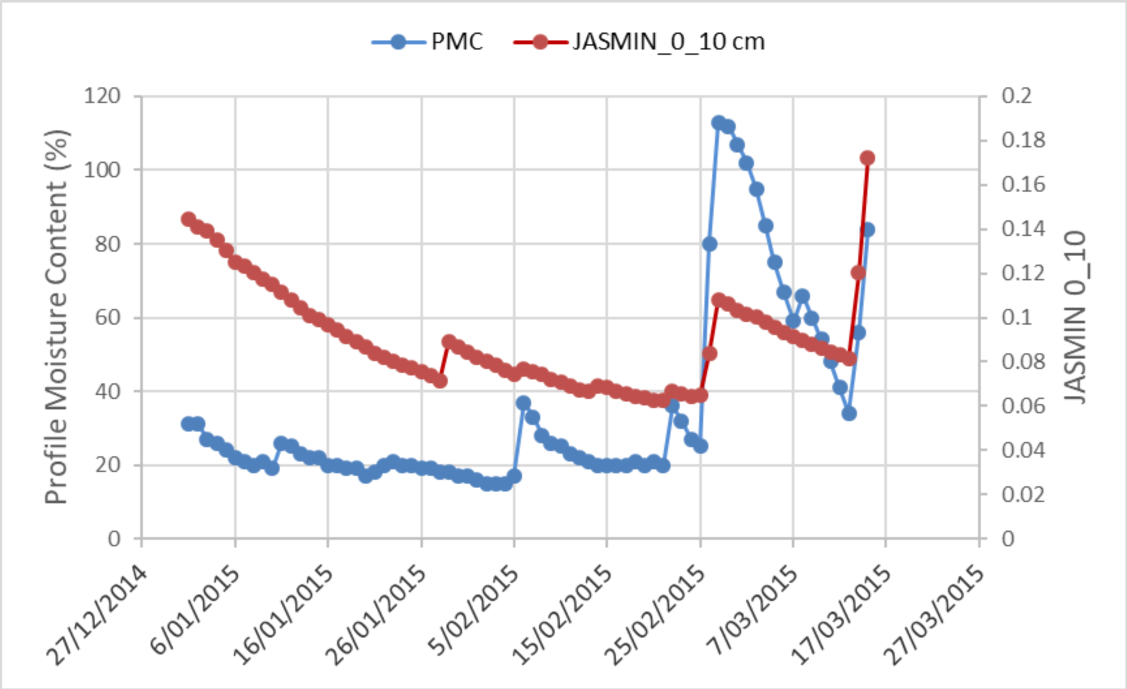
(-34.45, 116.04, 180 m asl)







Pattern of moisture and fuel availability Pemberton Jan-March 2015

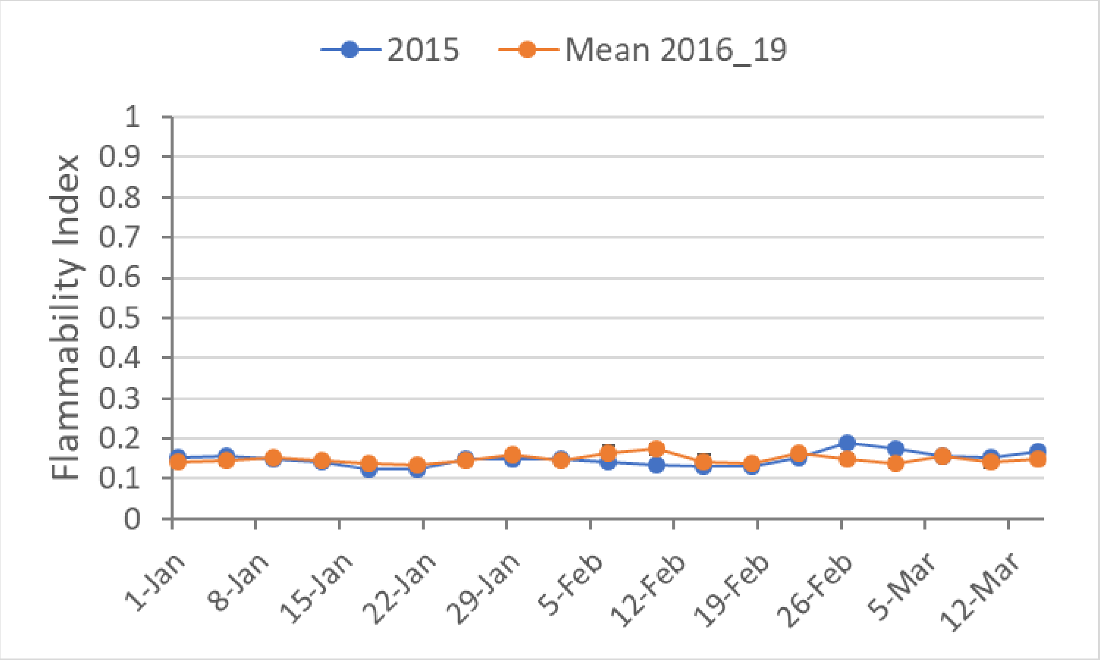


Comparison of PMC and JASMIN $_{0\_10cm}$ soil moisture

Pemberton Jan-March 2015

Australian Flammability Monitoring System

Flammability Index for tall open forest at Pemberton – Jan to March 2015-2019



Where to next?

- Tinkering with the Drought Factor won't capture important influences of summer rain and variation in forest structure and composition
- Potential to improve existing indices of fuel dryness (SMC, PMC) and availability to incorporate more factors (LAI, solar radiation) and a stronger physical basis
- Work towards a continental-scale model that can be paramaterised for local conditions using gridded input data derived from observational or model data
- Evaluate a 'shallower' version of JASMIN for near-surface soil layer?
- Meta-analysis of existing fuel moisture data sets for tall open forest?

International Association of Wildland Fire
6th Fuels and Fire Behaviour Conference
Sydney 29 April-3 May 2019

Fire Behaviour and Fire Behaviour Predictions stream

Evaluating fuel and soil moisture indices as a guide to fuel availability in tall open forests

Lachlan McCaw
Biodiversity and Conservation Science
Department of Biodiversity, Conservation and Attractions Western Australia
Manjimup WA 6258

Title slide

This presentation provides an overview of work done by Jennifer Hollis of the NSW Rural Fire Service as part of the Australian Fire Danger Rating project, and by myself over a number of years gathering data and observations during experiments and fire operations in tall open forests in south-west WA.

Our purpose today is to report on work in progress to understand fuel availability and fire behaviour in tall open forests and to suggest some approaches that may be constructive in advancing the ability to predict these factors reliably at timescales relevant to operational decision-making.

Jim Gould and Vijay Koul at CSIRO Land and Water Bushfire group have done a valuable service in collating significant historical bushfire behaviour data sets and we would like to acknowledge their contribution to this project.

Slide 2 – Context for tall open forests

Tall open forests can accumulate deep layers of dead organic material on the forest floor comprised of leaves, bark, woody stems and fallen branches. When dry, this layer becomes available to burn and can support fires that release very substantial amounts of heat and have a high resistance to extinguishment.

The dryness of the forest floor layer is important because it:

- Influences the likelihood of ignition and the rate of fire growth;
- Determines how much fuel will be consumed, and the resultant heat release.

The ability to predict fuel consumption informs decisions about how fire will affect vegetation and soil, atmospheric emissions, and burn security.

Rates of accumulation, and the equilibrium levels of surface fuel load reached in the absence of fire are influenced strongly by the structure and species composition of the forest overstorey and understorey vegetation, by climatic factors, and local site conditions.

Slide 3 – Topics

This presentation will focus on tall open forests of karri in the south-west of Western Australia but we expect that a number of the observations and principles will apply more broadly in comparable tall forests elsewhere in southern Australia.

The WA Forest Fire Behaviour Tables provide several indices to quantify the dryness of both shallow surface and deep fuel layers, and the proportion of the fuel bed available to burn. These indices were developed empirically from extensive field sampling in the late 1960s and early 1970s and have been used operationally since 1975. The are regarded as providing useful and robust guidance.

However, advances in analytical techniques and processing power now make it feasible to include a broader range of inputs than accounted for by the tables, and to produce gridded data layers rather than calculations based on point observations.

Our approach to date has focussed on evaluating performance of these and other relevant indices by:

- Comparison with fuel consumption data from experimental fires, and
- Examination of seasonal patterns

We also report on some initial work to evaluate outputs from recent work done through the Bushfire & Natural Hazards CRC on the JASMIN soil moisture system and the Australian Flammability Monitoring System.

Slide 4 – Fuel availability models used in WA

The Forest Fire Behaviour Tables provide indices of dryness for the

- upper layer of leaf litter 5-10 mm in thickness (Surface MC)
- entire litter bed above mineral soil (Profile MC) which may be 100-200 mm thick

The Available Fuel Factor represents the proportion of the litter bed available to burn and is derived as a ratio of SMC and PMC, ranging from zero (no consumption) to 1 (complete consumption expected).

The Mount Soil Dryness Index is used to indicate the dryness of very deep fuel beds and large coarse woody debris including ground logs.

Indices are calculated using simple weather variables with the SMC incorporating the most variables to account for diurnal moisture loss and uptake of atmospheric moisture overnight.

Calculations are performed using a simple book-keeping procedure.

Slide 5 – Fuel availability in experimental fires

Rick Sneeuwjagt and his research team with the WA Forests Department conducted a comprehensive experimental burning program in mature karri forest in the late 1960s to develop a capability for predicting fire behaviour and fuel consumption.

Experimental data still exist and are being collated into electronic form including scans of growth maps for individual fires by Jim and Vijay at CSIRO.

Experiments were done in forest 50-70 m tall with a dense shrub understorey, as shown in the slide, and throughout the season from October 1969 to March 1970.

Slide 6 – Range of experimental burning conditions

Burning conditions are summarised in the table and are typical for prescribed burning in karri forest which takes place in early summer and autumn.

The behaviour of one of the experimental fires is shown in the slide. Fires were typically circular in shape and relatively slow moving, dominated by internal convection generated by the heavy fuels.

Slide 7 – Distribution of experimental data

Charts show the distribution of experimental data for:

- measured PMC, skewed to 20-40% range ie. dry end
- fuel consumption, skewed to >60% consumption
- Available Fuel Factor, broadly matching the pattern of consumption

Also shown are a number of other measures of fuel availability and consumption including:

- Leaflet 80 available fuel factor for dry forest

- Two models derived by Greg McCarthy from experimental fires in Victoria that include measures of fuel dryness and fire behaviour
- Fuel availability indices developed for the Australian Fire Danger Rating System prototype for both dry and wet forests

Slide 8 – Performance of fuel availability measures

Fuel consumption data show a considerable scatter against all of the fuel availability measures with the central tendency along the 1:1 line being strongest for the WA Available Fuel Factor and the McCarthy model that includes moisture content, flame height and slope.

The central tendency of the WA Available Fuel Factor is not surprising given that it originated, at least partially, in the same set of field data.

Measures developed for dry forest are clearly biased and predict a much greater consumption of fuel than was observed.

The Australian Fire Danger Rating System fuel availability measure for wet forest appears to be insensitive with a tendency to predict lower fuel consumption than was observed.

Errors statistics for the models are:

WA AFF: MAE = 22.7%; MBE= -6.6 %

McCarthy M1: MAE = 21.3%; MBE= -14.1 %

McCarthy M2: MAE = 16.2%; MBE= 0.16%

AFDRS dry: MAE = 20.1%; MBE= 20.4 %

AFDRS wet: MAE = 25.2%; MBE= -5.01 %

Slide 9 – Seasonal patterns of dryness and availability

Seasonal patterns of fuel dryness and availability also provide insight into the robustness and utility of different indices. We use the 2015 season to illustrate this for several reasons including (1) availability of data allows for comparison of different indices and (2) this season saw the largest single fire event affecting tall open forest in WA for at least five decades with the O'Sullivan bushfire burning 98 000 ha.

Importantly, a light rainfall event across the fireground on 5 February played a transient but critical role in assisting containment of the fire.

Slide 10 – Seasonal pattern of SDI and KBDI

Charts show the seasonal trend in Soil Dryness Index and Keetch Byram Drought Index for Pemberton for six seasons including the first half of the 2014/15 season (in red). The mean of the five previous seasons is shown by the black line.

Points to note include:

- The consistency of the summer dry period across all years
- Peak values for both SDI and KBDI above 160 mm
- Nothing remarkable about the build up to 2014/15 season other than a slight tendency to drier than normal in late January 2015

Slide 11 – Pattern of profile moisture and fuel availability Jan-March 2015

This slide is a bit daunting but stay with me!

Data series presented for mid December 2014 to mid March 2015:

- Calculated Profile Moisture Content (blue) and Available Fuel Factor (black) from the WA tables

- McArthur Drought Factor as calculated for Pemberton by BoM (brown) – divided by 10 to show on the same scale as AFF

Points to note are:

- Steady fall in PMC during December accompanied by an increase in Available Fuel Factor
- Effect of minor rainfall events in early Jan 2015 reflected in oscillations in the AFF, and a more significant temporary fall in AFF caused by rain in early Feb. This event was enough to stop running fire for a day or two
- Drought Factor is already at 8 in mid December and remains at peak value of 10 throughout summer until a more substantial rainfall event at the end of February. Drought Factor does not clearly distinguish the effect of the rain in early February.

Slide 12 – Comparison of PMC and Jasmin

Soil moisture content modelled by JASMIN for the 0-10 cm depth layer is compared with predicted PMC at Pemberton. Overall, the trend is similar for both indices although JASMIN shows a rise in later January that is not apparent in the PMC and the effect of the rainfall on 5 February 2015 is more muted in JASMIN than in the PMC.

Slide 13 – Australian Flammability Monitoring System

Live fuel moisture content derived from satellite imagery and the linked Flammability Index from the Australian Flammability Monitoring System are illustrated for a representative location in tall open forest near Pemberton. The chart shows the trend in Flammability Index for January to March 2015 compared to the mean for the corresponding period in years 2016-2019 inclusive. Overall, the Flammability Index has a low value and no discernable trend over the summer period. This result in perhaps not surprising given the dense overstorey canopy and mid-storey layer in karri forest, both of which obscure the understorey and surface fuel layer.

Further work is required to test this finding more broadly and to examine variation across burn units that contain a mixture of vegetation and fuel types.

Slide 14 – Where to from here?

Tinkering with the Drought Factor won't capture important influences of summer rain and variation in forest structure and composition

Potential exists to improve existing indices of fuel dryness (SMC, PMC) and availability to incorporate more factors (LAI, solar radiation) and a stronger physical basis

Work towards a continental-scale model that can be paramaterised for local conditions using gridded input data derived from observational or model data

A 'shallower' version of JASMIN that represents the moisture dynamics of near-surface soil layer and deep litter profile could be evaluated.

Meta-analysis of existing fuel moisture data sets for tall open forest to explore common features and provide a stronger base for future models.