A Guide to Estimating Fire Rate of Spread In Spinifex Grasslands of Western Australia (Mk2v2)

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User Notes

This version includes additional data from recent experimental and operational fires. The model applies to spinifex-dominated grasslands of Western Australia that are:

- 6-25 years old
- Fuel load 3.5 -16 t/ha; fuel cover 20-70%; spinifex clump height 20-50 cm
- Spinifex clump profile moisture content 10-35%
- Winds @ eye level < 40 km/h (~<48 km/h @ 10 m)

The model below explained about 78% of the variation in rate of spread of 158 mostly small (0.5 - 2 ha) experimental *line fires* (50-100 m long) in the Great Sandy, Gibson and Great Victoria Deserts conducted over the period 1988 - 2015 (see Appendix). Data from four fires from the Mt Isa area (Qld) were kindly provided by Dr Paul Williams. Of these fires, 100 spread and 58 did not spread. Being an empirical model, it will be less reliable outside the range of experimental conditions (above). A Mk3 model is currently being developed but will not be ready for operational use until 2016.

The model does not incorporate spotting, which is not usually a feature of spinifex fires except where eucalypts/ mallees or other tree species are present. In this situation, spinifex fires have been observed to spot ~200 m or so, but may be capable of spotting further under extreme conditions.

Direct measurement of model inputs is best but is not always feasible, hence indirect measures are included and should be treated as a guide. Weather observations can be made using a Kestrel 4000-4500 series set at eye level.

The use of the Australian Water Availability Project data (http://www.csiro.au/awap/) for off-site estimation of the profile moisture content of live spinifex clumps has had limited testing, but shows promise. Remote sensing (satellite imagery) to estimate 'curing' and cover is also being investigated.

There is a great diversity of structures of spinifex grasslands across central WA, so not all will fit neatly into one of the five fuel classes shown below. Spinifex develops at different rates depending on the species, time since fire and local site conditions (soil, topography, rainfall). If you can't directly measure the fuel variables (preferable), choose the fuel class (below) that most closely resembles your situation.

As reflected in the model equation below, after peaking at 20-25 years, on some sites, fuel quantity and cover may decline in older spinifex.

Spinifex grasslands form a discontinuous fuel, so there are three critical thresholds to fire spread; wind speed, fuel moisture content and fuel cover. Therefore, predicting rate of spread is a 2-step process—the first step is to determine whether the spread thresholds are exceeded (SI>0). The second step is to calculate rate of spread and flame height.

Step 1: Will fire spread?

$$SI = 0.31(U) + 0.26(COV) - 0.57(PMC) - 3.23$$

Where:
SI = spread index.
U = wind speed (km/h) @ eye level. Open 10 m wind speed is approximately 1.2 x wind speed at eye level.
COV = live and dead spinifex fuel cover (%) (see below)
PMC = clump profile moisture content (%) (see below)

If SI < 0, then the fire is *unlikely* to spread; the more negative the SI, the less likely is fire spread. A test fire may be warranted. If the SI > 0, then the fire is *likely* to spread ; the more positive the SI, the more likely is fire spread. Go to the next step and calculate the likely Rate of Spread.

Likelihood of fire spread and potential ROS (m/h)

SI < -2	Very low - fire highly unlikely to spread (ROS = 0)
-2 < SI < 0	Low – fire could spread (ROS < 500)
0 < SI < 2	Moderate – fire should spread (ROS: 500 –1000)
2 < SI < 4	High – fire will spread (ROS: 1000 – 1500)
4 < SI < 6	Very High – fire will spread (ROS: 1500 – 2000)
6 < SI < 10	Extreme – fire will spread (ROS: 2000 – 3000)
SI > 10	Very Extreme – fire will spread (ROS > 3000)

Step 2: If SI > 0, calculate Rate of Spread and Flame Height

ROS = 137(U) + 44(FL) + 24(COV) – 207(PMC) + 1500; (see Appendix)

FH = (0.15 x ROS $^{0.39}$) + 0.49; (see Appendix)
Where:
ROS = head fire rate of spread (m/h)
FH = head fire flame height (m)
FL = fuel load (t/ha oven dry)
COV = live and dead spinifex fuel cover (%)
PMC = clump profile moisture content (%)

Slope Correction:
$ROS_{sl} = ROS * e^{0.068S}$
(Follows McArthur's rule – ROS doubles for every 10 degree increase in slope.)
Where:
ROS = rate of spread (m/h) on level ground
S = positive slope (degrees)
ROS_{sl} = rate of spread (m/h) corrected for positive slope

1. Estimating fuel load (FL; t/ha)
1A: Directly by destructive sampling (preferred). At least five 1 m x 1 m quadrats.
1B: Estimated indirectly from fuel age.
Fuel quantity (t/ha) = 1.21(fuel age yrs) X $(e^{-0.041 X fuel\ age})$
Note: This assumes average rainfall over the period.
1C: Estimated indirectly from fuel structure class (see below). Also assumes average rainfall.

2. Estimating fuel cover (%)
This is the projected ground cover of live and dead spinifex. Dead spinifex is the black spinifex in the middle of the clump or the 'mat' behind the growing front of older spinifex meadows. Fuel cover can be estimated by:
2A: Using a 50 –100 m tape and recording live/dead spinifex intercepts at 1 m intervals (preferred).
2B: 'Stepping' (% of 100 steps on or off live/dead spinifex, bare ground).
2C: Visually (not reliable).

3. Estimating the moisture content of spinifex clumps (Profile Moisture Content- PMC)
This is the moisture content of the whole clump including live and dead material. Take a profiler sample through the clump.
3A: Direct measurement (preferred) using a calibrated Wiltronics Fuel Moisture Meter, or by oven drying. Take at least five samples through the profile of from separate but representative clumps.
3B: Indirectly from clump colour (rough guide only —see examples next page).
3C: Indirectly from relative soil moisture (under evaluation, rough guide only —see below).

Class 2 spinifex fuel (6-10 years old):
PMC (%) = 40.4($AWAP_{UF}$*) + 18.5 (*$\sqrt{}$*(RH/20))*
Class 3 spinifex fuel (11-15 years old):
PMC (%) = 40.4($AWAP_{UF}$*) + 14.5 (*$\sqrt{}$*(RH/20))*
Class 4 spinifex fuel (16-20 years old):
PMC (%) = 40.4($AWAP_{UF}$*) + 10.5 (*$\sqrt{}$*(RH/20))*
Class 5 spinifex fuel (20-25 years old):
PMC (%) = 40.4($AWAP_{UF}$*) + 6.5 (*$\sqrt{}$*(RH/20))*

Where:
PMC = Clump profile moisture content (%)
RH = relative humidity (%)
$AWAP_{UF}$ = Australian Water Availability Project http://www.csiro.au/awap/
Use relevant "Monthly Relative Soil Moisture (Upper Layer) Fraction" value from map (website above)

Field Guide to Spinifex Clump Profile Fuel Moisture Content for a Class 2 (standard) fuel (<5% dead leaves)

1. Leaves bright green with few / no yellow leaves: Class 2 PMC ~30-40%

2. Leaves pale green with some yellow leaves: Class 2 PMC ~20-30%

3. Leaves yellow-green with many yellow leaves: Class 2 PMC ~15-20%

4. Leaves yellow / straw, no green leaves. Class 2 PMC ~10-15%

PMC correction for older fuels with a higher proportion of dead leaves and stems

Class 3 PMC = Class 2 PMC - (1/(0.03 x RH)) x 1.5;
Class 4 PMC = Class 2 PMC - (1/(0.03 x RH)) x 2.5;
Class 5 PMC = Class 2 PMC - (1/(0.03 x RH)) x 3.5;
Use Class 2 PMC mid-point

Example 1:
Step 1: The colour of live spinifex clumps is yellow-green (3 above), so PMC for a standard Class 2 fuel is ~15-20%.
Step 2: Measure RH = 18%.
Step 2: Now correct for the actual fuel class to be burnt— e.g., Class 3 fuel is to be burnt, so PMC correction using the class midpoint (15-20 = 17.5) is:
Class 3 PMC = 17.5 - (1/(0.03 x 18)) x 1.5
Class 3 PMC = 17.5 - (1.9 x 1.5) = 14.7%.
Example 2:
Step 1: The colour of live spinifex clumps is pale green with some yellow leaves (2. above).
Step 2: RH = 12%
Step 3: Therefore, standard Class 2 PMC is 20-30% - use midpoint = 25%
Step 4: Now correct for actual fuel class to be burnt, - e.g., Class 5 fuel is to be burnt, so PMC correction is:
Class 5 PMC = 25- (1/(0.03 x 12)) x 3.5;
Class 5 PMC = 25- (2.8 x 3.5) = 15.3%

Heading

Fuel Class 1 (<6 years old)

Spinifex seedlings mostly <15 cm tall and <15 cm wide. Plants are discrete, mostly separated. No dead leaves or stolons in centre of plant. Some residual stolons from pre-fire plants and some fresh charcoal evident on woody material. No flower or stalks on spinifex. Epicormic shoots may be evident on trees and shrubs. Soft grasses and herbs may be abundant.

Cover spinifex live(%)	Cover spinifex dead (%)	Cover Other (%)	Cover fuel total (%)	Bare ground (%)	Spinifex ht (cm)	Fuel load (t/ha)
15-20	0	15-25	20-40	60-80%	<15	<3.5

Rate of Spread (m/h)

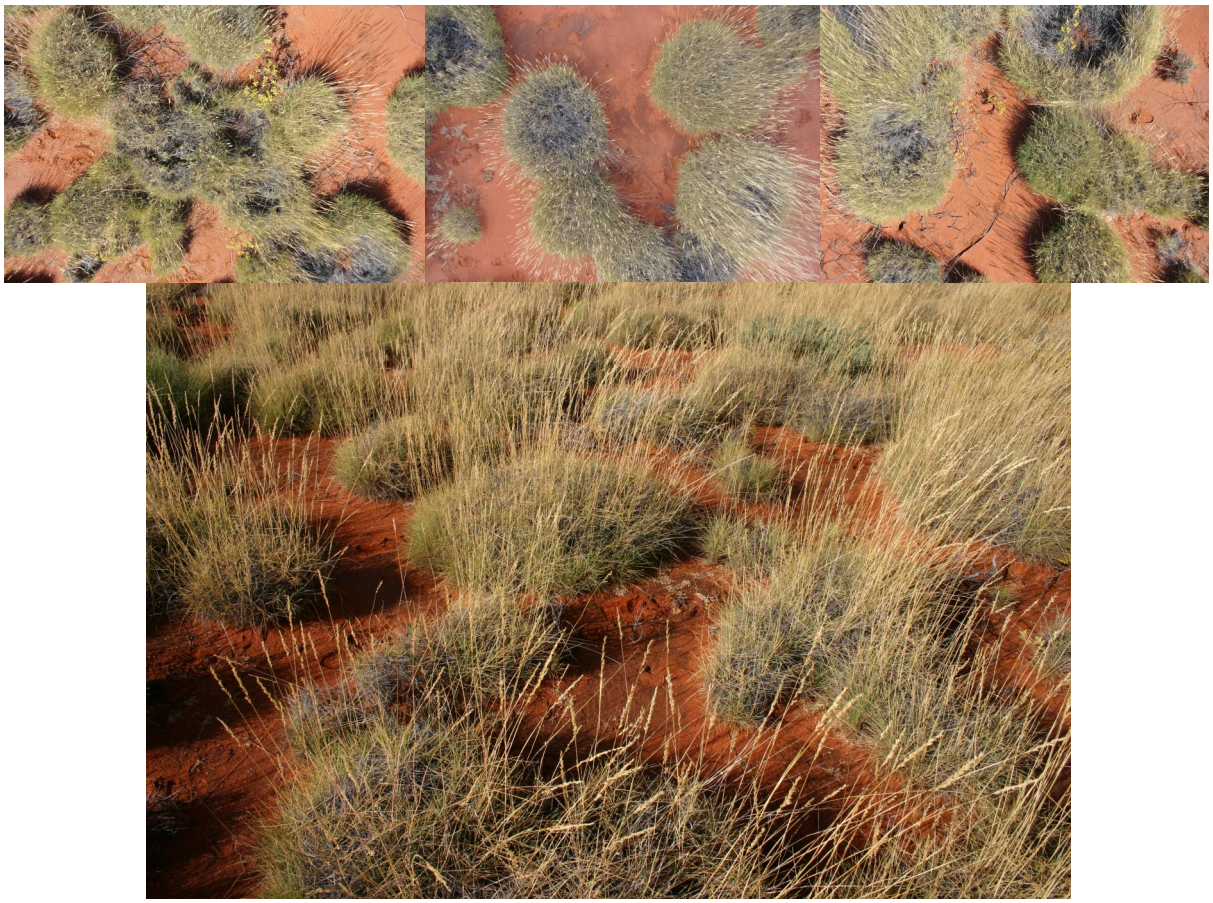
Fire is unlikely to spread in this fuel class unless there is a continuous (>70%) cover of cured soft grass and/or herbs, which can occur on some sites, especially following exceptional rainfall. In this situation, the Grass Fire Model applies.

Fuel Class 2 (6-10 years old)

Mostly discrete, compact hummocks, some joined. No or few dead (black/grey) leaves or stems evident in hummocks. Spinifex flower/stalks present. Most plants 20-30 cm tall and 20-30 cm wide.

Cover spinifex live(%)	Cover spinifex dead(%)	Cover Other (%)	Cover fuel total (%)	Bare ground (%)	Spinifex ht (cm)	Fuel load (t/ha)
30-40	<5	5-10	40-50	50-60	**Hi**: 25-30 **Lo**: 20-25	6.5 4.5

	Wind speed eye level (km/h) Rate of Spread (m/h) (~flame height m)							
PMC (%)	**>8** **Threshold**	**10**	**15**	**20**	**25**	**30**	**35**	**<40**
35 Hi **Lo**	0 0	0 0	0 0	0 0	0 0	0 0	300 1.4 0	1101 2.6 1013
30 Hi **Lo**	0 0	0 0	0 0	0 0	300 1.4 0	766 2.3 678	1451 3.0 1363	2136 3.3 2048
25 Hi **Lo**	0 0	0 0	0 0	431 1.8 0	1116 2.6 1028	1801 3.1 1713	2486 3.4 2398	3171 3.7 3083
20 Hi **Lo**	0 0	300 1.5 0	780 2.4 698	1466 3.0 1378	2151 3.3 2063	2836 3.6 2748	3521 4.0 3433	4206 4.3 4118
15 Hi **Lo**	446 1.8 350	1131 2.7 1040	1816 3.1 1728	2501 3.4 2413	3186 3.7 3018	3871 4.2 3783	4556 4.4 4468	5241 4.6 5153
10 Hi **Lo**	1481 3.0 1390	2166 3.3 2072	2851 3.6 2070	3536 4.0 3448	4221 4.3 4133	4906 4.6 4818	5591 4.7 5503	6270 5.0 6188



Fuel Class 3 (11-15 years old)

Plants are roughly circular, dome-shaped clumps 20-35 cm high, 20-50 cm wide. Many discrete, but many are joined. Most have dead (black/grey) leaves and stems forming in the centre of the hummock and in the growing front. Spinifex flower/stalks present.

Cover spinifex live(%)	Cover spinifex dead(%)	Cover Other (%)	Cover fuel total (%)	Bare ground (%)	Spinifex ht (cm)	Fuel load (t/ha)
35-45	5-10	3-6	45-55	45-55	**Hi**: 30-35 **Lo**: 25-30	8.5 6.5

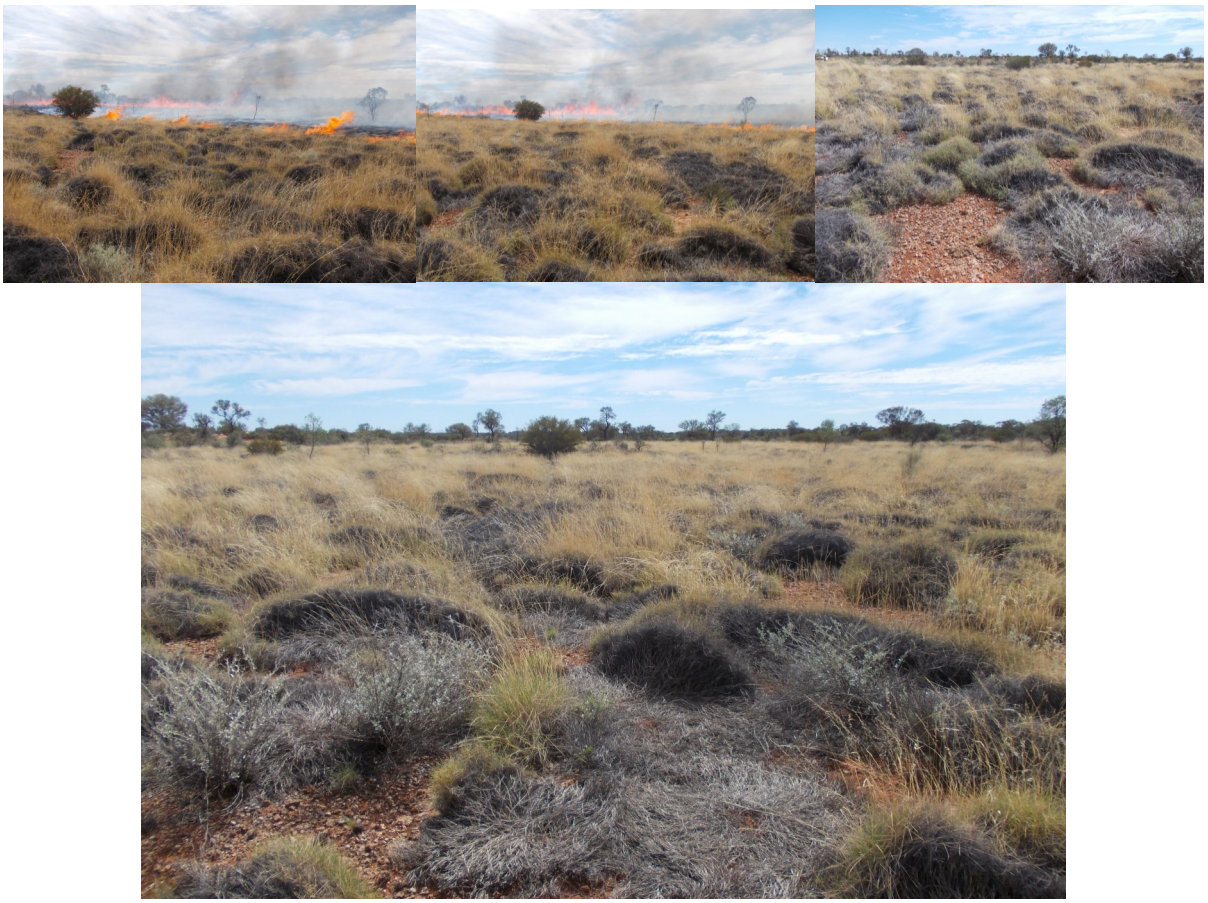
	Wind speed eye level (km/h) Rate of Spread (m/h) (~flame height m)							
PMC (%)	**>7** **Threshold**	**10**	**15**	**20**	**25**	**30**	**35**	**<40**
35 Hi	0	0	0	0	0	0	625 2.0	1309 2.6
Lo	0	0	0	0	0	0	536	1221
30 Hi	0	0	0	0	289 1.3	974 2.5	1658 3.1	2344 3.4
Lo	0	0	0	0	0	886	1571	2256
25 Hi	0	0	0	639 2.0	1325 2.6	2009 3.3	2694 3.6	3379 4.0
Lo	0	0	0	551	1236	1921	2606	3291
20 Hi	0	304 1.5	989 2.5	1674 3.1	2359 3.4	3044 3.7	3729 4.1	4414 4.5
Lo	0	216	901	1586	2271	2916	3641	4326
15 Hi	645 2.0	1339 2.6	2024 3.3	2709 3.6	3394 4.0	4079 4.3	4764 4.5	5494 4.6
Lo	566	1251	1936	2621	3306	3991	4676	5361
10 Hi	1689 3.1	2374 3.4	3059 3.7	3744 4.1	4429 4.5	5114 4.6	5799 4.8	6484 5.2
Lo	1601	2286	2971	3656	4341	5026	5711	6396

Fuel Class 4 (16-20 years old)

Oldest plants have formed 'donuts' up to 3 m diameter with bare ground or sparse dead stems in the centre and usually a band of dead stems behind the live front. Sometimes the growing front is fragmented. These meadows can be mixed age, with some younger plants.

Cover spinifex live(%)	Cover spinifex dead(%)	Cover Other (%)	Cover fuel total (%)	Bare ground (%)	Spinifex ht (cm)	Fuel load (t/ha)
40-50	10-15	5-8	50-60	40-50	**Hi**: 35-40 **Lo**: 25-35	10.5 8.5

	Wind speed eye level (km/h) **Rate of Spread (m/h) (~flame height m)**							
PMC (%)	**>6** **Threshold**	**10**	**15**	**20**	**25**	**30**	**35**	**<40**
35 Hi	0	0	0	0	0	0	832 2.5	1517 3.0
Lo	0	0	0	0	0	0	794	1429
30 Hi	0	0	0	0	497 2.0	1182 2.6	1867 3.1	2552 3.5
Lo	0	0	0	0	409	1094	1779	2464
25 Hi	0	0	162 1.0	847 2.5	1532 3.0	2217 3.4	2902 3.7	3587 4.1
Lo	0	0	0	759	1444	2129	2814	3499
20 Hi	0	512 2.0	1197 2.6	1882 3.1	2567 3.5	3252 3.9	3937 4.2	4622 4.5
Lo	0	424	1109	1794	2479	3164	3849	4534
15 Hi	862 2.5	1547 3.0	2232 3.4	2917 3.7	3602 4.1	4287 4.3	4972 4.6	5657 4.8
Lo	774	1459	2144	2829	3514	4199	4884	5569
10 Hi	1897 3.2	2582 3.5	3267 3.9	3952 4.2	4637 4.5	5322 4.6	6007 5.0	6692 5.2
Lo	1809	2494	3179	3864	4549	5234	5919	6604



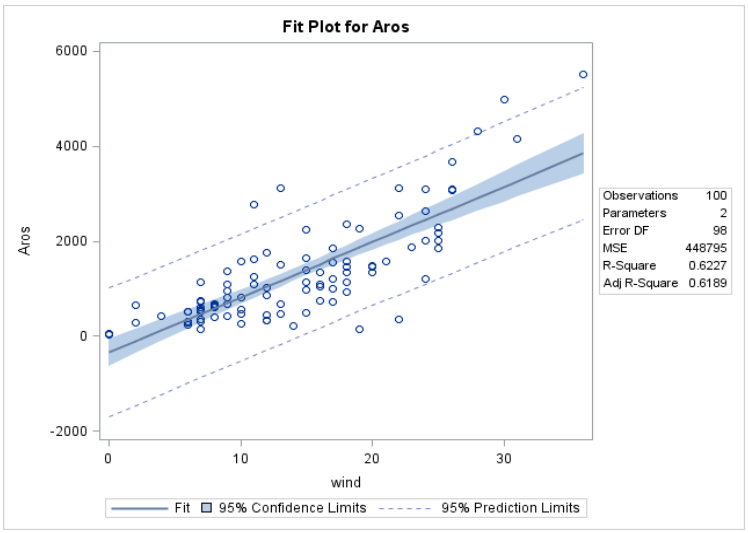
Fuel Class 5 (20-25 years old—productive sites)

Oldest plants have formed 'donuts' and semi-circles up to 3 m diameter with a dense mat of dead (black) leaves and stems behind the growing front. There are similar proportions of live and dead material. Sometimes the growing front is fragmented. These meadows can be mixed age, with some younger plants.

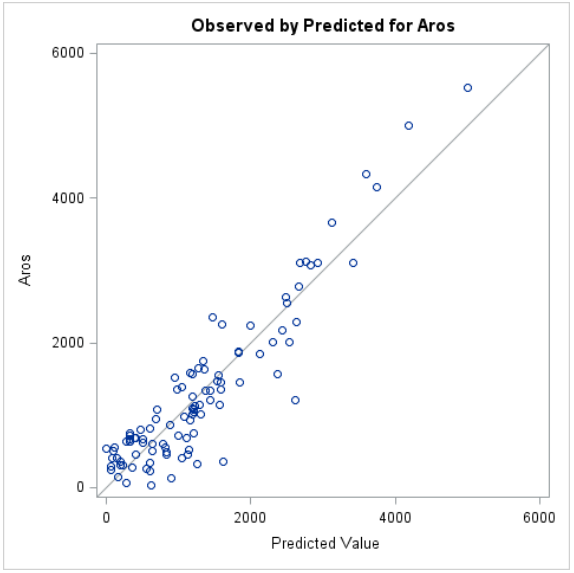
Cover spini-fex live(%)	Cover spinifex dead(%)	Cover Other (%)	Cover fuel total (%)	Bare ground (%)	Spinifex ht (cm)	Fuel load (t/ha)
30-40	30-40	<5	60-70	30-40	**Hi**: 40-45 **Lo**: 35-40	16.5 14.5

	Wind speed eye level (km/h) Rate of Spread (m/h) (~flame height m)							
PMC (%)	**>5**	**10**	**15**	**20**	**25**	**30**	**35**	**<40**
35 Hi	0	0	0	0	0	651 2.0	1336 2.5	2021 3.3
Lo	0	0	0	0	0	563	1248	1933
30 Hi	0	0	0	316 1.5	1001 2.6	1686 3.1	2371 3.4	3056 3.7
Lo	0	0	0	228	913	1598	2283	2968
25 Hi	0	420 1.8	666 2.0	1352 2.5	2036 3.3	2721 3.6	3406 4.0	4091 4.3
Lo	0	0	578	1263	1948	2633	3318	4033
20 Hi	330 1.5	1016 2.6	1701 3.1	2386 3.4	3071 3.7	3756 4.1	4441 4.5	5126 4.6
Lo	240	928	1613	2298	2983	3668	4353	5038
15 Hi	1366 2.5	2051 3.3	2736 3.6	3421 4.0	4106 4.3	4791 4.5	5476 4.6	6161 5.0
Lo	1278	1963	2648	3333	4018	4703	5388	6073
10 Hi	2401 3.4	3086 3.7	3771 4.1	4456 4.5	5141 4.6	5826 4.8	6511 5.2	7196 5.6
Lo	2313	2998	3683	4368	5053	5738	6423	7108

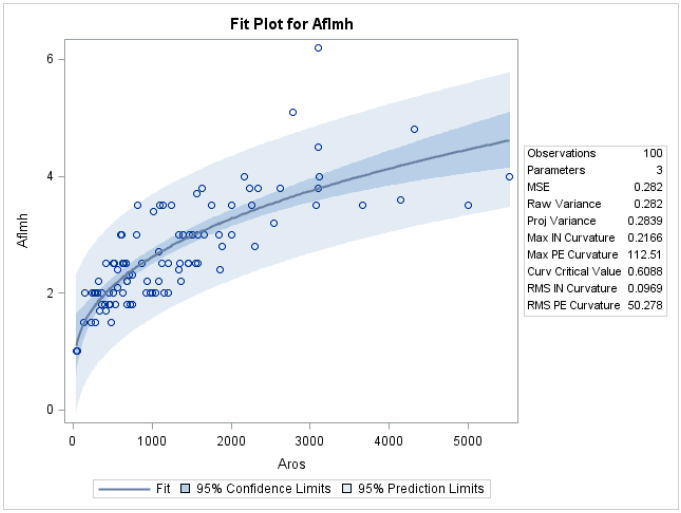
Appendix: Model fit scatterplots



Rate of spread (Aros -m/h) with wind speed (km/h) only



Actual ROS (Aros) with predicted ROS using wind speed, PMC, fuel load and fuel cover



Flame height (Afmh-m) with rate of spread (Aros-m/h)