A methodology for State-wide mapping of annual fuel load and bushfire hazard in Queensland

Glenn Newnham, Kimberley Opie, Justin Leonard

CSIRO Land and Water

A report to the Queensland Fire and Emergency Services

June 2017

EP175130

CSIRO Land and Water

Citation

Newnham, Glenn; Opie, Kimberley; Leonard, Justin; A methodology for State-wide mapping annual fuel load and bushfire hazard in Queensland: CSIRO 2017, csiro: EP175130

Copyright and disclaimer

Important disclaimer

Executive Summary

This document describes a method for mapping Annual Fuel Load (AFL) and Annual Bushfire Hazard (ABH) for Queensland. This approach builds on methods implemented for mapping Bushfire Prone Areas (BPA) including Potential Bushfire Hazard (PBH), in support of Queensland's State Planning Policy (Department of State Development, Infrastructure and Planning, 2014) to guide planning and development in bushfire prone areas (Leonard *et. al.* 2014).

AFL and ABH mapping are inputs to the preparation of bushfire mitigation plans and bushfire risk plans prepared by Government and various fire management organisations. The mapping has further potential for use in other initiatives such as community warnings, prioritising of planned burns, fire behaviour modelling and resource allocation projects.

AFL and ABH models modify estimates of Potential Fuel Load (PFL) and PBH by reducing fuel loads based on an assumed consumption of fuel from mapped wildfires or planned burns over 27 years (1987-2014), and by taking into account the time since the burn and the return of fuel load to its full potential.

While these models can be applied once each year to reflect the accumulated reduction of fuel from all identified fires, it is technically feasible to also apply these models at more frequent intervals if needed. As a starting point for further testing and validation of model outputs, there would be benefit in apply models in January each year at the end of the wildfire season and hazard mitigation season, in preparation for the planning of future activities.

The calculation of AFL and ABH in these models incorporates two major mechanisms to adjust PFL and PBH. These are the inclusion of mapped information on the extent of fire events that reduce fuel and the subsequent fuel accumulation to account for the gradual return of fuel load to an assumed steady state over time.

Reduction of fuel could occur given a number of natural or anthropogenic disturbance events. These can include grazing, pests and disease outbreaks, severe weather events or the harvesting of timber and crops. Significant disturbances that result in permanent or semi-permanent land use change events, such as land clearing for development, are captured in updates of Vegetation Hazard Class (VHC) mapping performed by the Queensland Fire and Emergency Services.

Reliable data on the timing and extent of planned burns and wildfire events is readily available through the Queensland Government Remote Sensing Centre using the method described by Goodwin and Collett (2014). Similar data is also maintained by land management organisations such as the Queensland Parks and Wildlife Service. It is important to recognise that remotely sensed sources of fire scar mapping provide an incomplete record of fire history (burnt areas) which do not effectively detect mild burning under canopy, or small scale fires.

The proportion of fuel removed by a fire event is assumed to be primarily dependant on the severity of the event. Because of the paucity of information on fire severity, long term Forest Fire Danger Indices data was used to model monthly fire severity using the associated Fire Danger Rating. The monthly temporal resolution of fire severity was chosen to match the resolution of the fire scar data.

The model assumes that the fuel accumulation after a fire event follows the model described by the Olson (1963) of the form:

$$x = x_{ss}(1 - e^{-k(t+t_x)})$$

where x_{ss} is the steady state fuel load, k is the decomposition rate and x is the total fuel load at time t, where t is adjusted by t_x to account for the fuel remaining after a disturbance.

Olson's fuel accumulation model assumes that fuel will asymptote to a maximum, to a steady state fuel load (x_{ss}), which is equated to the potential, or 80th percentile fuel load (see Leonard*et. al*, 2014) for any given VHC. Although the VHC steady state fuel loads are currently defined as the 80th percentile of their potential this process allows for alternative VHC steady state fuel load definitions.

Estimation of an annual fuel load therefore requires estimation of a value for *k* for each vegetation structure type in the VHC. Values for *k* have been determined through a review of experimental data documented in scientific literature. This review also identifies the time period observed for fuel load to recover to a percentage of the stead state fuel load (x_{ss}). The model incorporates a simple method for calculating *k* based on data from reviewed literature.

Fire weather parameters from Leonard *et. al.* (2014) are based on gridded historical records of precipitation, temperature, relative humidity and wind speeds without adjustment for climate change. This data is incorporated into the estimation of AFL and ABH based on an assumed exceedance probability for the historical observation of fire weather.

The modelling method developed from this study provides a framework for implementation of AFL and ABH mapping in Queensland. This framework allows for further improvements such as refined specification of fire events or other disturbance events, and parameters used to describe fuel accumulation models. These and other expert assumptions included in this model and can be improved in consultation with stakeholders and end-user organisations based on the assessments of model outputs.

Acknowledgements

This project has been funded by the Attorney-General's Department and the Queensland Government through the Natural Bushfire Mitigation Program (NBMP). This report has been compiled with assistance from Robert Preston (Queensland Fire and Emergency Services); Peter Leeson and Mark Parsons (Queensland Parks and Wildlife Service); John Neldner (Queensland Herbarium); and Andrew Sturgess (Queensland Fire and Emergency Services).

Contents

1 Introduction

The following document describes a methodology for mapping of Annual Fuel Load (AFL) and Annual Bushfire Hazard (ABH) that can be applied to Bushfire Prone Areas in Queensland. This approach adapts and builds on the methodology and tools developed for mapping Potential Bushfire Hazard (PBH) and Bushfire Prone Areas Leonard *et. al* (2014), developed to assist implementation of Queensland's State Planning Policy (Department of State Development, Infrastructure and Planning 2014), which guides planning and development in bushfire prone areas.

AFL and ABH mapping are useful inputs to the preparation of bushfire mitigation plans and bushfire risk plans prepared by Government and various fire management organisations. The mapping has further potential for use in other initiatives such as community warnings, prioritising of planned burns, fire behaviour modelling and resource allocation projects.

The current PBH uses estimates of the worst possible weather and fuel conditions for a given region to make a rational assessment of the worst possible fire line intensity in an area. The proposed ABH differs from PBH in that weather is not adjusted for climate change and the estimate of annual fuel loads is used in the assessment of the potential fire line intensity. As an example in regards to fuel load, if a disturbance event were to affect a region, the reduction in fuel load resulting from this event would reduce ABH for a period until fuel loads were returned to steady state. The same event would have no effect on PBH as this simply uses the steady state fuel load as a constant. Thus ABH is always less than or equal to PBH.

AFL and ABH models modify estimates of Potential Fuel Load (PFL) and PBH by reducing fuel loads based on an assumed consumption of fuel from mapped wildfires or planned burns, and by taking into account the time since the burn and the return of fuel load to an assumed steady state.

While these models can be applied once each year to reflect the accumulated reduction of fuel from all identified fire events, it is technically feasible to also apply these models at more frequent intervals if needed. As a starting point for further testing and validation of model outputs, there would be benefit in applying models in January each year at the end of the wildfire season and hazard mitigation season, in preparation for the planning of future activities.

The calculation of AFL and ABH incorporates two major mechanisms to adjust Potential Fuel Load and Potential Bushfire Hazard. These are the inclusion of mapped information on the extent of fire events that reduce fuel load below an assumed steady state, and fuel accumulation functions which describe the gradual return of fuel load to an assumed steady state over time.

Reduction of fuel could occur given a number of natural or anthropogenic disturbance events. These can include grazing, pests and disease outbreaks, severe weather events or the harvesting of timber and crops. Significant disturbances that result in permanent or semi-permanent land use change events, such as land clearing for development, are captured in updates of Vegetation Hazard Class (VHC) mapping performed by the Queensland Fire and Emergency Services.

Reliable data on the timing and extent of planned burns and wildfire events is readily available through the Queensland Government Remote Sensing Centre using the method described by Goodwin and Collett (2014). Similar data is also maintained by land management organisations such as the Queensland Parks and Wildlife Service. It is important to recognise that remotely sensed sources of fire scar mapping provide an incomplete record of fire history (burnt areas) which do not effectively detect mild burning under canopy, or small scale fires.

2 Bushfire Hazard Model

The bushfire hazard model used to estimate ABH utilises the same functions and models described in Leonard *et. al* (2014) which estimate potential fire-line intensity based on the Forest Fire Behaviour model developed by A. G. McArthur and implemented in the 1977 Mk5 forest fire behaviour meter (see McArthur 1967a and 1967b).

As outlined in Leonard *et al.* (2014), the calculation of fire line intensity is based on the combination of three spatial inputs; total fuel load (W), the McArthur Forest Fire Danger Index ($FFDI$) and terrain slope (θ), as follows:

$$FLI = 0.62\, W^2\, F \exp(0.069\, \theta)$$

2.1 Forest Fire Danger Index

As descried in Leonard *et. al*. (2014), the McArthur (1973) Forest Fire Danger Index (*FFDI*) is the most widely used fire weather index in Australia and forms part of many operational systems and instruments, such as AS3959 (Standards Australia, 2009).

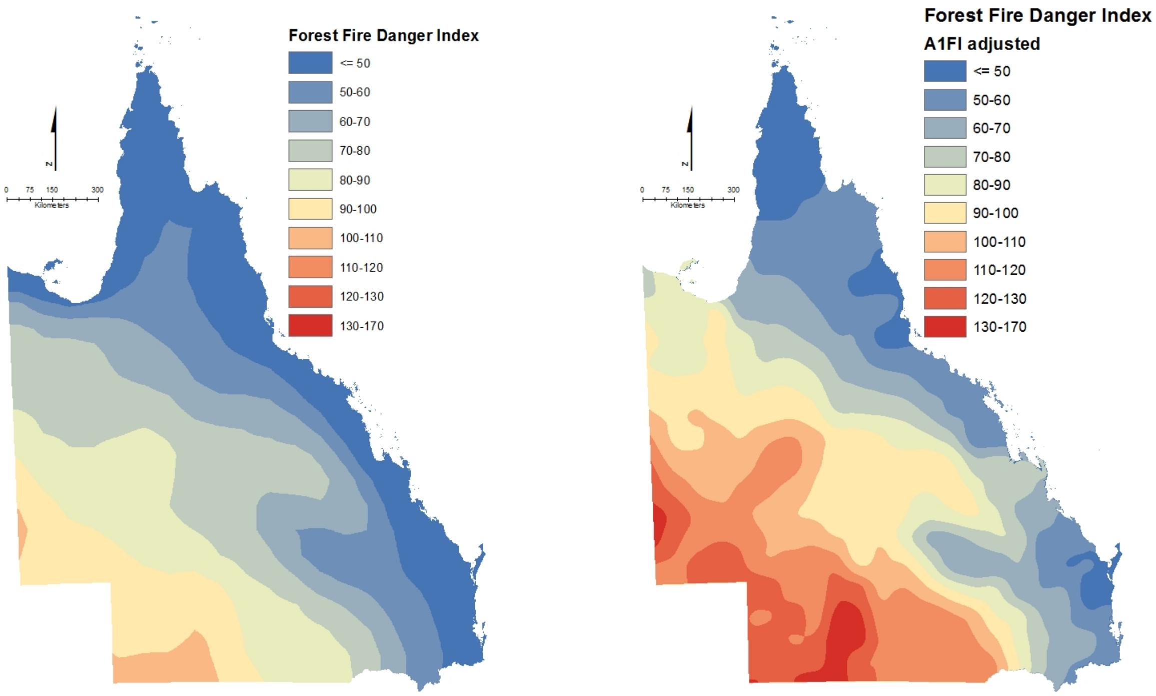

Figure 1: Example 5% exceedance probability Forest Fire Danger Index (FFDI) for Queensland (left) and FFDI with A1FI climate change applied (right).

The spatial modelling of *FFDI* is used in the calculation of fire-line intensity for estimating both PBH and ABH. The *FFDI* was developed from temperature, wind, relative humidity and precipitation weather products produced by the Australian Bureau of Meteorology (BoM) to create a gridded prediction of the *FFDI* (0.75 arc degree spacing or approximately 83km) at three hourly intervals over the period from 1979 to 2011.

In the case of PBH, the impact of climate change on *FFDI* input variable distributions was modelled to derive indicative distributions for the year 2050, using the IPCC A1FI climate scenario. This climate model was used to adjust temperature and relative humidity distributions. Wind speed and precipitation distributions were assumed constant due to higher level of regional uncertainty in climate change effects. In estimating PBH, *FFDI* for a 1:20 year fire scenario (5% annual exceedance probability) was used as the adopted *FFDI* for fire line intensity calculation (based on advice from the Queensland Fire and Rescue Service).

In the case of ABH, *FFDI* is calculated using the same method and parameters but without adjustment for climate change. The same 1:20 year fire weather scenario, without adjustment for climate change, is used to determine the value and distribution of input parameters used in the calculation of *FFDI* (Figure 1).

2.2 Topographic Slope

As described by Leonard *et. al* (2014), a map of maximum landscape slope for Queensland has been created from radar interferometric measurements of global land surface heights recorded during the February 2000 Shuttle Radar Topographic Mission (SRTM). The DEM-S derivative of STRM is a bare earth digital elevation model that is smoothed to remove instrument artefacts. It provides state wide coverage that is not available from airborne lidar and is well suited to landscape scale modelling of fire line intensity.

The estimation of ABH and PBH use the same estimates of maximum landscape slopes. These estimates are based on the fitting a surface (via least squares) within a moving five by five pixel window. The slope of this fitted surface is then attributed to the centre 25 m pixel.

2.3 Fuel Load

Fuel load in the context of this model and its intended application refers to the volume of vegetation that is available to burn during a bushfire. This includes surface, near surface, elevated fuel and bark fuel components, as defined by expert advice. The relative proportions of these fuel types varies considerably between different vegetation types or mapped Vegetation Hazard Class (Appendix A). The proportion of the available fuel consumed by a wildfire also varies from one vegetation type to the next. For example fire in a grassland environment can consume close to 100% of the total biomass, while fire in a eucalyptus dominated forest may consume less than 5% of the biomass (Luke & McArthur, 1978).

Despite some contradictory evidence (Turner & Lambert, 2002), it is generally recognised that most vegetation trends towards a maximum potential (or steady state) fuel load which is dependent on the vegetation type and environmental conditions (Walker, 1981). The maximum or steady state fuel load for both modelling of AFL and ABH is based on the mapping of six Vegetation Structure Classes associated with Vegetation Hazard Classes (Table 1).

Table 1. Vegetation Structure Classes

Vegetation Structure Class	Dominant Life Form	Density
1. Trees closed - mid dense	Trees	Closed to mid-dense
2. Trees sparse - very sparse	Trees	Sparse to very sparse
3. Shrubland	Shrubland	Closed to very sparse
4. Grassland	Tussock or Hummock Grassland	Closed to very sparse
5. Sedgeland	Herbland, Forbland, Ferbland, Vineland or Sedgeland	Closed to very sparse
6. Nil veg	Nil vegetation	Nil vegetation

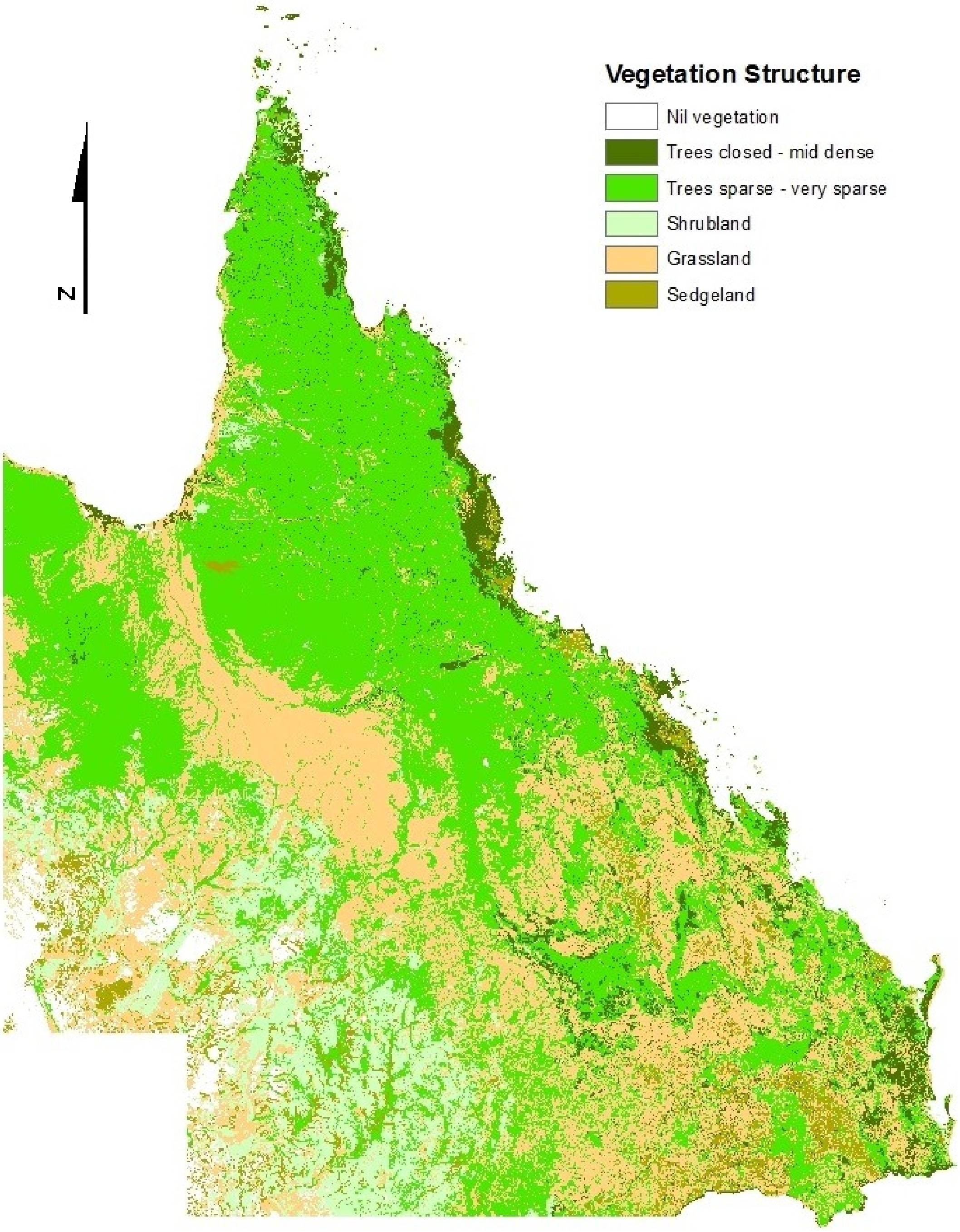

Figure 2. Vegetation Structure Classes for Queensland

Areas mapped as the same VHC are assumed to have the same potential fuel load. This does not suggest that the fuel load at any point in time will be the same across areas of the same type, but it does suggest that areas of the same type have the potential to reach the same fuel load given the absence of fire or other disturbances over a long period.

In order to calculate AFL and ABH, the potential fuel load for the mapped VHC is treated as the steady state fuel load, with reduction due to past bushfire events as described below.

3 Fuel Load Adjustment

This section describes the process for estimating the level of fuel reduction that would result of from a fire event and the modelling of a return in the fuel load to an assumed steady state fuel load.

3.1 Fuel Accumulation Model

While Gilroy & Tran (2006) showed that the annual fuel load can be estimated using a combination of fuel depth, time since fire and the projected foliage cover (PFC), it is not possible to measure fuel depth over any substantive area in order to estimate this throughout Queensland. Gilroy & Tran (2006) also show that although PFC is significant in the estimation of annual fuel load, the time since fire is more than three times as important. Olson (1963) describes the rate of return to steady state fuel load using the negative exponential equation based on:

$$x = \frac{L}{k}(1 - e^{-kt})$$

where: x is the current fuel load at time t,

L is the fuel accumulation rate and,

k is the decomposition rate.

At steady state $L = k\, x_{ss}$. The model can be applied to the total fuel load or to the estimation of a specific fuel type e.g. the leaf litter load. Substituting for k, the above equation can be simplified to:

$$x = x_{ss}(1 - e^{-kt})$$

This model allows estimation of the current fuel load as simply a function of the steady state fuel load, the decomposition rate and the time since disturbance (assuming disturbance caused the removal of all fuel). The convergence to x_{ss} is the primary reason that the Olsen model is preferred to that of Gilroy & Tran, since it conforms to the assumption of a steady state (maximum potential) fuel load for any given VHC. Theoretically, values for k can range from zero to infinity, where zero indicates no fuel accumulation, and infinity indicates immediate and full fuel accumulation to x_{ss}.

A broad theoretical range of k values is shown in Figure 3 to demonstrate the significance of k, although more realistic range of values based on available literature ranges from 0.09 in open alpine forests (Park, 1975) to 0.91 in a tropical rainforest (Bailey, 1978).

The Olson (1963) equation can be restated to calculate k based on a known time taken to reach some proportion ($p = x / x_{ss}$) of the steady state fuel load as follows:

$$k = \frac{-\ln(1 - p)}{t_p}$$

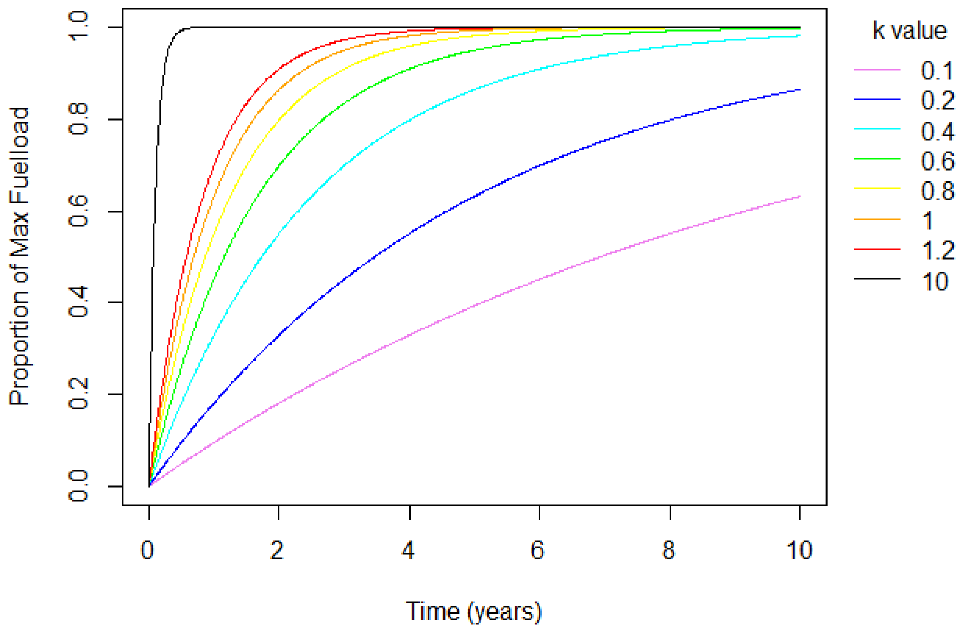

Figure 3: Examples of fuel accumulation towards steady state for different decomposition constant (k) values.

Thus, the decay constant given a known time period for recovery to 50%, 95% and 99% of x_{ss} are given by:

$$k = \frac{0.7}{t_{50}},\ k = \frac{3.0}{t_{95}} \text{ and } k = \frac{4.6}{t_{99}}$$

, respectively. This approach provides an estimation of *k* values from the literature which often provide estimate of x/x_{ss} for a given *t*, but not *k* directly. However, care must be taken when analysing these data to ensure that at time t=0 the fuel was zero, an assumption often implied but not explicitly stated. If this is not the case then there are two unknowns (*k* and t_{start}) as follows:

$$k = \frac{-\ln(1-p)}{t_{start} + t_p}$$

Two values, *p* and t_p, are therefore required to determine the appropriate *k* value. Alternatively *k* is often estimated at steady state, remembering that $L = k\, x_{ss}$, where *L* can be estimated using litter fall traps (e.g. Paul & Polglase, 2004).

Where the loss of fuel is not complete and a proportion of fuel remains after a disturbance an offset needs to be included in Olsen's model. This requires the evaluation of t_x, the time at which a proportion of fuel exists with consideration of the decay constant for each vegetation structure class.

$$t_x = \frac{-\ln(1-p)}{k}$$

Substituting this into Olsen's model it is possible to estimate the annual fuel load.

$$x = x_{ss}(1 - e^{-k(t+t_x)})$$

3.2 Decay Constant Estimates

The appropriate value for *k* may be dependent on nutrient and water availability in soils (Bresnehan, 2003), vegetation type (Birk & Simpson, 1980; Burrows, 1994; Raison et al., 1983; Thomas et al., 2014; Walker, 1981), as well as climate factors such as mean rainfall and temperature (Matthews et al., 2012; Thomas et al., 2014). Matthews et al. (2012) described a method for modelling *k* based on mean temperature (*T*) and annual rainfall (*r*) as follows:

$$k = a(1 - e^{-bT})(1 - e^{-cr})$$

where a, b and c are fitted parameters.

However, this equation ignores differences in the dominant vegetation type, which can often be correlated with underlying soil properties. Walker (1981) provides one of the more comprehensive summaries of *k* values for older studies in different forest types and regions of Australia. Some examples of studies from which *k* can be derived for different vegetation types throughout Queensland are listed in Table 2, including those mentioned by Walker (1981). A *k* value is analogous to the recovery time of a vegetation type from 0 to x_{ss}. Lower values (< 0.1) indicate that the recovery of that vegetation to the solid state will be very long (i.e. 20 years). Conversely, values of 1 and higher indicate that recovery may only take 2 years or less.

Table 2. Olson (1963) decay constant (k) for Queensland vegetation

Location	Vegetation Type	Author	*k* value	0-X_{SS} (approx. years)
Mundubbera	Grassy Open Forest	Walker (1981)	0.33	6
Rockhampton	Grassy Open Forest	Nichols (unpub), reported in Walker (1981)	0.45	6
Rockhampton	Closed Grassland	Walker (1981)	0.50	4
Talwood	Shrub Woodland	Leigh (1978), reported in Walker (1981)	0.26	10
Innisfail	Closed Tropical Forest	Bailey (1978)	0.91	2
Meandarra	Brigalow Woodland	Tunstall (1973) and Moore et al. (1967)	0.09	20
Cooloola	Eucalypt Forest	Sandercoe (1990)	0.64	6

Ideally, decomposition rates should be based on the dominant vegetation types as well as site climatology (Thomas et al., 2014). This process would require collation of a comprehensive data set with a broad geographic distribution of decomposition sampling sites for each of the major vegetation types across a range of biomass productivity regions.

Given the limited published information on decomposition rates, appropriate *k* values have been estimated for each of the five vegetation structural types associated with VHC mapping (Sections 3.2.1 to 3.2.5). These can be considered as a default values, from which further adjustment can be made as more comprehensive data sets are developed.

3.2.1 Trees Closed - Mid Dense

The majority of studies of fuel decomposition rates in Australia have targeted closed Eucalyptus forests. In theory this class includes forests as diverse as tropical rainforests, pine plantations and a broad range of denser Eucalyptus forest types. The relevant examples from Table 1 are the Innisfail tropical forest (*k*=0.91) and the Cooloola Eucalypt forest (*k*=0.64). Other examples outside Queensland include the study in *E.pilularis* (Blackbutt) forests by Birk & Bridges (1989) that indicated *k*=0.69 based on 75% recovery of fuel in 2 years after controlled burning. Paul & Polglase (2004) found the average *k* value for Eucalyptus leaves, over 29 studies, was 0.6. However, they suggest that other components such as bark (*k*=0.49), wood (*k*=0.2) and pine needles (*k*=0.42) recover towards x_{ss} over longer periods.

As are result, it is suggested that a *k* value of 0.65 is a reasonable default value for modelling decomposition in closed Eucalyptus forests. This value is supported by Roxburgh *et al.*'s (2015) review of 14 studies that found for Eucalyptus forests k=0.587 in the instance of a wildfire and k=0.768 in the instance of the controlled fire.

3.2.2 Trees Sparse - Very Sparse

Studies of sparse and open forests suggest a more gradual recovery to x_{ss} than for closed forests. Walker (1981) reports two studies in grassy open forests in Queensland in Mundubbera (*k*=0.33) and Rockhampton (*k*=0.45). Bridges (2004) study of 24 dry sclerophyll sites in southern New South Wales suggests a value of *k*=0.37, based on a 5 year recovery to 95% of x_{ss}. Fox et al. (1979) suggested a *k* value of 0.31 for open Eucalyptus forests near Seal Rocks on the central coast of NSW. However Raison et al. (1983) gives a lower range for k, from 0.11 to 0.31 in sub-alpine stands of *E. pauciflora*, E. dives and *E. delegatensis*.

Based on this literature, there is evidence for a more gradual recovery in sparse forest and suggest a *k* value of 0.35 as a reasonable and conservative decomposition rate.

In summary, a *k* value of 0.35 is a reasonable and conservative decomposition rate based on evidence of a more gradual fuel recovery rate in sparse forest.

3.2.3 Shrubland

Studies of decomposition rates in shrubland are less common than in forest environments. The fuel dynamics in shrublands are also more complicated than for forests as most of the fuel is comprised of living vegetation (Plucinski et al., 2009) and reaccumulation of fuel generally involves pyric succession (Specht et al., 1958). Walker (1981) calculated a *k* value of 0.26 from data recorded by Leigh et al. (1978) for Shrub Woodlands in Talwood in Queensland and at Ivanhoe in New South Wales. Given only one Australian study from which decomposition rate can be calculated, a *k* value of 0.26 has been adopted as the default value for *k* in shrublands.

3.2.4 Grassland

Grasslands within the Neldner et al. (2012) classification include slow growing Hummock and Tussock grasses common in arid regions of Australia. Ross & Cairns (1978) describe decomposition rates for two tussock grassland sites in New Zealand, quoting very low decomposition rates (< 0.01) under controlled conditions. For grassland, Roxburgh *et al.* (2015) and Walker (1981) suggest that grasslands will recover within a year if undisturbed. However, decomposition rates to accumulate the fuel necessary is slow and most areas would be impacted by herbivores. As a conservative estimate for accumulation of fuel, a *k* value of 0.8 is suggested as a default value in grasslands.

3.2.5 Sedgeland

The sedgeland class classification includes herbs, forbs, rushes, vines, ferns and sedges. Herbaceous vegetation by definition will generally recover most of its living biomass in the growing season following disturbance. However, the build-up of dead material, in the form of ground thatch, may take multiple years. Sedgelands may also be subject to episodic grazing which could limit accumulation. Given explicit examples in the literature, using a decomposition rate such that 90% of the fuel load is expected to return within a year of disturbance is suggested, which equates to a *k* value of 0.8.

Table 3. Summary of *k* values for each of the structural classes

Structure Class	Decomposition Rate (k)
1. Tree Closed – Mid Dense	0.65
2. Tree Sparse – Very Sparse	0.35
3. Shrubland	0.26
4. Grassland	0.8
5. Sedgeland	0.8
6. Nil vegetation	n/a

3.3 Bushfire Events

Bushfire events, such as wildfires, prescribed burns and mechanical fuel reduction are some of the key disturbance that affect available fuel load and fuel structure. Other natural or anthropogenic events including drought, severe weather events, pest infestations, outbreaks of disease, grazing by native or production livestock, or the harvesting of timber and crops can also substantially affect fuel loads. In the context of modelling AFL and ABH, disturbances do not include permanent or semi-permanent land use change events. Events such as land clearing for agriculture or urban development is captured in updates to the VHC.

Current and reliable data is required for any disturbance event to be included in the calculation of AFL. The methodology described here, is restricted to analysis of fire events as information on past fires is readily available through the Queensland Government Remote Sensing Centre (Goodwin & Collett, 2014) and is often compiled by land management organisations.

The Queensland Government Remote Sensing Centre fire scar mapping is derived from the Landsat satellite series and is produced annually for the period 1987 to 2014. On average, over 80% of fire scars captured in Landsat imagery have been correctly mapped with less than 30% false fire rate. Values represent the month in which a fire occurred (Figure 4).

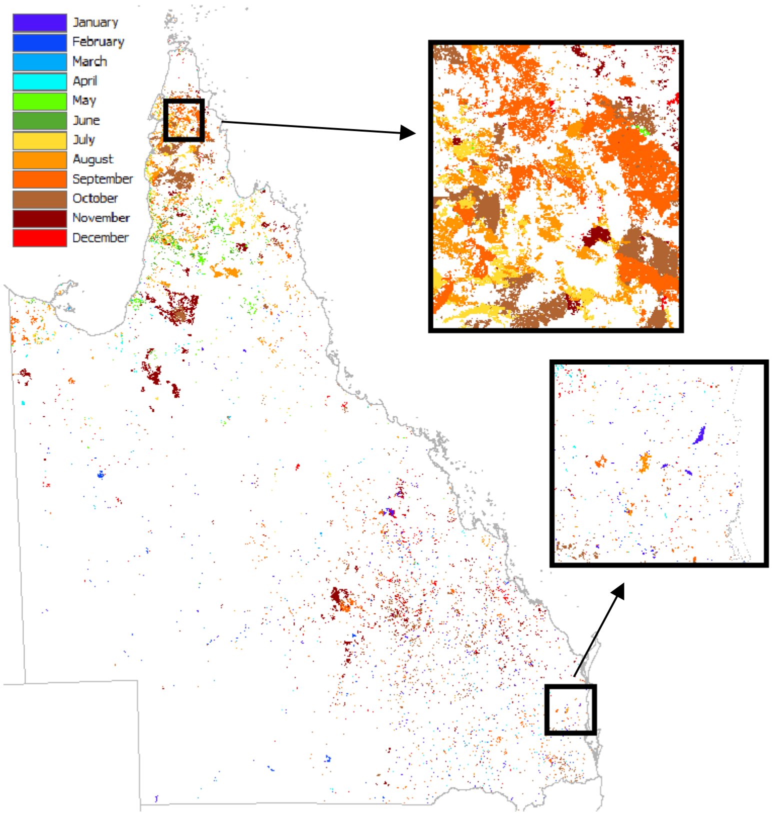

Figure 4: 1997 Queensland Government Remote Sensing Centre fire scar mapping.

3.4 Fuel Reduction Model

The proportion of available fuel removed in a given fire will depend on the fuel structure and the intensity of the fire event. In shrub and grass dominated communities, most of the available fuel can be expected to burn in a medium intensity fire event. In forest and woodland environments, complete consumption of the available fuels may only occur in very intense fire events. As such, the amount of fuel assumed lost in a given fire event will depend on the vegetation type and structure, and an assumed fire severity. For low intensity burns, a lesser proportion of twig and bark components of the total available fuel load are consumed when compared to live and dead foliage (Van Loon, 1969; Walker, 1981). For this reason, complete consumption of fuels in both closed and sparse treed environments can only be assumed if the fire severity is high.

Antecedent weather conditions provide a simple approach for estimating the intensity of any fire event, such as those captured by remote sensing based maps of burned area (e.g. Goodwin & Collett, 2014).

A fuel reduction model was developed to integrate the factors of monthly 1:20 year Fire Danger Index and Vegetation Structure Class based on expert estimates provided by officers of the Queensland Parks and Wildlife Service (Table 2). *FFDI* for each month was categorised into Fire Danger Rating (FDR) (Luke & McArthur, 1978) to assist in estimating the proportion of reduction per month.

Table 2. Assumed percentage of fuel remaining after bushfire by Vegetation Structure Class and 1:20 year FDR

Vegetation Structure Class	1:20 year Fire Danger Rating					
	Catastro-phic	Extreme	Severe	Very High	High	Low–Moderate
	FFDI 100+	FFDI 75-99	FFDI 50-74	FFDI 25-49	FFDI 12-24	FFDI 9-11
1. Trees closed - mid dense	0%	0%	10%	20%	40%	70%
2. Trees sparse - very sparse	0%	0%	10%	10%	20%	50%
3. Shrubland	0%	0%	10%	20%	40%	70%
4. Grassland	0%	0%	10%	10%	20%	50%
5. Sedgeland	0%	0%	10%	10%	20%	50%
6. Nil veg	0%	0%	10%	10%	20%	50%

Use of the calculated monthly 1:20 *FFDI* is a balance between the recognition of burning conditions during a fire disturbance, and the need to provide a realistic estimate of the approximate intensity. Assumed conditions need to reflect the need to sustain a fire and produce a realistic estimate of the likely proportion of fuel burnt. Two main considerations influencing the production of monthly 1:20 FDR are that *FFDI* varies significantly spatially throughout the state, and the limited temporal resolution of the monthly fire scar data used to account for bushfires. 1:20 Fire Danger Rating monthly maps are presented in Figure 5.

For the purpose of determining proportional fuel reduction, *FFDI* models for each month have been compiled from the 1:20 year probability of occurrence for a given month (Figure 5). The monthly 1:20 year *FFDI* fire scenario was determined from the mapped fire weather data described in Section 2.1 of this report.

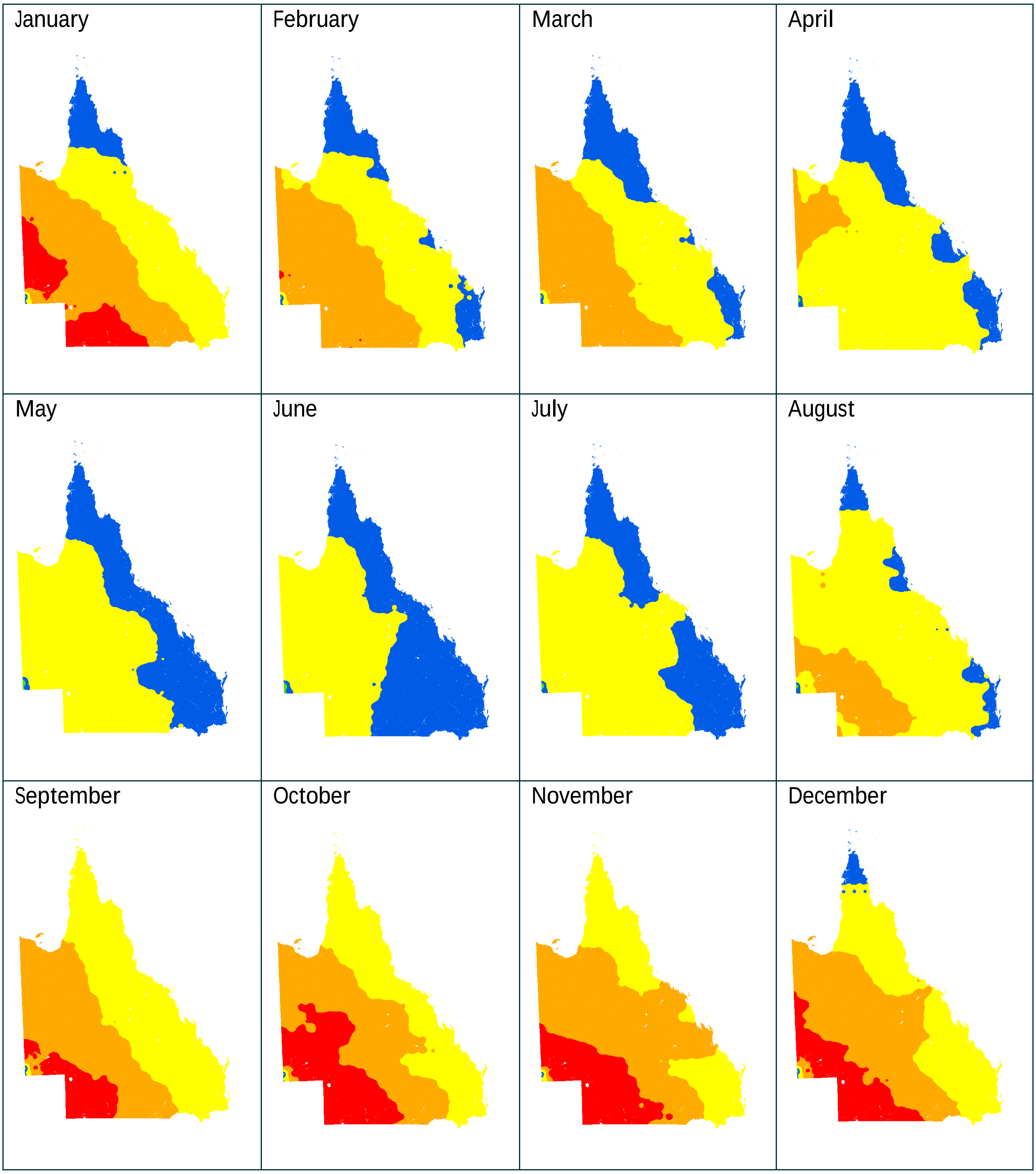

Figure 5: 1:20 FFDI for each month categoried into Fire Danger Ratings by month

4 Modelled Outputs

The process of applying the fire event reduction to PFL and the subsequent accumulation of fuels was applied to the data to generate the AFL. This was then used in the bushfire hazard model described in Section 2 to generate the ABH (Figure 6).

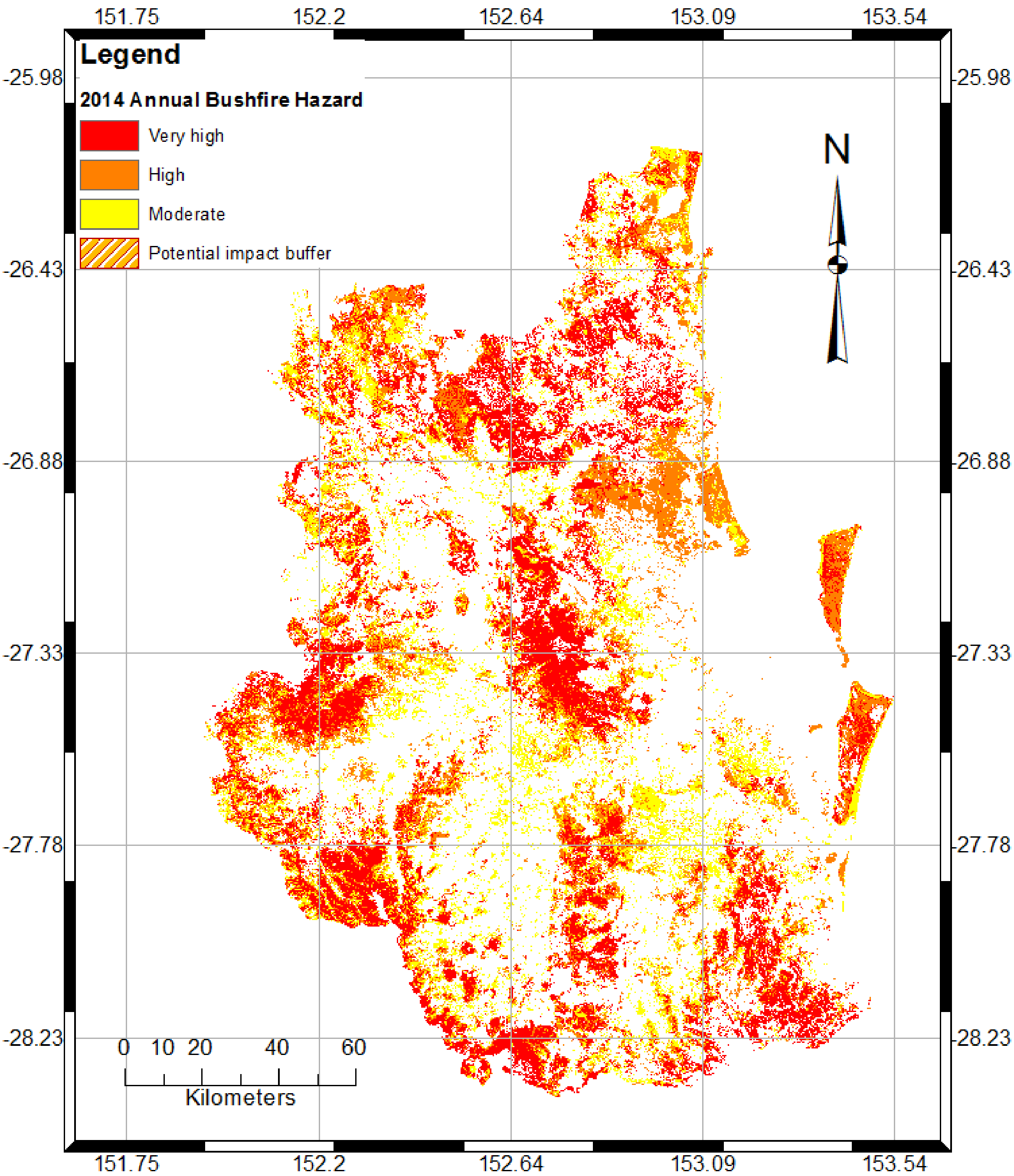

Figure 6: 2014 Annual bushfire hazard (ABH) for the local government areas within south-east Queensland.

As an example of the applied model AFL and ABH mapping for North Stradbroke Island, which incorporates all Landsat fire scar data available for the period between 1987 and 2014 can be seen in Figure 7. It's important to note that any artefacts in the source data, such as striping in the fire scar data (Wulder, 2008), will impact on the model outputs.

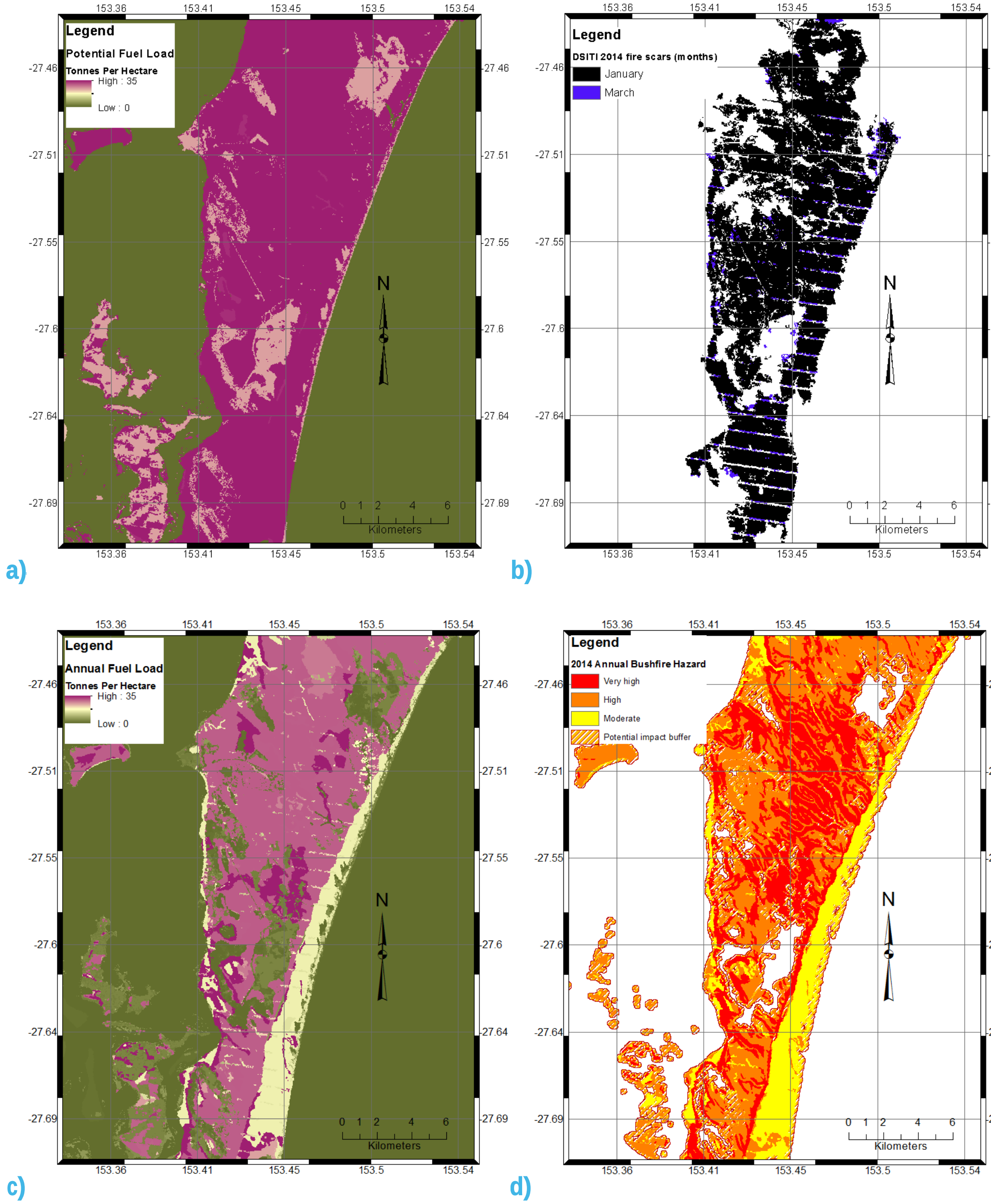

Figure 7: Demonstration of fire scar dataset artefacts and the impact on annual fuel load outputs a) potential fuel load, b) 2014 fire scar, c) 2014 annual fuel load and d) 2014 annual bushfire hazard.

5 Discussion and Conclusions

A system is proposed for mapping of Annual Fuel Load (AFL) and Annual Bushfire Hazard (ABH) for use by land managers as an input to bushfire mitigation plans and associated risk and other plans to inform at risk communities.

It would be feasible to calculate AFL and ABH in January each year, or at an alternative time of year depending on needs.

This mapping approach builds on information and methods used to map Potential Bushfire Hazard (PBH) including Vegetation Hazard Class and Potential Fuel Loads.

The modelling approach described here combines these data to adjust the potential fuel load, in locations where a fire event and its month of ignition is recorded. The proportion of fuel reduction from a fire is based on expert estimates that are framed according to the assumed severity of fire on a monthly basis, determined from the 1: 20 year FFDI, and the vegetation structure class.

The result of a fire disturbance may be partial or complete consumption of fuel depending on the fuel structure and assumed fire severity. Accumulation then occurs annually to a steady state , assuming the model structure proposed by Olson (1963).

Decomposition rates have been suggested for five vegetation structural classes that are represented in the VHC mapping. While these are representative of values from the literature for the structure classes defined in the VHC, the potential exists to update the decay constants. For example, attributing the VHC with classifications used elsewhere, such as the National Inventory Report (Department of Environment and Energy, 2014), would enable ready application of updated decay constants.

The modelling method developed from this study provides a framework for implementation of AFL and ABH mapping in Queensland. This framework allows for further improvements such as refined specification of fire events or other disturbance events and parameters used to describe fuel accumulation models. These and other expert assumptions included in this model and can be improved in consultation with stakeholders and end-user organisations based on the assessments of model outputs.

References

Bailey, S. W. (1978). Technical Memorandum 14: Seasonal variation of litter fall in three north Queensland rainforests. Division of Soils, CSIRO, Australia.

Birk, E. M., & Bridges, R. G. (1989). Recurrent fires and fuel accumulation in even-aged blackbutt (Eucalyptus pilularis) forests. Forest Ecology and Management, 29(1–2), 59–79.

Birk, E. M., & Simpson, R. W. (1980). Steady State and the Continuous Input Model of Litter Accumulation and Decompostion in Australian Eucalypt Forests. Ecology, 61(3), 481–485. Retrieved from http://links.jstor.org/sici?sici=0012-9658(198006)61:3%3C481:SSATCI%3E2.0.CO;2-U

Bresnehan, S. J. (2003). An Assessment of Fuel Characteristics and Fuel Loads in the Dry Sclerophyll Forests of South-East Tasmania. University of Tasmania, Hobart.

Bridges, R. G. (2004). Fine fuel in the dry sclerophyll forests of south-eastern New South Wales. Australian Forestry, 67(2), 88–100.

Burrows, N. D. (1994). Experimental development of a fire management model for Jarrah (Eucalyptus Marginata Donn ex Sm.) forest. Anustalian National University, Canberra.

Department of State Development, I. and P. (2014). State Planning Policy.

Department of Environment and Energy. (2014) National Inventory Report 2014 (revised) (Vol. 2), Retreived from https://www.environment.gov.au/system/files/resources/cab3140e-5adb-479f-9af4-a7c605d762dc/files/national-inventory-report-2014-revised-vol-2.pdf.

Fox, B. J., Fox, M. D., & Mckay, G. M. (1979). Litter Accumulation After Fire in a Eucalypt Forest. Australian Journal of Botany, 27(2), 157.

Gilroy, J., & Tran, C. (2006). A new fuel load model for eucalypt forests in Southeast Queensland. In 10th Biennial Australasian Bushfire Conference Series, Bushfire 2006: Life in a Fire Prone Environment - Translating Science Into Practice, 6-9 June 2006. Brisbane: Proceedings of the 10th Biennial Australasian Bushfire Conference Series, Bushfire 2006: Life in a Fire Prone Environment - Translating Science Into Practice, 6-9 June 2006.

Goodwin, N., & Collett, L. J. (2014). Development of an automated method for mapping fire history captured in Landsat TM and ETM+ time series across Queensland, Australia. Remote Sensing of Environment, 148, 206–221. Retrieved from http://ac.els-cdn.com/S0034425714001072/1-s2.0-S0034425714001072-main.pdf?_tid=b83f5806-1ed1-11e5-ade9-00000aacb35f&acdnat=1435632359_6f6ca2c082fc8e1585d40fc18d35d733

Leigh, J., Wilson, A., & Mulham, W. (1978). Seasonal variations in the leaf fall and quality of the leaves of four Australian fodder trees. The Australian Rangeland Journal, 1(2), 137–41.

Leonard, J., Opie, K., Newnham, G., & Blanchi, R. (2014). A new methodology for State - wide mapping of bushfire prone areas in Queensland. Australia.

Luke, R. H., & McArthur, A. G. (1978). Bushfires in Australia. Canberra: Australian Government Publishing Service.

Matthews, S., Sullivan, A. L., Watson, P., & Williams, R. J. (2012). Climate change, fuel and fire behaviour in a eucalypt forest. Global Change Biology, 18(10), 3212–3223.

McArthur, A. G. (1973). Forest Fire Danger Mater Mark 5. Canberra: CSIRO. Retrieved from http://www.royalcommission.vic.gov.au/Documents/Document-files/Exhibits/WIT-004-001-0315.pdf

Moore, A., Russell, J. S., & Coaldrake, J. E. (1967). Dry matter and nutrient content of a subtropical semiarid forest of Acacia harpophylla F. Muell (Brigalow). Australian Journal of Botany, 15, 11–24.

Neldner, V. J., Wilson, B. A., Thompson, E. J., & Dillewaard, H. A. (2012). Methodology for Survey and Mapping of Vegetation Communities and Regional Ecosystems in Queensland. Brisbane: Queensland Herbarium, Queensland Department of Science, Information Technology, Innovation and the Arts.

Olson, J. S. (1963). Energy Storage and the Balance of Producers and Decomposers in Ecological Systems. Ecology, 44(2), 322–331. Retrieved from http://www.jstor.org/stable/1932179

Park, G. N. (1975). Variation in nutrient dynamics and secondary ecosystem development in subalpine eucalypt forests and woodlands. Australian National University, ACT.

Paul, K. I., & Polglase, P. J. (2004). Prediction of decomposition of litter under eucalypts and pines using the FullCAM model. Forest Ecology and Management, 191(1), 73–92.

Plucinski, M. P., Gill, A. M., & Bradstock, R. A. (2009). Fuel Dynamics in Shrub Dominated Landscapes. Proceedings of the Royal Society of Queensland, 115, 145–151.

Raison, R. J., Woods, P. V, & Khanna, P. K. (1983). Dynamics of fine fuels in recurrently burnt eucalypt forests. Australian Forestry, 46(4), 294–302.

Ross, D. J., & Cairns, A. (1978). Influence of temperature on biochemical processes in some soils from tussock grasslands. New Zealand Journal of Soil Science, 21(4), 581–589.

Roxburgh, S., Volkova, L., Surawski, N., Meyer, M., Weston, C., & Roxburgh, S. (2015). Review of fuel loads , burn efficiencies , emissions factors and recovery functions used to estimate greenhouse gas emissions and removals associated with wildfire on temperate forested lands Prepared for the Department of the Environment.

Sandercoe, C. (1990). Fire Management of Cooloola National Park – Fuel Dynamics of the Western Catchment. In Fire Research in Rural Queensland. Queensland Fire Research Workshop Series 1980-1989.

Specht, R. L., Rayson, P., & Jackman, M. E. (1958). Dark Island heath (Ninety-Mile Plain, South Australia). VI. Pyric succession: changes in composition, coverage, dry weight, and mineral nutrient status. Australian Journal of Botany, 6(1), 59–88.

Standards Australia. (2009). AS3959 - Construction of buildings in bushfire prone areas. Sydney: Standards Australia. Retrieved from http://www.royalcommission.vic.gov.au/getdoc/2d486ba8-2cef-45a1-9f3c-6e058ec8a78a/WIT.3000.002.0108.PDF

Thomas, P. B., Watson, P. J., Bradstock, R. a., Penman, T. D., & Price, O. F. (2014). Modelling surface fine fuel dynamics across climate gradients in eucalypt forests of south-eastern Australia. Ecography, 37(9), 827–837.

Tunstall, B. R. (1973). Water relations of a brigalow community. University of Queensland.

Turner, J., & Lambert, M. J. (2002). Litterfall and forest floor dynamics in Eucalyptus pilularis forests. Austral Ecology, 27(2), 192–199.

Van Loon, A. P., & A, Q. U. B. B. (1969). Investigations into the effects of prescribed burning on young, even-aged Blackbutt : establishment and preliminary progress report. Department of Conservation, Forestry Commission of NSW. Taree.

Walker, J. (1981). Fuel dynamics in Australian vegetation. In A. M. Gill, R. H. Groves, & I. R. Noble (Eds.), Fire and the Australian Biota (pp. 101–27). Canberra: Australian Academy of Science.

Wulder, M. A., Ortlepp, S. M., White, J. C., & Maxwell, S. (2008). Evaluation of Landsat-7 SLC-off image products for forest change detection, 34(2), 93–99.

Appendix A Vegetation Hazard Classes

Table 3 below shows the Vegetation Hazard Classes (VHCs) and their associated 80th percentile potential fuel loads for individual fuel components and total fuel load. The VHCs are based on 35 broad groups within the Regional Ecosystem (RE) types mapped by the Queensland Herbarium (Neldner et al, 2012) which are also subdivided into dominant structural classes, as defined by Specht (1970). Associated decay constant (*k*) values associated with the structure classes are shown in Table 4.

Table 3. Vegetation Hazard Class Descriptions and Potential Fuel Load*

Vegetation Hazard Class		Potential Fuel Load (t/ha)						Prone Type [1]		Fuel Continuity[2]		
		Surface	Near Surface	Elevated	Bark	Total (Remnant)	Total (Non- Remnant)	Remnant	Non-Remnant	Remnant	Non- Remnant	*Structural class*
1.1	*Complex mesophyll to notophyll vine forests*	2.6	0	0	0	2.6	12	3	1	2	1	1
2.1	*Complex to simple, semi-deciduous mesophyll to notophyll vine forest*	3.5	0	0	0	3.5	12	3	1	2	1	1
3.1	*Notophyll vine forest*	4.5	0	0	0	4.5	12	3	1	2	1	1
3.3	*Notophyll vine thicket*	4.4	0	0	0	4.4	12	3	1	2	1	3
4.1	*Notophyll and notophyll palm or vine forest*	4.5	0	0	0	4.5	12	3	1	2	1	1
5.1	*Notophyll to microphyll vine forests*	3.9	0	0	0	3.9	12	3	1	2	1	1
5.2	*Notophyll to microphyll vine forest with sparse overstorey*	3.9	0	0	0	3.9	12	3	1	2	1	2
5.5	*Sedgeland within Notophyll to microphyll vine forests*	3.9	0	0	0	3.9	12	3	1	2	1	5
6.1	*Montane Notophyll vine forest and microphyll fern forest*	3.9	0	0	0	3.9	12	3	1	2	1	1
6.3	*Montane Notophyll vine thicket and microphyll fern thicket*	3.9	0	0	0	3.9	12	3	1	2	1	3
7.1	*Semi-evergreen to deciduous microphyll vine forest*	6	0	0	0	6	12	3	1	2	1	1
7.2	*Sparse semi-evergreen to deciduous microphyll vine forest*	6	0	0	0	6	12	3	1	2	1	2
8.1	*Wet eucalypt tall open forest*	28	3	2	2	35	35	1	1	1	1	1
8.2	*Wet eucalypt tall woodland*	18	3.1	1.7	1	23.8	23.8	1	1	1	1	2
9.1	*Moist to dry eucalypt open forests on coastal lowlands and ranges*	17.5	3.5	2.2	1	24.2	24.2	1	1	1	1	9

- Not for general distribution

Vegetation Hazard Class		Potential Fuel Load (t/ha)						Prone Type [1]		Fuel Continuity[2]		
		Surface	Near Surface	Elevated	Bark	Total (Remnant)	Total (Non- Remnant)	Remnant	Non-Remnant	Remnant	Non- Remnant	*Structural class*
9.2	*Moist to dry eucalypt woodland on coastal lowlands and ranges*	11.4	3.5	1.3	1	17.2	17.2	1	1	1	1	2
9.3	*Shrubland within moist to dry eucalypt on coastal lowlands and ranges*	7.8	3	1.9	0	12.7	12.7	1	1	1	1	3
10.1	*Spotted gum dominated open forests*	16.3	3	1.5	0	20.8	20.8	1	1	1	1	1
10.2	*Spotted gum dominated woodlands*	14	3	1	0	18	18	1	1	1	1	2
11.2	*Moist to dry eucalypt woodlands on basalt areas*	7.5	4	0.5	1	13	13	1	1	1	1	2
12.1	*Dry eucalypt open forest on sandstone and shallow soils*	15	3.5	1.5	1	21	21	1	1	1	1	1
12.2	*Dry eucalypt woodlands on sandstone and shallow soils*	12	2.6	1.8	1	17.4	17.4	1	1	1	1	2
13.1	*Dry to moist eucalypt open forests on undulating metamorphics and granite*	15.9	3.5	1.4	1	21.8	21.8	1	1	1	1	1
13.2	*Dry to moist eucalypt woodlands on undulating metamorphics and granite*	9.4	3.4	0.6	1	14.4	14.4	1	1	1	1	2
13.3	*Shrubland associated with dry to moist eucalypt woodlands on undulating terrain*	4.3	2.3	0.9	0	7.5	7.5	1	1	1	1	3
14.1	*Open forest dominated by Darwin stringybark, Melville Island bloodwood or scarlet gum*	22.3	1.4	2.1	2	27.8	27.8	1	1	1	1	1
14.2	*Woodlands dominated by Darwin stringybark, Melville Island bloodwood or scarlet gum*	8.4	2.4	0.8	1	12.6	12.6	1	1	1	1	2
14.3	*Shrubland associated with woodlands dominated by Darwin stringybark, Melville Island bloodwood or scarlet gum*	1.1	3.4	3.3	1	8.8	8.8	1	1	1	1	3
14.6	*Sparsely vegetated areas associated with Darwin stringybark, Melville Island bloodwood or scarlet gum*	0	0.3	1.3	0	1.6	1.6	3	3	2	2	6
15.1	*Temperate open eucalypt forests*	23.7	0.3	1.8	1	26.8	26.8	1	1	1	1	1
15.2	*Temperate eucalypt woodlands*	10.2	1.8	1.8	0	13.8	13.8	1	1	1	1	2
16.1	*Eucalyptus dominated forest on drainage lines and alluvial plains*	10	3.8	1.2	1	16	16	1	1	1	1	1
16.2	*Eucalyptus dominated woodland on drainage lines and alluvial plains*	7.5	3.6	0.5	0	11.6	11.6	1	1	1	1	2
16.3	*Shrubland associated with Eucalyptus woodlands on drainage lines*	5.8	2.7	0.1	0	8.6	8.6	1	1	1	1	3
16.4	*Grassland associated with Eucalyptus dominated woodlands on drainage lines*	0.3	2.1	0.1	0	2.5	2.5	2	2	1	1	4
16.5	*Sedgeland associated with Eucalyptus woodlands on drainage lines**	3.9	5	3.5	0	12.4	12.4	1	1	1	1	5
16.6	*Sparsely vegetated areas associated with Eucalyptus woodlands on drainage lines*	1.2	2	0	0	3.2	3.2	3	3	2	2	6

Vegetation Hazard Class		Potential Fuel Load (t/ha)						Prone Type [1]		Fuel Continuity[2]		
		Surface	Near Surface	Elevated	Bark	Total (Remnant)	Total (Non- Remnant)	Remnant	Non-Remnant	Remnant	Non- Remnant	*Structural class*
17.1	*Dry open forests dominated by poplar box, silver-leaved ironbark or White's ironbark on sand or depositional plains*	10.6	4.1	0.3	0	15	15	1	1	1	1	1
17.2	*Dry woodlands dominated by poplar box, silver-leaved ironbark or White's ironbark on sand or depositional plains*	6	3	0.6	0	9.6	9.6	1	1	1	1	2
18.1	*Dry eucalypt open forests on sand or depositional plains*	10.8	3.4	0.6	0	14.8	14.8	1	1	1	1	1
18.2	*Dry eucalypt woodlands on sand or depositional plains*	7.1	3.3	0.6	0	11	11	1	1	1	1	2
18.5	*Sedgeland associated with dry eucalypt woodlands on sand or depositional plains*	3.9	3.4	3.5	0	10.8	10.8	1	1	1	1	5
19.2	*Low open eucalyptus woodlands dominated by snappy gum, Cloncurry Box or Normanton box*	4.3	3	0.8	1	9.1	9.1	1	1	1	1	2
19.3	*Shrubland associated with low open eucalypt woodlands dominated by snappy gum, Cloncurry Box or Normanton box*	1.7	1.5	1.3	0	4.5	4.5	1	1	1	1	3
19.4	*9Grassland associated with low open eucalypt woodlands dominated by snappy gum, Cloncurry Box or Normanton box*	1.6	3.3	0.3	0	5.2	5.2	2	2	1	1	4
20.1	*Open forests dominated by white cypress pine or coast cypress pine*	12.5	2.4	0.6	1	16.4	16.5	1	1	1	1	1
20.2	*Woodlands dominated by white cypress pine or coast cypress pine*	5.4	3.1	0.8	0	9.3	9.3	1	1	1	1	2
21.1	*Melaleuca dry open forest on sandplains or depositional plains*	7.8	3.7	1.4	2	14.9	14.9	1	1	1	1	1
21.2	*Melaleuca dry woodlands on sandplains or depositional plains*	3.7	3.4	0.6	1	8.7	8.7	1	1	1	1	2
21.3	*Shrubland associated with Melaleuca dry woodlands on sandplains or depositional plains*	4.3	2.3	0.9	0	7.5	7.5	1	1	1	1	3
21.6	*Sparsely vegetated areas associated with Melaleuca dry woodlands on sandplains or depositional plains*	2.5	0.2	1.8	0	4.5	4.5	3	3	2	2	6
22.1	*Melaleuca open forests on seasonally inundated lowland coastal swamps*	15.4	8	3	2	28.4	28.4	1	1	1	1	1
22.2	*Melaleuca woodlands on seasonally inundated lowland coastal swamps*	10.6	7.1	1	1	19.7	19.7	1	1	1	1	2
22.3	*Shrubland associated with Melaleuca woodlands on seasonally inundated lowland coastal swamps*	4.3	2.3	0.9	0	7.5	7.5	1	1	1	1	3
22.5	*Sedgeland associated with Melaleuca woodlands on seasonally inundated lowland coastal swamps **	6	5	1.8	1	13.8	13.8	1	1	1	1	5

Vegetation Hazard Class		Potential Fuel Load (t/ha)						Prone Type [1]		Fuel Continuity[2]		
		Surface	Near Surface	Elevated	Bark	Total (Remnant)	Total (Non- Remnant)	Remnant	Non-Remnant	Remnant	Non- Remnant	*Structural class*
23.2	*Mulga dominated woodlands on red earth plains, sandplains or residuals*	1.2	3.6	0.2	0	5	5	1	1	1	1	2
23.3	*Shrubland associated with mulga on red earth plains, sandplains or residuals.*	1.4	3.2	0.1	0	4.7	4.7	1	1	1	1	3
23.4	*Grassland associated with mulga on red earth plains, sandplains or residuals*	1.6	3.3	0.3	0	5.2	5.2	2	2	1	1	4
24.1	*Acacia open forest on residuals*	6.9	2.6	0.6	0	10.1	10.1	1	1	1	1	1
24.2	*Acacia woodlands on residuals*	4.5	2.8	0.9	0	8.2	8.2	1	1	1	1	2
24.3	*Acacia shrublands on residuals.*	2.6	2.1	2.1	0	6.8	6.8	1	1	1	1	3
24.4	*Grassland communities associated with Acacia on residuals.*	1.6	3.3	0.3	0	5.2	5.2	2	2	1	1	4
24.6	*Sparsely vegetated areas associated with Acacia on residuals*	0.3	3.6	0	0	3.9	3.9	3	3	2	2	6
25.1	*Brigalow belah open forests on heavy clay soils*	10.5	2.6	1.9	0	15	15	1	1	1	1	1
25.2	*Brigalow belah woodlands on heavy clay soils*	3.4	2.1	0.7	0	6.2	6.2	1	1	1	1	2
25.3	*Shrubland communities associated with brigalow belah on heavy clay soils*	2	1.4	0.4	0	3.8	3.8	1	1	1	1	3
26.1	*Gidgee blackwood dominated open forest*	6	1	1.4	0	8.4	8.4	1	1	1	1	1
26.2	*Gidgee blackwood woodland*	2	1.6	0.2	0	3.8	3.8	1	1	1	1	2
26.3	*Shrubland communities associated with Gidgee blackwood woodland*	1.4	1.9	1.5	0	4.8	4.8	1	1	1	1	3
27.1	*Mixed species open forests dominated by western whitewood, boree or wooded downs*	2.1	0.7	0.1	0	2.9	2.9	1	1	1	1	1
27.2	*Mixed species woodlands dominated by western whitewood, boree or wooded downs*	2	2.5	0.3	0	4.8	4.8	1	1	1	1	2
27.3	*Shrubland communities associated with mixed species woodlands*	1	0.9	0.1	0	2	2	1	1	1	1	3
27.4	*Grassland communities associated with mixed species woodlands*	0.1	4	0	0	4.1	4.1	2	2	1	1	4
27.5	*Sedgeland communities associated with mixed species woodlands*	1.6	4.3	0.1	0	6	6	1	1	1	1	5
28.1	*Open forests in coastal locations with species such as she-oak or swamp box*	22.2	2.7	2	0	26.9	26.9	1	1	1	1	1
28.2	*Woodlands in coastal locations with species such as she-oak or swamp box*	13.8	3.2	1.3	0	18.3	18.3	1	1	1	1	2
28.3	*Shrubland associated with woodlands in coastal location*	12.2	2.2	2.5	0	16.9	16.9	1	1	1	1	3
28.4	*Grassland associated with woodlands in coastal locations*	8	2.4	2	0	12.4	12.4	1	1	1	1	4
28.5	*Sedgeland associated with woodlands in coastal locations**	6	5	3.5	1	15.5	15.5	1	1	1	1	5

Vegetation Hazard Class		Potential Fuel Load (t/ha)						Prone Type [1]		Fuel Continuity[2]		
		Surface	Near Surface	Elevated	Bark	Total (Remnant)	Total (Non- Remnant)	Remnant	Non-Remnant	Remnant	Non- Remnant	*Structural class*
28.6	*Sparsely vegetated areas associated with woodlands in coastal locations.*	1	1	1.3	0	3.6	3.6	3	3	2	2	6
29.1	*Forests associated with heathlands and scrubs*	18.1	2.6	3.2	1	24.9	24.9	1	1	1	1	1
29.2	*Woodlands associated with heathlands, scrubs and shrublands*	12	4.8	7.5	0	24.3	24.3	1	1	1	1	2
29.3	*Heathlands and associated scrubs and shrublands*	11.6	2.9	5.6	0	20.1	20.1	1	1	1	1	3
29.4	*Grassland communities associated with heathlands, scrubs and shrublands*	4.8	4.4	2	0	11.2	11.2	1	1	1	1	4
29.5	*Sedgeland communities associated with heathlands, scrubs and shrublands*	3	5	3.5	0	11.5	11.5	1	1	1	1	5
29.6	*Sparsely vegetated areas associated with heathlands, scrubs and shrublands*	0	2.1	0.5	0	2.6	2.6	3	3	2	2	6
30.2	*Woodlands associated with Mitchell grass or bluegrass*	1	2.9	0.1	0	4	4	1	1	1	1	2
30.3	*Shrublands associated with Mitchell grass or bluegrass*	0.8	2	1.4	0	4.2	4.2	1	1	1	1	3
30.4	*Mitchell grass or bluegrass tussock grasslands*	0.8	4	0	0	4.8	4.8	2	2	1	1	4
30.5	*Sedgelands associated with Mitchell grass or bluegrass*	1.6	4.3	0.1	0	6	6	1	1	1	1	5
31.2	*Woodlands associated with inland forblands to tussock grasslands*	1	3	0.7	0	4.7	4.7	1	1	1	1	2
31.3	*Shrublands associated with inland forblands to tussock grasslands*	0.8	2	1.4	0	4.2	4.2	1	1	1	1	3
31.4	*Mixed open forblands to tussock grasslands in inland locations*	0.6	2.1	0.1	0	2.8	2.8	2	2	1	1	4
31.5	*Mixed open sedgelands associated with inland tussock grasslands*	0.6	0.2	0.1	0	0.9	0.9	3	3	2	2	5
32.2	*Woodlands associated with coastal closed tussock grasslands*	2.4	4.4	0	0	6.8	6.8	1	1	1	1	2
32.3	*Shrubland associated with coastal closed tussock grasslands*	0.8	2	1.4	0	4.2	4.2	1	1	1	1	3
32.4	*Closed tussock coastal grasslands*	2.1	3.6	0.3	0	6	6	2	2	1	1	4
33.3	*Shrublands associated with Hummock grasslands*	0.8	2	1.4	0	4.2	4.2	1	1	1	1	3
33.4	*Hummock grasslands dominated by spinifex or sand hill cane grass*	0.6	1.2	0.2	0	2	2	2	2	1	1	4
33.5	*Sedgeland associated with hummock grasslands*	0.4	1.1	1.2	0	2.7	2.7	3	3	2	2	5
34.1	*Open forest dominated wetlands*	6	3.4	5.3	1.7	16.4	16.4	1	1	1	1	1
34.2	*Woodland dominated wetlands*	2.5	4	0.2	1.3	8	8	1	1	1	1	2
34.3	*Shrubland dominated wetlands*	1.3	3.3	2.3	0	6.9	6.9	1	1	1	1	3
34.4	*Grass dominated wetlands*	1	4	0	0	5	5	2	2	1	1	4
34.5	*Sedgeland dominated wetlands**	3	5	5	0	13	13	1	1	1	1	5

Vegetation Hazard Class		Potential Fuel Load (t/ha)						Prone Type [1]		Fuel Continuity[2]		
		Surface	Near Surface	Elevated	Bark	Total (Remnant)	Total (Non- Remnant)	Remnant	Non-Remnant	Remnant	Non- Remnant	*Structural class*
34.6	*Sparsely vegetated wetlands*	1.1	3.1	0	0	4.2	4.2	3	3	2	2	6
35.1	*Closed to open forest mangroves*	0	0	0	0	0	0	3	3	2	2	1
35.3	*Shrubland associated with mangroves and tidal saltmarshes*	0	0	0	0	0	0	3	3	2	2	3
35.4	*Tidal saltmarshes*	1	2.9	0.2	0	4.1	4.1	2	2	1	1	4
35.5	*Sedgeland associated with mangroves and tidal saltmarshes*	0.4	1.3	0	0	1.7	1.7	3	3	2	2	5
35.6	*Sparsely vegetated areas associated with mangroves and tidal saltmarshes*	0.9	1.9	0.2	0	3	3	3	3	2	2	6
36.1	*Exotic & hardwood plantation*	22.3	1.5	1.2	1	26	26	1	1	1	1	1
37.1	*Hoop plantations*	3	2	0	0	5	5	3	3	2	2	1
38.4	*Continuous dryland cropping and horticulture*	0.8	3	0	0	3.8	3.8	2	2	1	1	4
38.5	*Discontinuous irrigated cropping and horticulture*	0.5	1	0.5	0	2	2	3	3	2	2	5
39.2	*Low to moderate tree cover in built-up areas*	2	3	2	1	8	8	3	3	2	2	2
40.4	*Continuous low grass or tree cover*	0.5	4	0.5	0	5	5	2	2	1	1	4
41.4	*Discontinuous low grass or tree cover*	0.5	2	0.5	0	3	3	3	3	2	2	4
42.6	*Nil to very low vegetation cover*	1	1	0	0	2	2	3	3	2	2	6
43.6	*Water bodies or very low vegetation cover*	0	0	0	0	0	0	3	3	2	2	6

Table 4 - Structure class decay contants (*k*)

Structure Class	Description	Decay constant (*k*)
1	Trees closed - mid dense	0.65
2	Trees sparse - very sparse	0.35
3	Shrubland	0.26
4	Grassland	0.8
5	Sedgeland	0.8
6	Nil veg	0

CONTACT US

t 1300 363 400
+61 3 9545 2176
e enquiries@csiro.au
w www.csiro.au

FOR FURTHER INFORMATION

CSIRO Land and Water Flagship
Justin Leonard
t +61 3 9252 6353
e justin.leonard@csiro.au