Verification of time-since-fire in Gippsland from charring retained on stringybark trees

Fire and adaptive management report no. 92

Lucas Bluff | November 2014

Department of Environment and Primary Industries

State Government Victoria

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Cover image: Base of a stringybark eucalypt showing bark charring following a planned burn (Lucas Bluff).

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Contents

Figures and tables

Abbreviations

AIC, AICc	Akaike Information Criterion; a measure of the quality (e.g. parsimony) of a statistical model, AICc is a modified version with correction for finite sample size
CSDL	Corporate Spatial Data Library; DEPI's main repository of GIS data
DBH	Diameter at Breast Height; a measure of tree diameter, conventionally taken at 1.3 metres above ground, over bark
DEPI	Department of Environment and Primary Industries, Victoria; formed in 2013 by the amalgamation of the DSE and the Department of Primary Industries
DSE	Department of Sustainability and Environment, Victoria; see DEPI, above
EVD	Ecological Vegetation Division; a high-level grouping of vegetation classes, each EVD comprises more than one Ecological Vegetation Class
GIS	Geographical Information System
LME	Linear Mixed Effects; a statistical modelling method that includes fixed and random effects
ML	Maximum Likelihood; a method for estimating the parameters of a statistical model
NLS	Non-linear Least Squares; a statistical model-fitting method as applied by an R function of the same name
R	An open-source statistical computing environment
REML	Restricted Maximum Likelihood; as for ML but generally considered more robust
SE	Standard Error; the standard deviation of a statistical parameter
SEM	Standard Error of the Mean; the standard deviation of the estimate for the mean
TSF	Time-Since-Fire

Summary

The Department of Environment and Primary Industries (DEPI) is responsible for bushfire management on public land in Victoria.

Landscape-scale mapping of time-since-fire is a key tool that enables DEPI to fulfil its fire-management objectives related to human risk and ecological resilience. However, existing fire history datasets are known to be imperfect.

Collecting accurate data on local fire history is reliant on an accurate means of accepting or rejecting the mapped fire history by comparison with conditions observed on the ground. This report tests the idea that charring retained on the base of stringybark eucalypts can provide a reliable indicator of time since the last fire.

Statistical modelling of data from 2000 trees across 100 sites found that stringybark charring was strongly negatively related to the time elapsed since fire, with a secondary positive relationship to tree diameter. A simplified method of fire history verification was then developed for use in the field by practitioners of fire planning, fire ecology or planned burning. Statistical models and the simplified field method were tested on a separate dataset of 420 trees across 21 sites. The field method resulted in the identification of correct fire history for at least 20 of the 21 sites.

The method of visual fire history verification provided as an Appendix to this report is therefore recommended for initial usage at sites within the ecological envelope of the current datasets. The rationale developed here can be used to develop datasets of broader geographical and ecological scope.

Figure 1: Charred trunks reveal comparatively recent fire history in a wet gully, East Gippsland (Lucas Bluff).

Context

The *Code of Practice for Bushfire Management on Public Land* (DSE 2012) provides two primary objectives for fire management:

- To minimise the impact of major bushfires on human life, communities, essential and community infrastructure, industries, the economy and the environment.
- To maintain or improve the resilience of natural ecosystems and their ability to deliver services such as biodiversity, water, carbon storage and forest products.

The Code requires monitoring, evaluation and reporting of metrics for both of the primary objectives. It also requires that the learnings from science are used to refine models that support decision making. This in turn requires an accurate spatial dataset of fire history, and confidence in the fire history information associated with incoming field data.

Spatial fire history data are typically accessed via the Department of Environment and Primary Industries (DEPI) Corporate Spatial Data Library (CSDL; e.g. the FIRE_HISTORY and FIRE_HISTORY_LASTBURNT layers). Past, present and/or proposed uses of this dataset include:

- Mapping predicted fuel levels and prioritisation of sites for planned burning or other fuel reduction measures
- Prediction of bushfire spread using Phoenix Rapidfire software
- Monitoring, reporting, and planning for ecological resilience on the basis of Tolerable Fire Intervals (Cheal 2010, DEPI 2013)
- Monitoring, reporting, and planning for ecological resilience on the basis of fauna abundance as a function of time-since-fire (MacHunter et al. 2009, DEPI 2013)
- Identifying ecological values, such as long-unburnt vegetation in key vegetation types, for protection during and via planned burning
- Design and conduct of monitoring programs for fuel hazard (Tolhurst & Kelly 2003, McCarthy 2007) and ecological modelling (e.g. Muir et al. 2013).

Confidence in fire history spatial data is clearly needed for many activities DEPI undertakes to satisfy the Code of Practice. However, existing data are imperfect because:

- Very little fire mapping, especially of planned burning, pre-dates the 1970s; many earlier fires are unmapped
- Until the early 1990s, fire mapping was conducted on paper maps that were stored locally and when these maps were later digitised, data were not necessarily complete
- Planned burns are mapped at Fire District level and mapping standards have varied over time and between Districts
- Considerable inconsistency remains between Fire Districts and Regions on whether submitted fire history data include ‘treated area’ (i.e. block polygons of the burn boundaries, ignoring burnt and unburnt patches), or finer-resolution mapping of only areas that were actually burnt
- Detailed post-fire mapping on a large scale requires substantial investment and development of appropriate methods.

This document reports on work undertaken as part of the HawkEye – Biodiversity Monitoring for Improved Fire Management Project to develop a method for validation of fire history data during field surveys. A landscape-scale monitoring program was undertaken in Gippsland by the HawkEye project in collaboration with the Arthur Rylah Institute (Muir *et al.* 2013). Candidate sites were stratified by, among other factors, time-since-fire (identified by GIS methods). Field staff then assessed sites on the ground for inclusion in the program. This process revealed that comparing fire-history mapping to actual conditions at a site is challenging, and even experienced field staff may lack confidence, accuracy, and/or precision.

Introduction

Most previous work on inferring past fire history has used dendrochronology (i.e. tree-ring dating). The bulk of this research has been conducted in North America (Gill and McCarthy 1998), but some studies have applied the method to Australian forests (e.g. Simkin and Baker 2008, Zimmer *et al.* 2010, Gosper *et al.* 2013). However, the method requires specialist equipment and techniques, species with clear annual growth rings, is restricted to higher-severity fires, and does not provide results *in situ* to inform site selection for monitoring. An alternative method for inferring past fires can be used where one or more flora species is (at least partially) killed by fire and regrows at an estimable rate. For example, Clarke and colleagues (2010) successfully developed and tested estimates of time-since-fire based on stem diameter of Mallee eucalypts. This method is most suitable for systems where fire causes complete stand replacement, however it can in principle be adapted to partial stand replacement. For example, composition of mixed-age stands and understorey structure differ between Ash forest age classes even if fire events are non – or partially – stand replacing (Lindenmayer *et al.* 2000). However, use of the method in non-stand-replacing systems would (i) involve considerable forest mensuration effort, (ii) be affected by even selective, historical logging, and (iii) be less reliable for the low-severity, patchy fires often produced by planned burning in dry forest types.

This project tests the reliability of an alternative measure of time-since-fire: charring retained on the bases of stringybark eucalypts. Stringybark trees have highly flammable bark (DSE 2010) that ignites in all but the very lowest fire intensities, and retains a charred appearance long after fire (Figure 2). Brief field inspection of recently burnt versus long-unburnt sites shows that: a) the bases of stringybarks are mostly charred immediately after fire; b) long-unburnt trunks have little or no charring; and c) trees that have never experienced fire have no charring. If the decrease in the extent of charring on stringybark bases is a reliable function of increasing time-since-fire, it may provide a quick and easy method of validating DEPI's fire mapping at individual sites. The rationale of the project is (i) to quantify the charring on the base of stringybarks at a large number of sites over the greatest possible range of times-since-fire, (ii) to investigate statistically the relationship between char, time and other variables, in order to (iii) develop a method for accepting or rejecting mapped fire histories and (iv) test this method using a second, independent dataset.

Figure 2: Base of a White Stringybark *Eucalyptus globoidea* showing charring consistent with mapped fire history, 16 years after a planned burn (Lucas Bluff).

Aims

This project aims to develop and test methods to produce:

1. Exploratory statistical modelling to inform fire history verification at site level in future monitoring programs, including:
    - Quantification of site and tree-level variables influencing char
    - Examination of alternative statistical models for the relationship between char and time-since-fire
    - Development of a method for identifying sites with suspect fire history, taking into account site- and tree-level predictors.
2. A visual guide to fire history verification for use by field staff, which:
    - Allows field staff to accept or reject alternative fire histories on-site
    - Provides a basis for making decisions that are objective and quantitative, rather than subjective and qualitative
    - Is intuitive and quick to use, with no statistical knowledge and minimal training required.

Methods

Pilot project

An opportunistic pilot project commenced in late 2011, as part of the Retrospective Fire Project in Gippsland (see Muir *et al.* 2013). Two Ecological Vegetation Divisions (EVDs), Grassy/Heathy Dry Forest and Tall Mixed Forest were selected for study on the basis of their prevalence in areas subject to planned burning across Gippsland. The other primary stratification was conducted on the basis of fire history categories that were combinations of counts of fire since 1970 and time-since-fire. The 50 sites (of a total of 154) funded by the HawkEye project were allocated to three time-since-fire categories: 0–5 years, 11–20 years, and 40+ years since fire. While visiting sites for other surveys, an opportunistic dataset was compiled of 300 photographs, from six trees per site. Photos were of the bottom 1.2 m on the eastern aspect of the three stringybarks greater than 20 cm diameter at breast height (DBH; taken at 130 cm above ground level), and the three stringybarks less than 20 cm DBH, closest to the plot centre. A subset of 10 photos was chosen to represent char levels ranging from 1 (negligible charring) to 10 (complete charring) (see Appendix 1). Each of the 300 stringybark trunk photos was randomly renamed, then viewed in random order and classified to one of the 10 char levels. This process was repeated independently by four observers. Scores were compared across observers to test for reliability of char-level classification. Scores for each tree were averaged across observers, and scores for sites were averaged across trees within each of the two size classes. The resulting char scores were plotted against time-since-fire, with logarithmic trend-lines fitted in Microsoft Excel 2003. Sites without mapped fire history (n = 7) were initially fitted to this plot as last burnt in 1965 (i.e. corresponding to the largest unmapped fire in the broader area).

These graphs were used to re-assess fire history at all 154 sites in the Retrospective Fire Project, initially via comparison against vegetation plot photographs, followed up by field visits to suspect sites. Mapped fire history was compared to char levels on stringybarks (versus trendlines from 50 sites), and other markers of fire history such as coarse woody debris, fuel hazard, and presence and size of fire intolerant flora species. Fire history at individual sites was classified as correct, probably correct, plausible, probably or definitely incorrect. Sites in the latter category (n = 20) were reallocated to the most likely alternative fire history for project analysis purposes.

A final extension of the pilot project focused on improving confidence at longer times-since-fire. Targeted surveys were conducted at a new set of sites (n = 12) without fire history data, but which were within the footprint of the 1965 fire (based on contemporaneous newspaper reports). Data from these new sites were included and other sites without mapped fire history were excluded from the plots used in the field to screen potential sites for the current project (see Field Methods, below).

Site selection: model-building dataset

A target sample size of 100 sites for model construction and 20 sites for model testing was determined *a priori* based on the level of variation observed in the pilot project. Likewise, a sample size of 20 trees per site was selected on the basis of within-site variation levels observed in the pilot project.

Occurrence of both type I and II error (false positives and false negatives, respectively) in fire mapping necessitated exclusion of sites with clearly incorrect fire history. For efficiency, a subset of sites (n = 47) deemed to have correct fire history (from photographic and/or field verification) was selected from the Retrospective Fire Project. Original stratification of this project was conducted within 20 x 20 km landscape tiles to avoid geographical confounding with stratification variables. This set of sites was complemented by GIS work to locate additional sites, producing the most even distribution feasible across the following factors: seven time-since-fire bins (1–5, 6–10, 11–21, 22–31, 32–41, 42+ years), two types of fire (planned burn, bushfire) and two EVDs (Grassy/Heathy Dry Forest, Tall Mixed Forest). Additional desirable criteria were to spread sites geographically, to spread sites across years within time-since-fire bins, and to place each site in a unique fire event if possible. The last criterion was unavoidably breached at longer times-since-fire due to temporal bias in fire mapping completeness; oversampling bushfire events from 1965 (n = 7) and 1939 (n = 7) was needed to boost sample size in the oldest time-since-fire bin. However, these were very large fires and permitted a large geographical spread of points within their footprints to minimise pseudoreplication.

Site selection: model-testing dataset

Data collection for the second, independent set of sites for model testing (n = 21) was interspersed with collection for the primary (model-building) dataset. These sites were selected haphazardly and when logistically convenient (e.g. time available after visiting primary target sites), without knowledge of fire-history mapping. An effort was made to distribute sites evenly across the full range of stringybark char levels. Site-level variables (EVD, fire type, time-since-fire) for these sites were derived from the CSDL. Given known error in vegetation mapping, sites which appeared to match one of the target EVDs on the ground, but were mapped as being outside of these EVDs, were allocated to whichever EVD was geographically closest.

Field methods

Data collection was conducted between the 15th November 2012 and 3rd January 2013. Site visits commenced with a visual assessment to exclude sites with clearly incorrect fire history. This assessment included a standard fuel hazard assessment (DSE 2010) as well as consideration of presence and abundance of: woody debris, moss and lichen, understorey and midstorey flora species, especially the fire-sensitive, bird-dispersed taxa *Elaeocarpus reticulatus* and *Exocarpus cupressiformis*. Stringybark charring was also examined against the graph produced by the pilot project with data from trees greater than 20 cm DBH, however sites were not excluded on this criterion alone unless there was an obvious conflict with the pilot dataset. At Retrospective Fire Project locations, the original plot centres were not revisited (i.e. all trees included in the new dataset had not been sampled previously). For the model-testing dataset, sites were not checked against fire-history mapping but were screened for within-site consistency of observable signs of fire history. In total, data were collected from 101 and 21 sites for the model-building and model-testing datasets, respectively. One model-building site was subsequently excluded from analysis (see Results), i.e. the final dataset included 100 sites.

Once a site was accepted, 20 stringybark trees were sampled haphazardly on the basis of proximity: the nearest qualifying tree to the current tree was visited next. In a minority of cases (~10%) trees were targeted on the basis of DBH; larger or smaller than average (for the site) trees were occasionally sampled to facilitate subsequent model fitting. Trees were not sampled if they were less than 30cm DBH, dead or senescent, or had evidence of physical damage that would impede tree growth (e.g. strong die-back, broken crowns, hollowbutt). Species included were *Eucalyptus baxteri*, *E. consideniana*, *E. conspicua*, *E. globoidea*, *E. macrorhyncha*, *E. muelleriana*, and *E. obliqua*. A Trimble Nomad field computer was used to record tree position (fixes per tree: 50.72 ± 0.32; mean number ± SEM), tree species and DBH, as well as photograph the tree for subsequent char assessment. Photographs were taken of the tree base from the ground to at least 1.2m, from a northern aspect to avoid shadow where possible, and a measuring tape was included in the photograph for scale.

Data management

Differential correction of tree position succeeded in the majority of cases (95.0%). In the remainder of cases, uncorrected coordinates were used. Each tree photograph was renamed to a random code, and photos were classified by the same observer (LB) in random order, according to the ten defined levels of charring (Appendix 1). Therefore, tree char classification was independent of, and naïve to, site-level predictor variables (e.g. time-since-fire). While classification was purely on the basis of the amount of charring visible below 120cm, it was also recorded whether the observed char level was due to initial patchiness of fire, to tree growth since fire, or to both effects in combination. File name codes were then used to unite tree char values with tree- and site-level predictor variables in Microsoft Excel 2003.

Exploratory statistical analysis

A set of complementary statistical modelling approaches was implemented in R 3.0.1 (The R Foundation for Statistical Computing, 2013), using the model-building dataset exclusively. Exploratory curve fitting for the [char ~ time-since-fire] relationship was conducted using the nls() and loess() functions. Curves of the form [char ~ a x log(time-since-fire)+b] and [char ~ a x $e^{-b \times \text{time-since-fire}}$ + c] provided visually satisfactory fits, but the former was selected as easier to implement in other functions. Linear mixed effects modelling was commenced using REML estimation after Zuur *et al.* (2009), with site as a random effect and appropriate random effect structure (none/random slope/random intercept and slope) determined by AIC values of saturated models. After the random slope (only) structure was chosen, model selection based on AICc values was conducted for all possible subsets of the saturated model using ML estimation (fixed predictors: log[time-since-fire], EVD, fire type, DBH, plus all interaction terms and site as a random effect). Final model parameters were reported for (i) the single best (lowest AICc) model, and (ii) the average of all models where the AICc were within two units of the best model. Model assumptions for (i) were checked using standard residual plots. This approach was repeated with the addition of species as a fixed factor, for a subset of trees (n = 1,177) from species with sample sizes > 100 (*E. consideniana*, *E. globoidea*, *E. macrorhyncha* and *E. muelleriana*), excluding cases of original char patchiness, and from sites (n = 77) with ≥10 qualifying trees. The addition of species required dropping EVD *a priori* for models to converge; this was deemed acceptable given EVD was not a retained term in final models for the full dataset. Equivalent r^2 values for final models were calculated after Nakagawa and Schielzeth (2013).

Heuristic fire history validation tool for field use

The mixed-effects modelling approach described above takes into consideration several explanatory variables at both tree- and site- level, but it requires statistical training to implement and is only suited to desktop analysis within larger projects. The more immediate aim of this project is to produce a heuristic tool that provides practitioners with an objective basis on which to accept or reject the mapped fire history at a site *while in the field.* To achieve this, tree-level char data were aggregated to the site level, and quantile regression was conducted for (char ~ log[time-since-fire]), i.e. ignoring tree diameter, species and site EVD. Quantile regression can be used to provide a selected inter-quantile zone containing (for example) 90% of observed data between the 0.05 and 0.95 percentiles. This zone can then be used to identify new data that are inconsistent with previously observed data; for example, to identify whether individual children fall outside the growth rates of previously observed 'normal' children (Wei e*t al.* 2006). In the present application, quartile regression provides the end user with a visual 'band of previous data' for the relationship between time-since-fire and stringybark char, against which they can compare a new site. The supplied version of the tool is based on the full inter-quartile range, i.e. all data from 100 sites in the model-building dataset. This is a conservative approach, as an unknown proportion of the sites at the extremities of the inter-quartile range will have incorrect fire history, meaning that the inter-quartile range of an error-free dataset would be smaller.

Two approaches were taken to test whether the simplified fire history validation tool is fit for purpose. First, the simplified (char ~ log[time-since-fire]) model was compared to the best mixed model, both statistically and visually. Secondly, the tool was applied to the set of model-testing sites (n = 21) that were sampled without knowing their mapped fire history and had not been used in the model-building process. Sites beyond the fitted 100% regression quartiles (i.e. beyond the extremities of the char versus time-since-fire relationship observed across the preceding 100 sites) were re-assessed to determine their actual (versus mapped) fire history. This included a combination of: desktop GIS mapping, contact with experienced local DEPI Land and Fire personnel, and field visits to reassess fire history.

Results

Exploratory statistical analysis

One site with a long time-since-fire (1939 bushfire) formed a high char-level outlier and was ambiguously close to a more recent (1959) fire. Excluding this site from further analysis left a model-building dataset of 2,000 stringybark trees across 100 sites and a further 420 trees across 21 sites for model validation. Sites were spread across an area of ~ one million hectares (Figure 3) and ranged from 2 to 74 years since fire (Figure 4).

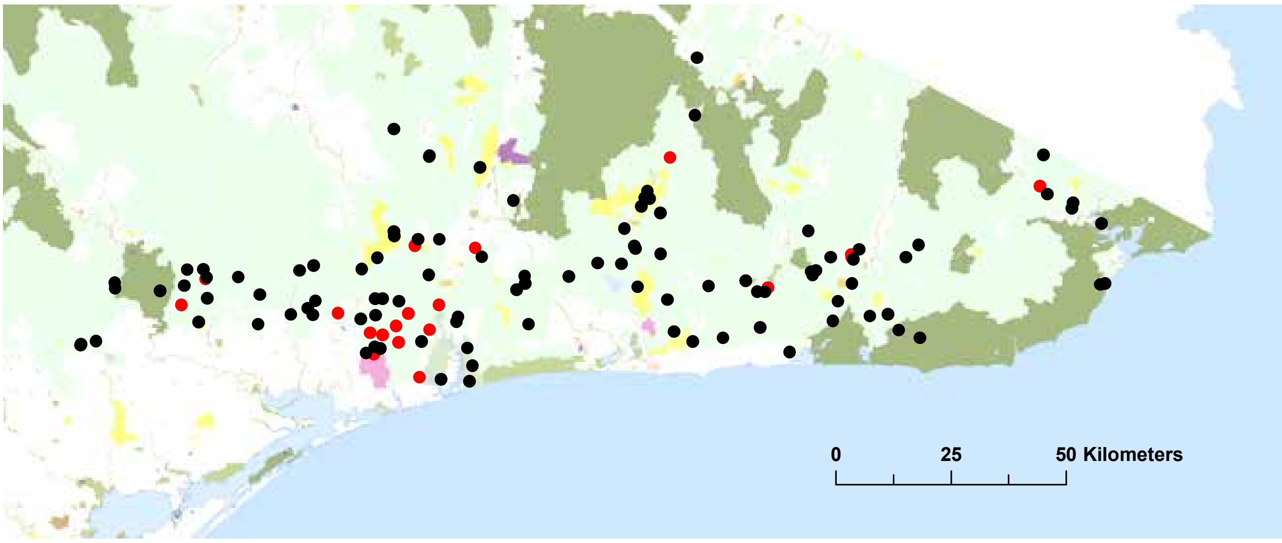

Figure 3: Map of n = 100 model-building sites (black) and n = 21 model-testing sites (red).

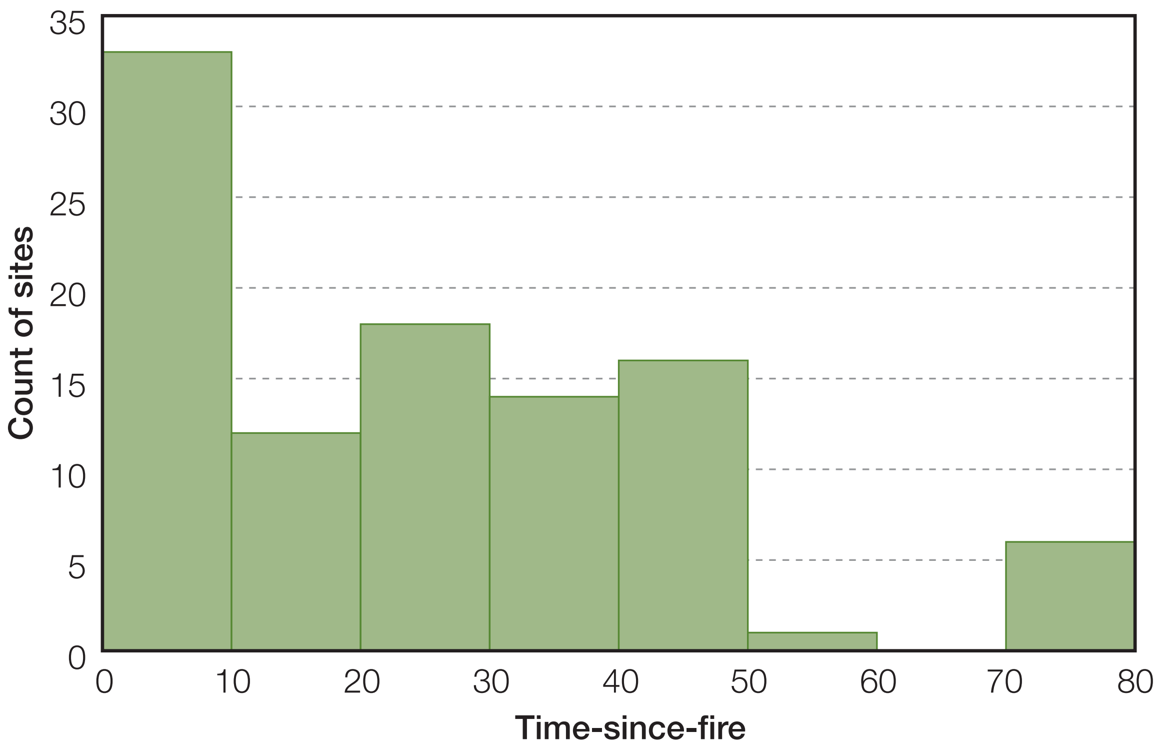

Figure 4: Histogram of n = 100 sites by time-since-fire (10 year bins).

The dominant predictor variables for bark charring in all models were time-since-fire and an interaction between time-since-fire and DBH (Table 1). There is strong evidence for a decrease in charring observed on stringybark trees as time progresses after a fire (Table 1 and Figure 5). Moreover, the significant interaction between time-since-fire and DBH (Table 1, Figure 6) suggests that tree growth may be the causal factor for the decrease in charring over time; larger trees have relatively lower rates of DBH increase and therefore higher retained charring as a function of time. There was some evidence from the reduced dataset that stringybark species differ in their char retention over time (Table 1); however, interpretation of this and other main effects (e.g. fire type) was complicated by interactions. Overall, the effects of species and fire type appear to be subordinate to, and mediated by, dominant relationships between charring, time-since-fire, and tree diameter (Figures 5 and 6).

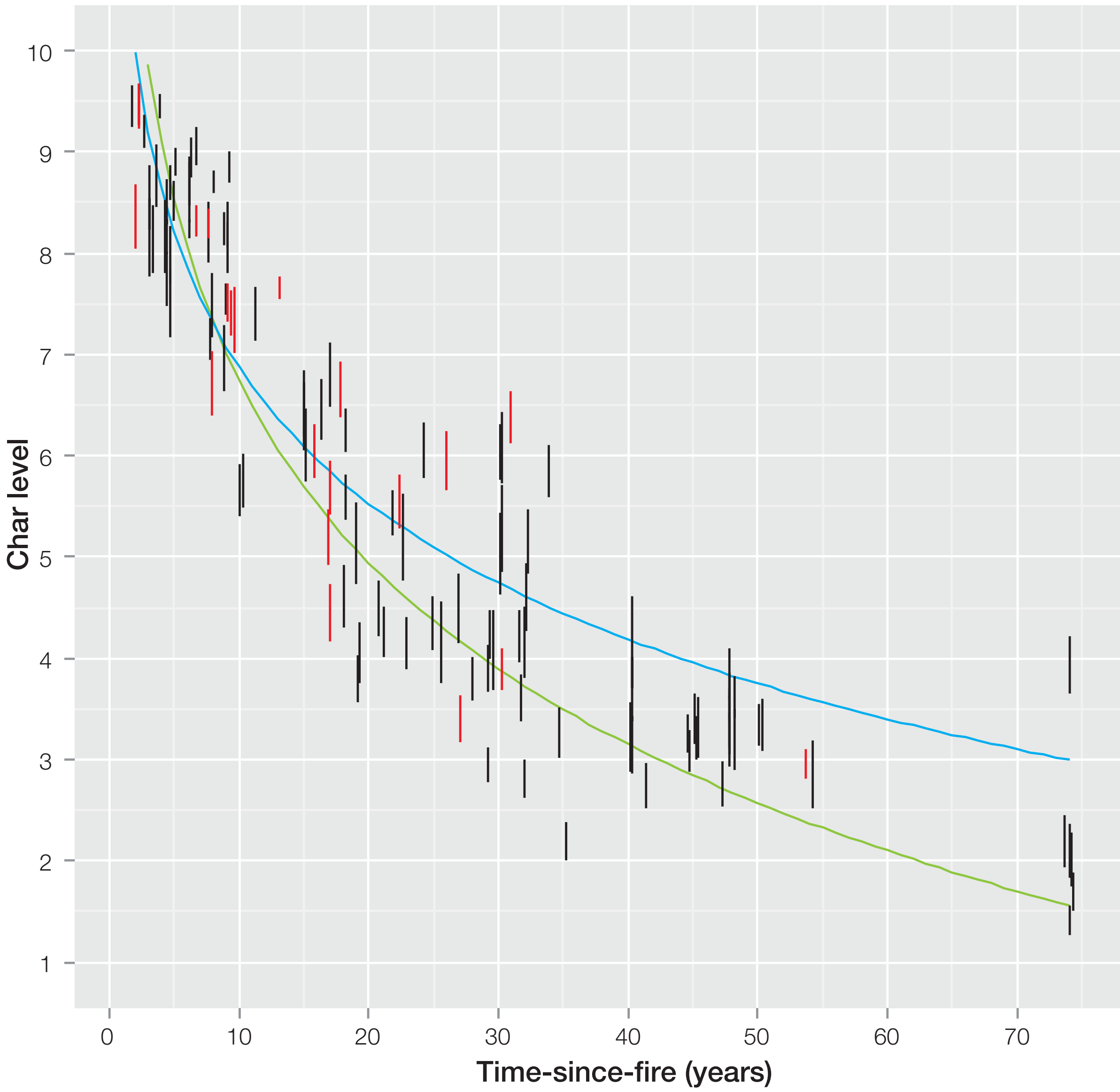

Figure 5: Data and modelled relationship between stringybark char level and time-since-fire. Black lines represent mean ± SEM charring across n = 20 trees for each of n = 100 sites across Gippsland that formed the model-building dataset. Red lines represent the same measure for n = 21 sites forming an independent model-testing dataset collected without *a priori* knowledge of fire history at sites. Two representative lines of model fit are shown for different parameters in the most parsimonious single model (Table 1): the blue line is for trees of 100 cm DBH exposed to bushfire; the green line is for trees of 30 cm DBH exposed to planned burning.

Table 1: Details of linear mixed models for charring retained on individual stringybark trees. Results are reported for the full model-building dataset (n = 2,000 trees), and separately for the reduced dataset including trees of four main species (n = 1,177, see methods). In each case, the predictor variables retained in the most parsimonious model (lowest AICc), and averaged over all models where the AICc was within two units of the most parsimonious model. Variables with significant effects at the $p < 0.05$ level are shown in bold, and variables that were not included in the model selection process are shaded grey.

	Full model-building dataset						Reduced dataset inc. tree species					
	Lowest AICc			Average of 5 models < 2 AICc			Lowest AICc			Average of 4 models < 2 AICc		
Predictor variable	**Estimate**	**SE**	**p-value**	**Estimate**	**SE**	**p-value**	**Estimate**	**SE**	**p-value**	**Estimate**	**SE**	**p-value**
(Intercept)	**12.770**	**0.422**	**<0.001**	**12.656**	**0.553**	**<0.001**	**12.817**	**0.656**	**<0.001**	**12.624**	**0.724**	**<0.001**
Diameter at Breast Height	**-0.014**	**0.007**	**0.030**	-0.016	0.008	0.051	-0.013	0.011	0.206	-0.012	0.011	0.280
Fire type: Bushfire	0.064	0.291	0.827	0.297	0.645	0.648	-0.399	0.364	0.276	-0.198	0.578	0.735
log (Time-Since-Fire)	**-2.868**	**0.151**	**<0.001**	**-2.810**	**0.209**	**<0.001**	**-2.835**	**0.222**	**<0.001**	**-2.795**	**0.243**	**<0.001**
EVD 7				-0.146	0.156	0.355						
E. globoidea							0.228	0.153	0.137	0.352	0.286	0.218
E. macrorhyncha							0.123	0.196	0.530	0.405	0.556	0.466
E. muelleriana							**0.514**	**0.182**	**0.005**	**0.490**	**0.302**	**0.105**
DBH: Bushfire	0.010	0.005	0.030	0.013	0.009	0.171	**0.018**	**0.006**	**0.002**	**0.018**	**0.006**	**0.002**
DBH: log(TSF)	**0.009**	**0.002**	**<0.001**	**0.010**	**0.003**	**0.001**	**0.007**	**0.004**	**0.043**	**0.007**	**0.004**	**0.048**
DBH: *E. globoidea*										-0.005	0.007	0.499
DBH: *E. macrorhyncha*										**-0.020**	**0.010**	**0.046**
DBH: *E. muelleriana*										0.002	0.008	0.839
Bushfire: log(TSF)				-0.164	0.269	0.546				-0.229	0.254	0.374
Bushfire: *E. globoidea*										**-0.638**	**0.315**	**0.043**
Bushfire: *E. macrorhyncha*										-0.365	0.402	0.365
Bushfire: *E. muelleriana*										-0.159	0.377	0.673
DBH: Bushfire:log(TSF)				-0.006	0.005	0.277						

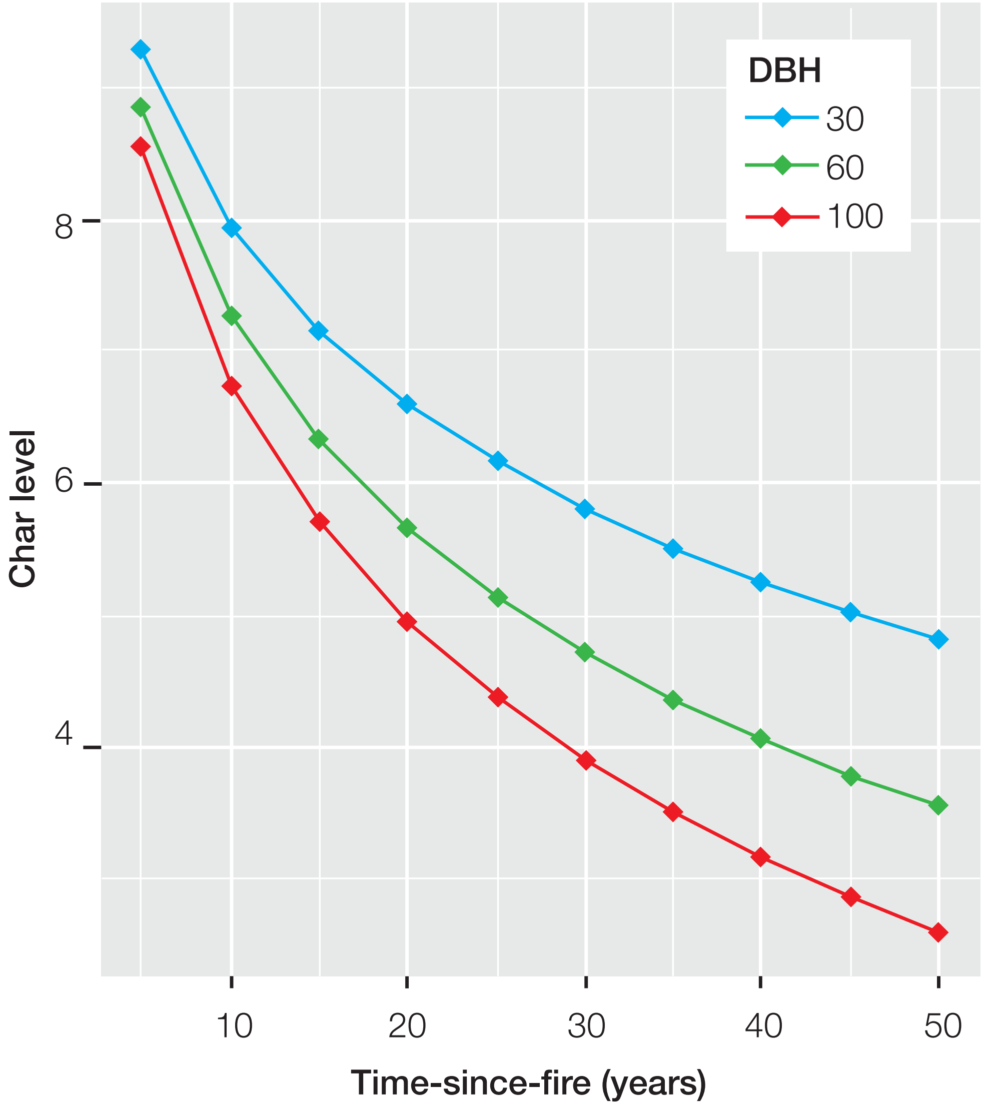

Figure 6: Plot of model predictions for the lowest AICc, full dataset model (see Table 1), illustrating the interaction between DBH(cm) and time-since-fire. Larger diameter trees apparently have a slower rate of decrease in charring. This supports the notion that tree growth is the main mechanism of char decrease over time.

Quantifying the predictive ability of statistical models

Models explained a satisfactory amount of the observed variation in tree char. The most parsimonious model using the full model-testing dataset (Table 1) explained 71% of variation (r^2 equivalent, see Nakagawa and Schielzeth 2013) in charring with fixed effects only, and 79% when site-level random effects were included. While this full model had significantly better fit to the data than a minimal model with time-since-fire as the only fixed effect ($p < 0.001$), the minimal model was only marginally lower in terms of variation explained (68% fixed-effects only, 77% including site-level random effects). This indicates good potential for a simplified model to successfully predict time-since-fire.

Both the most parsimonious/full dataset model and the simplified time-since-fire only model were applied to the test dataset (subsequent to correction of mapped fire histories in the test dataset, see below). The correlation between the simple model predictions of bark charring and observed test data was in fact higher (r = 0.75) than between the full model and the test data (r = 0.64). Again, these relatively high correlations between model predictions and independent test data at individual tree-level support the use of a simple time-since-fire based model to validate fire history at new sites.

Testing the fire history validation tool

The graphical method for site-level, fire history validation (Appendix 1), was trialled on the test dataset that had been collected with no knowledge of fire history at individual sites. This was a two-step process; given the known errors in the fire history layer, any significant discrepancy between predicted and observed fire history required secondary inspection of mapped fire histories and revisits to sites. Mapped fire history was between the 100% regression quantiles for 15 of 21 sites. Of the remaining six sites, one was correctly identified as a false positive (i.e. a mapped fire that did not extend to the site visited), and two sites were correctly identified as false negatives (i.e. plot coordinates were just outside mapped boundaries of fires that would result in a match between predicted and observed charring). The remaining three sites plotted higher than the top regression quantile for their mapped time-since-fire, with no nearby alternative fires to provide explanations. One of these was obviously a false negative, which was confirmed by the local Operations Coordinator. A further putative false negative site contained a population of *Banksia spinulosa*, for which growth rates for several morphometrics have been established (Muir 2011). As both char and *B. spinulosa* growth models were in tight agreement with each other and disagreement with the mapped fire history, this was deemed another correctly-identified false negative. The remaining putative false negative could not be resolved; the char level was higher than the 100% quantile band, but local contacts could not recall any intervening fire events. This last case could result from (i) a genuine false negative, (ii) exceptional retained charring, e.g. due to poor growth rates, (iii) non-exceptional variation and/or sampling error at the rate expected for $\alpha = 0.05$. In short, the simple graphical method for fire history verification successfully diagnosed correct and incorrect fire histories in at least 20 of 21 cases.

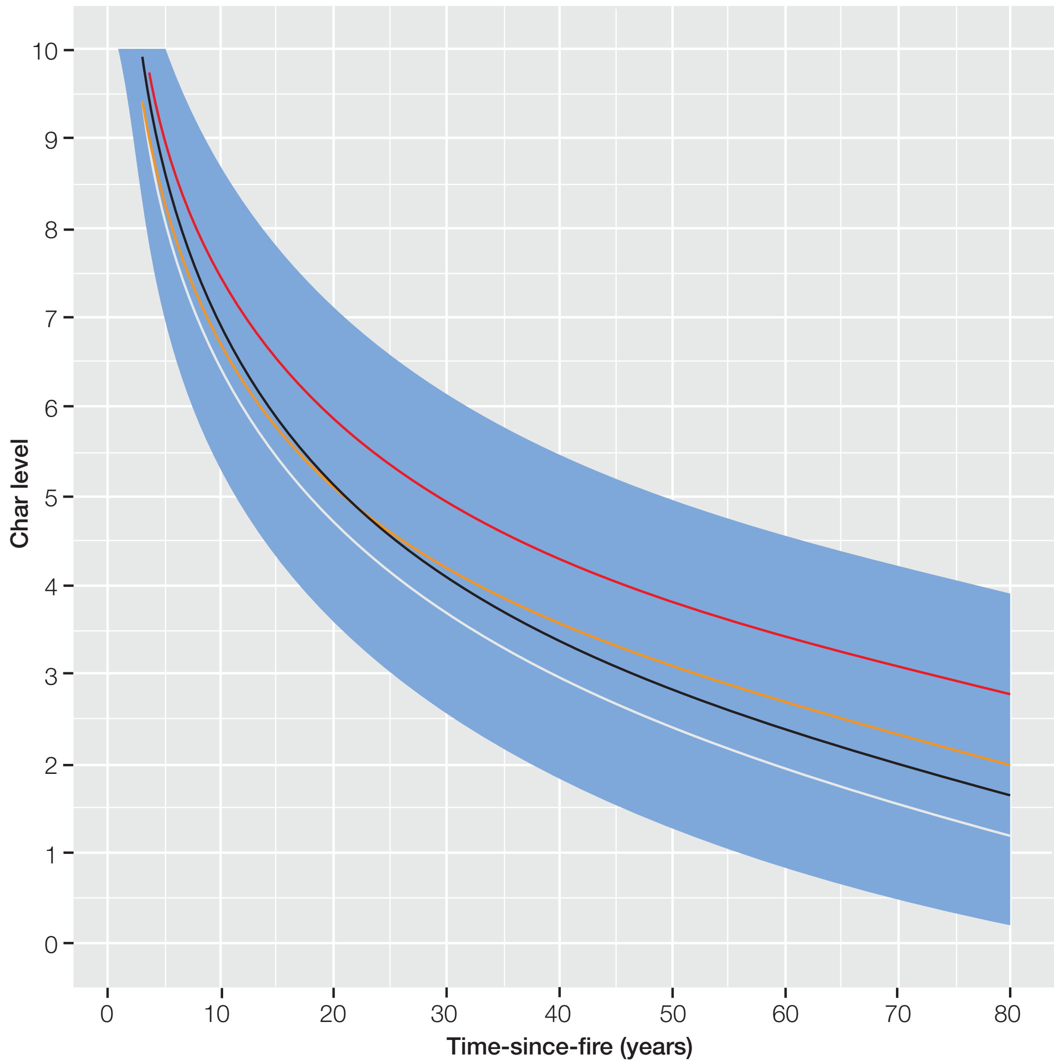

Figure 7: Plot of comparison between the simplified fire history assessment tool and the best full model. The blue area corresponds to the 100% inter-quantile zone (blue), for quantile regression of site-level mean char at n=100 sites in the model-testing dataset. The four lines represent model fits to extreme permutations of tree-level (DBH) and site-level (fire type) factors, in the most parsimonious full model (Table 1). Red and orange lines are predictions for charring on trees of DBH 69 cm (the greatest site-level mean DBH observed among sites in the model-testing dataset), that were exposed to bushfire and planned burning respectively. Black and grey lines are predictions for trees at the opposite extreme of observed site-level mean tree DBH (38 cm), exposed to bushfire and planned burning respectively. Model fits to these permutations are well within the inter-quantile zone, suggesting that the simplified fire history tool is reasonably robust to expected levels of site-level variation in fire type and DBH.

Discussion

Accurate fire history mapping is integral to DEPI's ability to meet the objectives of the Code of Practice for Bushfire Management on Public Land (DSE 2012). It enables researchers and planners to quantify relationships between fire events and variables such as fuel hazard, or the abundance of a given species. Existing fire mapping GIS layers are a valuable, but imperfect, resource.

This report documents the development and testing of a method to assess whether the mapped fire history for a location is correct. The underlying idea is a simple one: stringybark trees char readily when exposed to fire. Subsequent tree growth causes bark expansion and splitting (Figure 2), resulting in decreasingly visible charring as time goes by.

Field surveys were conducted at across Gippsland, and charring levels across a large sample of trees showed relationships between bark charring, tree diameter and time-since-fire (Table 1, Figures 5 and 6). The simplest statistical model (expressing char level as the logarithm of time since fire) accounted for a large proportion of the observed variation in char level, and produced predictions that were well-correlated with observations from an independent model-testing dataset. The remaining variation unexplained by statistical models could have many potential sources, such as: variations in bark characteristics, severity of the previous fire, microsite effects (e.g. shading/dominance), soil productivity, rainfall gradients, aspect and hydrology. However, a highly multivariate approach is not suitable for use in the field. Some potential sources of variation were contained by initial site selection and tree sampling constraints: the driest EVD 3 (Grassy/Heathy Dry Forest) ridgelines were avoided, as were damaged, senescent or otherwise obviously impeded trees. These limitations should be kept in mind when applying the resulting models (see below).

A simple, graphical method of accepting or rejecting the mapped fire history of a site was developed (Appendix 1). This method succeeded (as far as could be determined) at 20 of 21 model-testing sites, including the identification of erroneous fire history mapping at five sites. Based on this initial success, the method shows promise as a rapid assessment tool for use in the field with minimal training. The method could be reasonably applied to areas of EVD 3 and 7 (Tall Mixed Forest [eastern]) eastwards of Melbourne with some confidence. With a degree of caution, the method could be trialled over a greater range of forest EVDs across Victoria, e.g. EVDs 8 (Foothills Forest), 9 (Forby Forest) and 10 (Moist Forest). Some major caveats to these extrapolations are: a) the presence of stringybarks is obviously required; b) heavily logged sites may show different growth rates; and c) sites with depauperate/dry ridges and northerly aspects may exhibit stunted growth, even in EVD 3. Sites dominated by small (~30cm) or large (~100cm) DBH trees may require some degree of correction (e.g. based on Figure 6). Even after applying these limitations, the footprint over which the method can be applied is considerable; stringybarks are widespread and typically occur in mixed-age stands. In more disparate vegetation types (e.g. woodland), the logic of the method should still apply, but new datasets will be required for calibration. Any large monitoring program seeking to use time-since-fire as a key predictor variable could, at modest marginal cost, collect a comparable dataset to the one analysed here for internal fire history validation.

Confidence in fire history assessment could be increased by a retrospective-design program to measure mid-storey species growth rates. Visually prominent species that are readily killed by fire and either do not resprout (e.g. smaller *Hakea* and *Banksia* spp.) or resprout as juveniles (e.g. *Exocarpus cupressiformis, Elaeocarpus reticulatus*) could provide a useful 'second opinion' on time-since-fire. This approach proved successful at one test site in the current study, where estimates of time-since-fire from Banksia spinulosa morphometrics (Muir 2011) were tightly aligned with stringybark char-based estimates. As *E. cupressiformis* and *E. reticulatus* are reliably bird-dispersed, both their abundance and size of the largest individuals should increase with time-since-fire. Coarse estimates of abundance and largest size of these species were collected in the present study but flaws in the electronic data-collection method precluded analysis. Finally, the following appear to be good indicators of the absence of fires for 40+ years (LB pers. obs.): senescent *E. cupressiformis*; elevated abundance of lichen and large size of individual crustose or foliose lichen patches; elevated abundance of large coarse woody debris (fallen branches and trees) in all states of decay.

Extremely low fire severity is the most likely source of misclassification using the proposed graphical fire history verification method. It is plausible that, for planned burns, some fuel structures and ambient conditions can result in a fire intensity that consumes surface fuels while producing minimal or highly variable charring on stringybarks. The rate at which this occurs (as a proportion of all burns) is unknown, but anecdotal observations suggest it is relatively infrequent. This is certainly an area for further research (e.g. by visiting recent burns). As it applies to the current dataset, error was minimised by (i) recording char level for the bottom 1.2 m of trees only, (ii) recording data for 20 trees per site, (iii) for the model-building dataset, a site acceptance process that applied some prior expectation of char levels from a trial project, and (iv) for the model-testing dataset, including sites that showed reasonably consistent char levels across trees. A further practical measure that can be applied to reduce error rates is to replicate sites within the mapped fire perimeter. However, burns with sufficient coverage to meet their fuel reduction objectives and/or form a meaningful ecological event are highly likely to char the bases of stringybarks.

An important consideration in any project seeking to systematically verify fire mapping is that error rates are not independent of the date of the mapped fire (Figure 8). Rather, type I error rates would have been initially low, but would have risen since ~1970. Conversely, type II error rates have certainly fallen over time but are still above zero. One beneficial outcome is that verification of long-unburnt areas can adopt one-sided hypothesis tests. However, there may be negative implications for projects, like this one, that seek to fit statistical models across several decades. Models typically assume that error is independent of predictor variables, an assumption that is clearly breached in this case. However, back-calculating the effects of this breach would be confounded by other factors such as variation in the overall rate of fire over time, differential mapping error rates for bushfire and planned burning, and variation in the relative frequencies of these types of fire over time.

Conclusion

This report shows that the charring observed on stringybark trees can be used to verify mapped fire history data, or to estimate time-since-fire where no fire history data are available. The relationship between char level and time-since-fire is mediated by other factors, most notably tree diameter. However, a simple graphical tool is sufficient to classify sites as having correct/incorrect fire history during field surveys, on the basis of consistency with data from 100 sites in East Gippsland. This tool can now be applied (with caution and within the limitations discussed above) to assess fire history for a range of forested locations in Victoria.

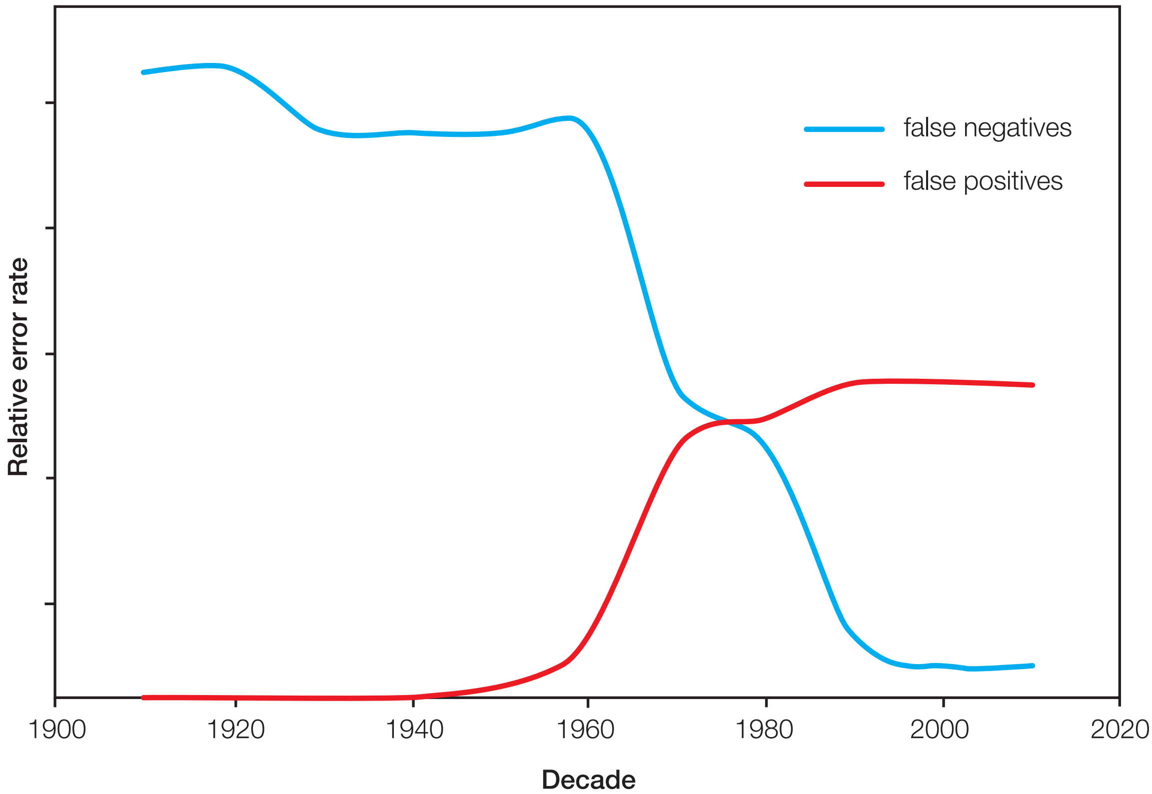

Figure 8: Hypothetical variation in fire mapping error rates as a function of fire date. Prior to 1970, few fires were mapped, resulting in high rates of type II error (false negatives). This rate has decreased substantially over time. However, the rate of type I error (false positives) has increased, as more fires have been mapped, but unburnt areas within mapped fire boundaries remain. The actual magnitudes of these error rates are unknown.

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Appendix 1: Method for fire history verification using stringybark char

Context

Field workers can quickly and objectively assess whether a location's mapped fire history is correct on the ground using charring retained on the bark of *Eucalyptus* trees after fire. The base of stringybark trees chars readily, even at low fire intensity, and charring decreases as trees grow over subsequent decades.

A field survey of 2000 trees across 100 sites in East Gippsland found a strong relationship between time-since-fire and the level of charring on stringybarks. A simple field validation method has been developed from this dataset.

Constraints

- Requires presence of stringybarks
- Original data are from Tall Mixed Forest and Heathy/Grassy Dry Forest. Caution is needed when applying to other vegetation types.
- Exceptionally low or high severity fire may cause trees to have lower or higher than anticipated char levels, respectively.
- Trees must be live, healthy and greater than 30cm in diameter at 130cm above ground.
- Trees should not have physical defects that may have suppressed growth (hollow butt, dead crown, dieback, senescence).
- The trees sampled at a site should be a range of sizes. If all trees at a site are large (>80cm), char level will be higher than predicted. Avoid cohorts of trees younger than the most recent fire.
- Trees on dry ridges or very poor soils will grow slower and char level will be higher than predicted.
- Where no fire history exists, time-since-fire estimation by this method should be used for anecdotal purposes only. Research or systematic monitoring programs will need to fit reversed models (i.e. of time-since-fire as a function of observed char level).

Components

Part A: Defined levels of charring are illustrated in the supplied photographs.

Part B: Graph of plausible variation in char level over time.

Method

To accept or reject a site's mapped fire history:

Access fire history for the area (e.g. via the FIRE_HISTORY layer in the Corporate Spatial Data Library).

Visit the site and following Step 1, using Part A to assess the scores of at least 20 suitable stringybark trees (see Constraints). Individual tree selection can be random but should ignore charring.

Assess the bottom 120cm of trunks only.

Calculate the average (mean) score of all trees.

Following Step 2, using Part B, assess whether the mean score is within the blue 'plausible zone' for the site's mapped time-since-fire.

- If the mean score is within the blue zone, the mapped fire history can be accepted.
- If the mean score is below the blue zone, it is likely that the most recent mapped fire did not occur at the site. Test whether the site score is within the blue zone for the second most recent fire. Bear in mind that low intensity, patchy burns may cause lower than expected char levels.
- If the mean score is above the blue zone, it is likely that there has been a more recent, unmapped fire. Search fire history maps for a nearby fire that is consistent with the blue zone and could plausibly have extended to the site. However, slow tree growth can also cause higher than expected char levels (see Constraints).

To estimate time-since-fire for a site with no mapped fire history:

Using Part A, determine the average char level across at least 20 trees.

Using Part B, find the point on the black (central) line matching the observed average char level.

The x axis value at this point is the most likely estimate of time-since-fire.

Reference: Bluff, L. (2014) *Verification of time-since-fire in Gippsland from charring retained on stringybark trees.* Department of Environment and Primary Industries, Melbourne.

Step 1: Using Part A, score the charring on at least 20 stringybark trees over 30cm diameter.

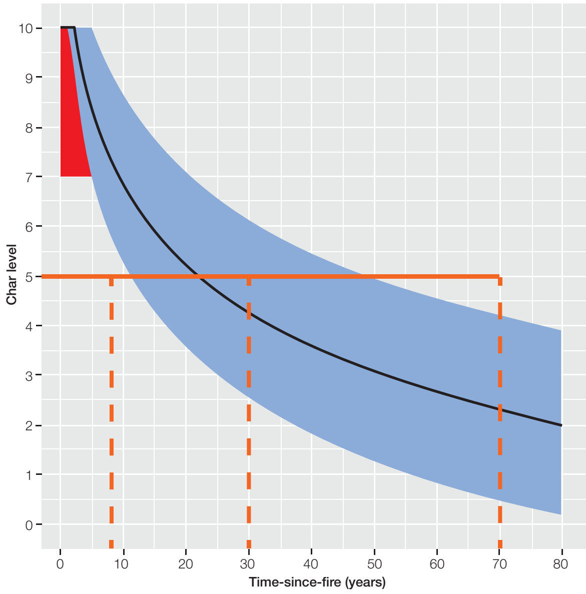
Tree number	Char score	DBH (cm)*
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		
Average of 20 trees		

* Collection of tree diameters is not necessary for all users but would aid in the further testing and development of this validation tool. DBH should be measured perpendicular to the trunk and over bark, at 130cm above ground. Please submit raw data, together with site coordinates, to lucas.bluff@depi.vic.gov.au

Step 2: Using Part B, estimate the time-since-fire.

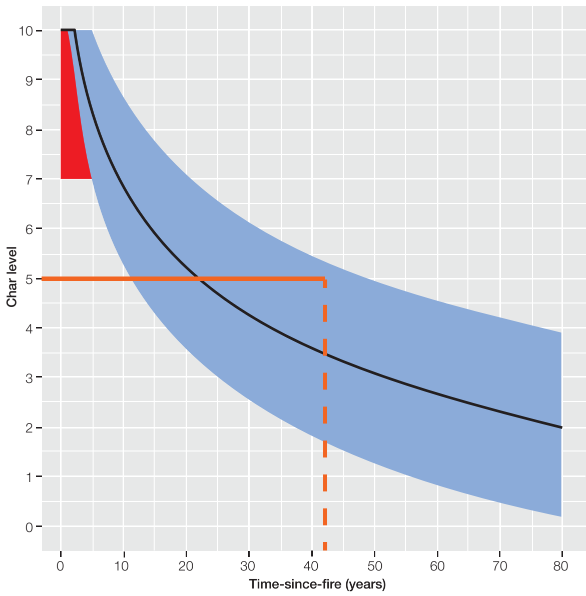
Mapped fire history

Using the calculated average char score, see if the mapped fire history falls within the blue area. In the example below, the site has an average char score of 5 and mapped fire history at 8, 30 and 80 years. The most recent mapped fire (8 years ago) falls below the blue area and most likely did not occur at the site. The 80-year-old fire is above the blue area: it is likely that there has been a more recent fire. It is probable that the most recent fire occurred at the site 30 years ago.



Fire history unknown

Using the calculated average bark char score (in this example 3.5, red solid line) then the estimated time-since-fire is 43 years (red dashed line intersect with x axis). See constraints note on previous page.



Part A: photographs illustrating levels of charring between 1 and 10

At level 1, little or no char is visible. At level 10, the trunk is almost entirely charred.

Note that tree assessment is done on the base of the trunk, up to 130cm from the ground.

10

9

8

7

6

5

4

3

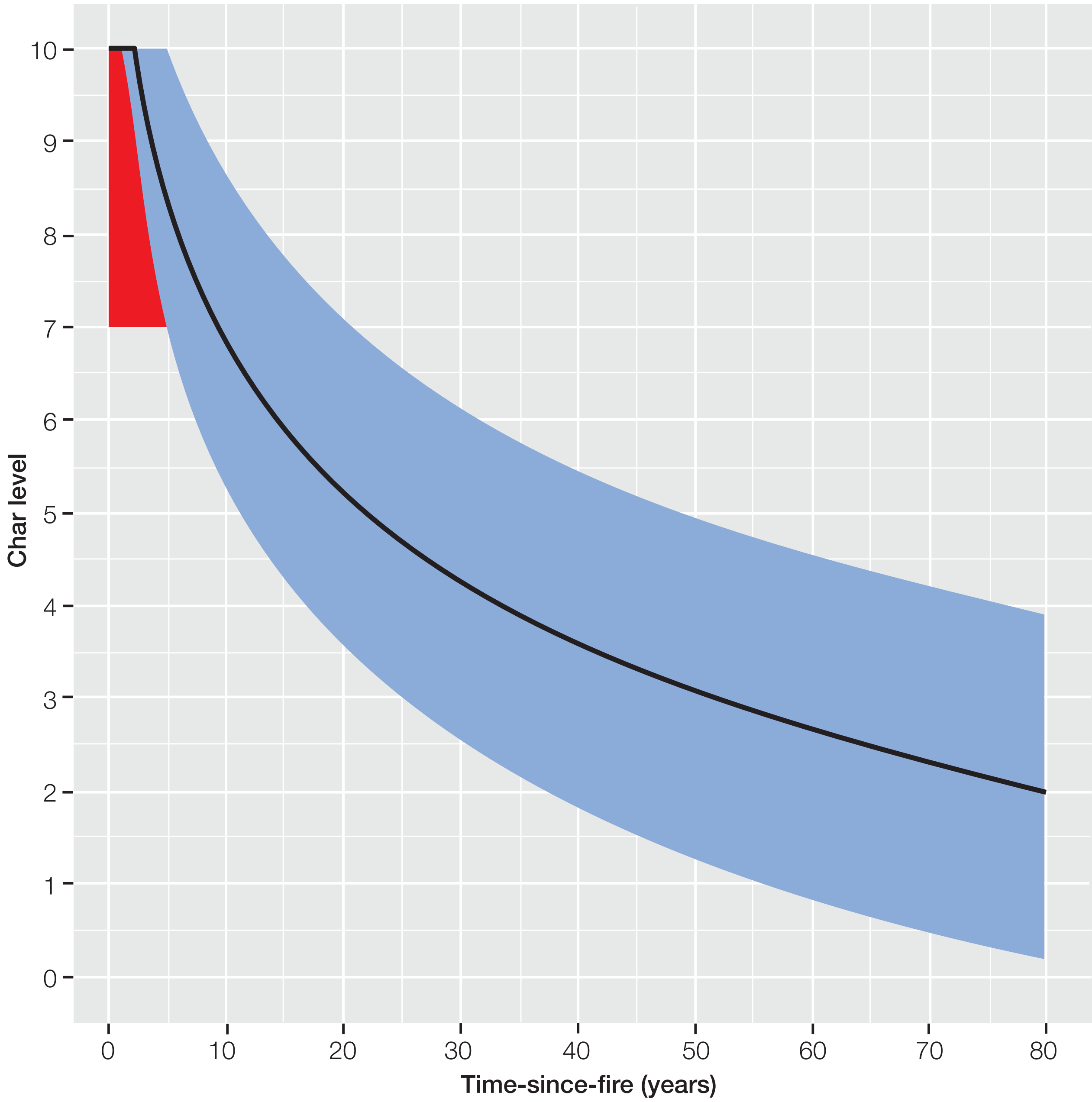
2

1

Part B: Expected average char level (across 20 stringybarks) as a function of time-since-fire

Blue zone defined by 100% quantile regression fitted to observed data from 100 sites in Gippsland.

Red zone illustrates an area that exceptionally low severity planned burns may occupy, but where other cues to recent fire will be evident



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