# Reducing the effect of planned burns on hollow-bearing trees

Fire and adaptive management report no. 95

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2016

VICTORIA State Government | Environment, Land, Water and Planning

Victorian Government Department of Environment, Land, Water and Planning,
Melbourne, February 2016



Printed by Impact Digital, Brunswick

ISBN 978-1-76047-031-9 (print)
ISBN 978-1-76047-032-6 (pdf)



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**Cover Image:** A Sooty Owl *Tyto tenebricosa* attending a nesting hollow in Gippsland (David Hollands). This species is one of four large forest owls dependent on hollow-bearing trees in eastern Victoria, all of which are Listed under the FFG Act 1988.

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# Abbreviations

| | |
|---|---|
| **AIC** | Akaike Information Criterion; a measure of the parsimony of a statistical model |
| **CSDL** | Corporate Spatial Data Library; DELWP's main repository of GIS data |
| **DBH** | Diameter at Breast Height; a common metric of tree size |
| **DELWP** | Department of Environment, Land, Water and Planning, Victoria (2015–onwards). Previously: see DEPI, DSE. |
| **DEPI** | Department of Environment and Primary Industries, Victoria (2013–2014) |
| **DSE** | Department of Sustainability and Environment, Victoria (2002–2013) |
| **EVD** | Ecological Vegetation Division; composed of multiple Ecological Vegetation Classes |
| **FCS** | Full Crown Scorch; a fire severity class |
| **FFG** | Flora and Fauna Guarantee Act 1988 |
| **FOP** | Fire Operations Plan |
| **GIS** | Geographical Information System |
| **GLM** | Generalised Linear Model |
| **GPS** | Global Positioning System |
| **HBT** | Hollow-Bearing Tree; a tree containing one or more hollows. Refer to Table 1 for full definition. |
| **PCS** | Partial Crown Scorch; a fire severity class |
| **UB** | UnBurnt; a fire severity class |
| **USB** | Under-Storey Burnt; a fire severity class |

# Acknowledgements


## Many thanks to the following contributors, in chronological order:

The HawkEye team supported this project from start to finish: Fiona Hamilton, Stephen Platt, Nevil Amos, Michelle Ibbett and Natasha Schedvin.

Members of the Gippsland Fire Ecology Working Group provided guidance at the outset of the project, particularly Stephen Henry, Rob Poore and Evan Lewis.

A trial study was conducted in 2012 with help from Rohan Bilney, Aileen Collyer, Steve Fall, Aimee Clarke and the Nowa Nowa Project Fire Fighters. Fiona Hamilton also helped test field methods.

Valuable feedback on project design and methods was contributed by Amelia Koch, Natasha Schedvin, Fiona Hamilton and Ralph MacNally.

The DELWP Gippsland Land and Fire staff was helpful in providing advice on planned burns. In addition, Greg McCarthy, Gary Carr and Luke Smith supplied high-quality, aerial-interpreted fire severity mapping.

Staff from Ecosystems Management Australia collected field data with accuracy and efficiency: Tess Camm, Ashleigh Shiells, David Lockwood, Tim Willersdorf, Nick Willersdorf and Kelly Phillips. Tess Camm and Ian Long project-managed the data collection.

Comments and editorial improvements on this report were contributed by Fiona Hamilton, Stephen Henry, Michelle Ibbett, Amelia Koch, Stephen Platt, James Todd, Gordon Friend and Liam Fogarty. This report was edited by Jeanette Birtles (Organic Editing), and a statistical review was provided by Graham Hepworth (Statistical Consulting Centre, University of Melbourne). Any errors, however, remain my own. Images for the report were supplied by Rohan Bilney, Mick Bramwell, David Hollands and David Lockwood.

This work was funded by the Victorian Government under the HawkEye Project.

# Summary

There is inadequate information on the fate of hollow-bearing trees (HBTs) subject to planned burns in Victoria. This study aimed to provide a methodologically robust estimate of the collapse rate of HBTs in planned burns in the forests of Gippsland. The study's primary goal was to quantify the impact on HBTs of exposure to a single instance of planned fire; the secondary goal was to provide evidence-based options for managers seeking to reduce this impact.

The Department of Environment, Land, Water and Planning (DELWP) manages bushfire risk on public land in Victoria, taking into account risks to human life, communities, essential and community infrastructure, industries, the economy and the environment (DSE 2012). Planned burning is the major tool used by DELWP for this task, with burning conducted across more than 200,000 ha of public land annually. The ecological costs and benefits of this burning program are addressed through a range of processes, from landscape-scale strategic planning to operational prescriptions for deployment of fire in particular locations, seasons, intensity and patchiness. These processes are in turn supported by systems harnessing expert opinion and ecological data, for example in defining tolerable fire intervals for different vegetation types. The methods for incorporating the habitat needs of fauna species into burn planning are continually being refined.

Land management decisions need to consider the availability of HBTs at the extended spatial and temporal scales that are relevant to the persistence of hollow-dependent fauna. A full account would balance losses from natural (e.g. tree decomposition, wind throw, bushfire) and human-induced causes (e.g. forestry, mining, planned burning, hazard reduction), with gains in natural hollow production, including through fire. Also important are the availability of hollows in the locations where they are needed by particular fauna species, and other factors limiting local fauna populations (e.g. predation, drought). Measuring and modelling all the relevant processes is beyond the scope of the current report, which is constrained to analysing outcomes for existing HBTs in single planned burns in one region of Victoria.

This report considers the interaction between planned burns and habitat for a particular set of species: hollow-dependent vertebrate fauna. Hollows in the trunk and branches of standing trees, particularly eucalypts, are a key habitat element for a wide range of fauna species. There is anecdotal evidence that planned burns and bushfires can cause collapse and consumption of HBTs, with consequent loss of a key habitat component for hollow-dependent fauna. In order to evaluate this risk, DELWP requires systematic and well-quantified assessment of ecological impact so that the value of any changes to fuel-management practices can be fully evaluated. At present, there has been little quantitative work connecting planned burning and HBTs (see Introduction). In particular, no published study in Australia has conducted pre- and post-fire visits to individual HBTs across multiple planned burn sites and matching control plots. The current study addresses this gap and provides an improved evidence base for DELWP (and other Australian land management agencies) for connecting fuel management activities with habitat outcomes for hollow-dependent fauna.

In 2012–2013, study plots in EVDs 3 and 7 ('Grassy/Heathy Dry Forest' and 'Tall Mixed Forest') were assessed for HBTs. Unburnt control plots were used to determine background rates of tree collapse.

Across a sample of 34 study plots in 13 different burns, HBTs in areas mapped as burnt were on average 22.4 times more likely to collapse than trees in control plots. HBTs directly reached by fire were on average 27.9 times more likely to collapse than trees not reached by fire. While these results indicate that, in general, planned burns significantly increase the collapse rate of HBTs in comparison with that on 'no burn' control plots, the causes of variation in collapse rate can provide additional insight.

The rate at which all trees (as a proxy measure for HBTs) collapsed was positively associated with the extent and severity of burns within study plots. The probability of collapse of individual HBTs was positively associated with a range of tree characteristics: the tree being dead; the number and size of hollows present; and the degree of previous basal damage.

These predictors of HBT collapse indicate a clear set of evidence-based management strategies (see Box 2 on page 43) and present an opportunity to inform DELWP strategic planners and operational staff about means for reducing the impact of planned burns on HBTs.

There is a need for longitudinal modelling of HBT abundance under alternative landscape management scenarios, including bushfire. The current project has created a widespread network of study plots with identified HBTs, which over the longer term has the capacity to inform longitudinal modelling by intersection with future bushfire events and/or sequences of planned burns.

It is clear from the current study that planned burning reduces hollow availability, but to understand the relative impact of this collapse rate on hollow-dependent fauna would require a comparison of this rate with the background rate due to natural loss (from factors such as tree decomposition, wind throw and bushfire), together with an understanding of the strategic importance of different parts of the landscape for hollow-dependent fauna. It would also need to take into account any reduction in natural tree collapse, arising from the reduced probability of bushfire due to planned burning activities.

**Figure 1**: Successful use of rake-hoe protection to prevent collapse of a hollow-bearing tree during a planned burn (Mick Bramwell). While this report only considered tree outcomes in the absence of protection, further work is being conducted on the effectiveness of rake-hoe treatment.

# Introduction

## Tree hollows are a key habitat component for some 300 Australian vertebrate fauna species, of which a third have formal conservation status (Gibbons and Lindenmayer 2002).

Given their importance to charismatic groups such as owls, parrots, and arboreal mammals, it is unsurprising that hollow-bearing trees (HBTs) have been a prominent topic in the Australian ecological literature for approximately three decades. The extent to which management activities may affect HBTs, and thereby fauna populations, has at times been controversial and polarised (e.g. Mawson and Long 1997, Stoneman et al. 1997). Concern over the impacts of forestry, land-clearing and fire on HBTs led to listing of 'loss of hollow-bearing trees from Victorian native forests' as a Potentially Threatening Process under the Flora and Fauna Guarantee Act 1988 (DSE 2003).

The ecological importance of HBTs and the conservation concerns surrounding their loss are relevant to DELWP's bushfire management activities, given that both planned burns and bushfires are purported to cause the collapse of HBTs. It has also been suggested that bushfires can facilitate the development of hollows over a longer time frame, but the intensity typical of planned fire is probably insufficient to have this effect (Adkins 2006). For large areas of public land in Victoria, DELWP is responsible for reducing the impacts of bushfire on human life and property, as well as for maintaining ecosystem resilience (DEPI 2012) and protecting threatened species (Flora and Fauna Guarantee Act 1988). A major tool applied to public land management is planned burning; thus, there is a clear need for DELWP to understand and take into account whatever actual impact planned burning has on HBTs.

Few quantitative data are available to assess the effect of planned fire on HBTs in Australia. In only one Western Australian study (Inions et al. 1989) have HBTs been identified, exposed to a planned burn (or at a non-burn control site), and then revisited to examine the post-burn collapse rate. At the site exposed to burning, 37.8% of HBTs collapsed or were severely damaged (Inions et al. 1989). However, the generality of this study was limited, given that (i) the set of study trees were those in active use by two possum species (rather than HBTs supplying habitat for all species), (ii) there was only one burn and one non-burn study site, i.e. treatment was not replicated, and (iii) the single planned burn was noted as being particularly intense. In New South Wales, an opportunistic study (Parnaby et al. 2010) examined the frequency of HBT collapse across three burns and 29 post-fire plots, and reported collapse rates of from 14 to 26%. As the authors of this study point out, it had several design limitations that constrained its inference regarding a generalised rate of HBT collapse. These limitations included (i) that HBTs were not identified before fire, (ii) there was no control sample, and (iii) that study sites were located by visual assessment from within a vehicle and may not have been typical of the burnt area. The greater number of studies of indirect relevance to the fate of HBTs in planned burns includes the following. Collapse rates of retained trees following logging in East Gippsland were 14% and 37% in low- and high-severity slash burns respectively (Gibbons et al. 2000a), but not all trees were hollow bearing, and slash burns are not typical planned burns. Collapse of retained habitat trees after logging in south-west Western Australia was associated with basal fire scars and with the total number of fires (Whitford and Williams 2001), but this was a retrospective-design study that again did not distinguish hollow-bearing from non-hollow-bearing trees, nor bushfires from planned burns. In short, no existing published work provides a methodologically robust estimate of the collapse rate of HBTs in planned burns anywhere in Australia, and there is '…an urgent need for comprehensively designed studies to address the impacts of prescribed burns on hollow-bearing trees' (Parnaby et al. 2010).

**Figure 2:** An anecdotal instance, prior to the current study, of fire leading to habitat loss for an FFG Act–listed species.

**Inset:** Sooty Owl *Tyto tenebricosa* attending a nesting hollow in 2006 (David Hollands).

**Main image:** arrow points to the same hollow after tree collapse resulting from a back-burn during bushfire suppression in 2007 (Rohan Bilney).

The current report details a DELWP initiative to quantify the rate of collapse of HBTs in planned burns across Gippsland, and to identify the most effective, evidence-based management strategies for reducing the impact of planned burning on HBTs. The project was instigated following discussions in 2011 among members of the Gippsland Fire Ecology Working Group concerning fire-ecology monitoring needs in Gippsland. The Working Group included representatives from Parks Victoria and (then) DSE Land and Fire, Environment and Water, and Project HawkEye. Further discussion of how this work addresses DELWP's policy and legislative requirements is provided in Box 1. The intent of this report is to establish typical rates of HBT collapse under normal planned burning conditions in Gippsland (rather than in worst-case scenarios), taking into consideration the background rate of HBT collapse (i.e. in the absence of fire), and to provide clear and constructive management options.

Ultimately, land management decisions need to consider the availability of HBTs at the extended spatial and temporal scales that are relevant to the persistence of hollow-dependent fauna. A full account would balance losses from natural (e.g. tree decomposition, wind throw, bushfire) and human-induced causes (e.g. forestry, mining, planned burning, hazard reduction), with gains in natural hollow production. Also important are the availability of hollows in the locations where they are needed by particular fauna species, and other factors limiting local fauna populations (e.g. predation, drought). Measuring and modelling all the relevant processes is beyond the scope of the current report, which can only aim to elucidate the outcomes for HBTs in single planned burns.

## Box 1: Management applications

How this report addresses DELWP's policy and legislation requirements

### Victorian Bushfires Royal Commission Recommendations

- Recommendation 57 identifies the need for DELWP to report annually on prescribed burning outcomes, including impacts on biodiversity. This project provides a basis for estimating effects of prescribed burning on habitat availability for hollow-dependent species.
- Recommendation 58 identifies the need for DELWP to conduct improved monitoring and modelling of effects of bushfires and planned burning on biodiversity. This project was a component of Project HawkEye, and as such was designed to address this recommendation directly. The relationship between bushfire management activities and fauna habitat has been one of Project HawkEye's key themes.

### Code of Practice for Bushfire Management on Public Land

- The Code (DSE 2012) documents DELWP's primary objectives for bushfire management, which are to minimise the impact of bushfire on human life, property and the environment (among other values), and to maintain or improve ecosystem resilience and biodiversity (among other values). This report supports the following processes identified in the Code: (i) risk-based bushfire management and planning, (ii) adaptive management and (iii) monitoring, evaluation and reporting.
- Risk-based bushfire management and planning recognises the necessity for trade-offs between the Code's objectives. This report provides an evidence basis for one dimension of a trade-off between planned burning and fauna habitat retention, and may help to quantify the effects of alternative management strategies on hollow-dependent species.
- This report fulfils a key step in the adaptive management process: it investigates the effects of current fire management practice in order to inform future management decisions.
- This report constitutes a worked example of targeted monitoring (or applied research) and provides learnings to improve bushfire management strategies.

### Flora and Fauna Guarantee Act 1988

- This report relates to a listed potentially threatening process – 'inappropriate fire regimes causing disruption to sustainable ecosystem processes and resultant loss of biodiversity' – and addresses several of the management actions identified in the Action Statement for 'Loss of hollow-bearing trees from Victorian native forests and woodlands' (DSE 2003).
- This report could be used to estimate the effects of bushfire management strategies on habitat availability for a range of hollow-dependent species [including species on the Advisory List (DSE 2013a) and/or species with existing FFG Action Statements].

# Methods

## Pre-treatment surveys

### Design

The study was designed with the primary criteria of quantifying the collapse rate of HBTs exposed to planned burns (compared with that of non-burn controls), and of identifying predictors of HBT collapse via replication at multiple levels (individual tree, plot, burn). The starting point for the design was power analysis (conducted in G*Power, Faul et al. 2007) for the sample size required to have a 90% chance of the observed collapse rate being within 5% of the true collapse rate, over a range of possible true collapse rates (10– 30%). The qualifying sample size at a true collapse rate of 10% was 59 HBTs and at 30% was 305 HBTs. A second power analysis indicated that to have a 90% chance of successfully discriminating between two populations of HBTs with different collapse rates could require much larger sample sizes (depending on the magnitude of the difference between the two populations' true collapse rates). The first power analysis was used as a target for the minimal sample size (of HBTs within burns) required, and the project was budgeted to deliver this sample size, with allowance for (i) scheduled burns not being ignited or being ignited and not reaching their percentage cover objectives, and (ii) a matching control sample of HBTs outside planned burns. Other considerations in the design were (i) to spread plots geographically and across the largest feasible number of planned burns, and (ii) to test for an association between HBT density and aerial image–assessed properties of forest stands (Fox et al. 2009, Koch and Baker 2011).

## Plot selection

Plots were located, using GIS software, through the following sequence of actions. Inputs were sourced from regional datasets for the Fire Operations Plan (FOP) and Ecological Vegetation Divisions (EVDs), as well as layers from the DELWP Corporate Spatial Data Library (CSDL) such as forest stand polygons (SFRIFRED07) and previous fire history (LASTBURNT_100). These layers were intersected in GIS to create polygons of consistent forest stand identity, EVD, and fire history. The polygons were filtered to include only EVDs 3 and 7 ('Grassy/Heathy Dry Forest' and 'Tall Mixed Forest (Eastern)', respectively – the dominant EVDs treated with planned burning in Gippsland) and to exclude polygons smaller than 2 ha or further than 500 m from access tracks. Next, individual planned burns were selected from the Gippsland Fire Operations Plan (FOP) for Autumn 2013 (see Fig. 4), on the basis of (i) containing forest stand polygons that meet the preceding criteria, and (ii) preference for higher percentage cover in burn objectives (to increase the likelihood of sampled HBTs being reached by fire). However, note that the eventual list of burns sampled covered the full spectrum of percentage cover objectives. Within each selected burn, forest stands were selected in pairs (to facilitate safe and efficient field work by a two-person team). The first stand was selected on the basis of a high proportion of irregular crowns (>5% cover of irregular crowns, from existing aerial-image assessment), with the second having a lower proportion of (<5%) irregular crowns, but otherwise matching in EVD and fire history. Individual burns had between one and three pairs of selected stands, with the target being at least two pairs, and if possible differing fire history among pairs. Exceptions to this general process included (i) control plots, where 'pseudoburns' were created from geographically similar and spatially interspersed areas not on the FOP, but the process was otherwise consistent, and (ii) location of some burns in areas that did not have existing forest stand mapping, where analogous polygons were created haphazardly, but followed consistent practice for EVD and fire history. In total, 150 target polygons were identified, of which 126 polygons were distributed across 30 scheduled burns and 24 across six non-burn control areas. Plots were 100 m in length and 50 m in width (area = 0.5 ha), and a single plot was located manually within each target polygon in GIS using the following rules: plot at least 50 m from the polygon edge, preferably more than 100 m from mapped tracks, and placement otherwise haphazard with regard to orientation and topography. A spatial representation of survey structure from landscape-level to tree-level is shown in Fig. 4. An example of plots laid out within target polygons within a single burn is shown in Appendix 1, but note that this case was selected for ease of display (a small burn with clustered plots) and is atypically compact.

## Field work

All pre-treatment field work was conducted between 8 November 2012 and 22 January 2013, under contract with Ecosystems Management Australia.

The full protocol for pre-fire HBT surveys is attached as Appendix 1, but basic features of the protocol were as follows. Field assessors were naïve to the full design of the study and the basis for selecting individual burn areas (actual burns vs controls) and individual stands within burns (see above). Most field assessors had previous forest mensuration experience, and all were given a training session in the field prior to the commencement of data collection. Assessors surveyed plots independently, but pairs of assessors worked in neighbouring plots. Plot layout was developed with advice from Amelia Koch (pers. comm., Koch and Baker 2011) and subsequent field trials. On arrival, the assessor walked to the supplied GPS coordinates (for the end of the plot nearest the track) and laid out a 100 m tape measure on a supplied bearing in order to define the central axis of the plot. Plot ends were marked with flagging tape, and standard DELWP fuel assessments (Hines et al. 2010) were conducted at either end of the plot. In brief, this method was a visual assignment of fuel hazard categories (from 'low' to 'extreme') across different fuel components within a fixed radius (10m radius for surface, near-surface and elevated fuel; 20m radius for bark fuel). The assessor then walked freely around the plot, scanning all trees for hollows with binoculars and with the naked eye, and attempted to cover the whole plot and view candidate trees from multiple aspects. All HBTs within 25 m of the central axis [horizontal distance (perpendicular to the plot axis) measured with a laser rangefinder] were considered 'in' and were surveyed in detail. Assessors continued until they had surveyed all HBTs within the plot. If the plot was completed in <3 h, the assessor continued to search for and survey HBTs outside the plot (but within the same forest stand polygon) until the 3 h had elapsed. In subsequent analyses, both 'in' and 'out' trees were included by default, except for results reported on a per-plot or per-hectare basis, in which case only 'in' trees were included.

Assessment of an individual HBT involved measuring or qualitatively judging some 25 variables (some of which were contingent on the state of other variables) and photographing the tree's crown and the weakest point of its base. An abbreviated list of the key tree-level variables used in analysis for this report is shown in Table 1, and the full list of all recorded variables is provided in Appendix 1. A small subset of HBTs ($n$ = 43) was marked with inscribed aluminium tags if they were judged to be easily confusable with nearby trees with similar characteristics. All plot-level and tree-level data were recorded on Trimble Nomad hand-held computers, and GPS positions were later differentially corrected.

**Table 1.** Definitions and permissible values for a subset of variables recorded for individual HBTs

| VARIABLE | VALUES | DEFINITION |
|---|---|---|
| **Hollow bearing?** | Yes/no | Yes if one or more qualifying hollow identified; hollows were defined as an opening ≥5 cm in its smallest dimension, and at least as deep as its smallest aperture dimension. Fissures were excluded, but basal hollows (if present) were included (see below). |
| **Hollows 5 to <10 cm** | Integer | Count of qualifying hollows from 5 cm to <10 cm, classified by smallest aperture dimension. Reference images of circles matching the boundaries of size classes were used in the field. |
| **Hollows 10 to <20 cm** | Integer | Count of qualifying hollows from 10 cm to <20 cm, as above. |
| **Hollows ≥20 cm** | Integer | Count of qualifying hollows of ≥20 cm, as above. |
| **Basal hollow** | Yes/no | Yes if qualifying hollow within 2 m of the ground and satisfying the same definition for all hollows (above). Basal hollows also contributed to the totals in the fields above. |
| **Species type** | Box<br>Gum<br>Ironbark<br>Peppermint<br>Silvertop<br>Stringybark | Functional type classification for eucalypts – trees were also identified to species level where possible. |
| **Living?** | Alive/dead | Dead if no green leaves or clearly living tissue were visible. |
| **Crown score** | Integer (1–10) | Refer to pictorial guide (Whitford 2002) for scores of senescence (if tree was alive) or dead branch order (if tree was dead). |
| **DBH 130 cm** | Integer | Diameter in centimetres, measured at 130 cm above ground, over bark and perpendicular to the axis of the trunk. |
| **Intact base %** | Integer (1–100) | The percentage of the original cross-sectional area of the trunk still occupied by structurally sound wood. This percentage was assessed at the point with the least cross-sectional area remaining, within 2m of the ground. |
| **Hollowbutt** | Yes/no | Cavity or hole in the bottom 2 m of trunk (e.g. due to disease, fire or physical damage). May not necessarily comply with basal hollow definition above (i.e. does not need to be as deep as its smallest aperture dimension). |
| **Dry wood** | Yes/no | Yes if dry wood exposed (i.e. absence of bark or cambium) within 2 m of the ground. |
| **Termites** | Yes/no | Yes if evidence that the tree was or had been occupied by termites. E.g. frass or dirt mounds. |
| **Fuel hazard** | L/M/H/VH/E | Overall fuel hazard, compiled from fuel hazard scores of individual fuel components after Hines et al. (2010), but assessed within a 2m radius of the trunk. |
| **Woody fuel** | Yes/no | Yes if dead woody fuel present of >5 cm diameter, within a 1m radius of the trunk, where the radius of the fuel item was greater than its distance from the trunk. |

Note that the variables shown here are the reduced set used in tree-level analysis; the full list of collected variables is supplied in Appendix 1.

## HBT classification and auditing

The identification and classification from the ground of individual hollows in forest trees are subject to type I and type II error (Koch 2008). Previous studies have attempted to quantify these errors using either double sampling (Harper et al. 2004, Rayner et al. 2011), climbing surveys (e.g. Harper et al. 2004) or tree-falling surveys (e.g. Koch 2008). Given the scale of the current study, these methods were not feasible, but the project had two features that reduced its sensitivity to error in hollow identification. First, the unit of measurement was a hollow-bearing tree rather than an individual hollow. Accuracy of classification of trees to hollow-bearing/non-hollow-bearing status has been found to exceed 80% (Harper et al. 2004); also, ground and post-falling counts of hollows have been found to be highly correlated with one another ($r$ = 0.787, Koch 2008). Second, the project focused on an outcome (tree collapse) occurring within the sample of identified HBTs — it did not attempt to compare the rates of HBT collapse and non-HBT collapse. The diameter and senescence state of trees are both strongly associated with the presence and abundance of hollows (Whitford 2002) and with the proportion of hollows that are used by fauna (Koch et al. 2008). It was expected that the study would identify a non-random subsample of all HBTs (i.e. larger and more senescent), but (i) this is impossible to overcome using ground-based surveys and (ii) sampling biases are consistent with biases in HBT selection by hollow-dependent fauna. Regardless, for data quality purposes, the author conducted audits at a subset of plots ($n$ = 18) between 11 February and 26 March 2013. The intent of the audits was to assess the detectability of HBTs, the consistency of HBT counts per plot, the repeatability of individual tree-level variables, and observer-level effects. Accordingly, audits were conducted without knowledge of previous results at individual plots, i.e. were independent replicates of the method within sites.

## Planned burns

The autumn 2013 planned burn season was an overall success in Gippsland, with the total treated area meeting regional targets (DEPI 2013). Burns containing HBT plots were located across five Fire Districts, and operational staff were naïve to the placement of plots within burns. Not all scheduled burns containing study plots were ignited, and the fire extent within ignited burns did not intersect all plots (see Results). However, ignition of burns containing study plots occurred between 5 April and 16 May 2013. Data on individual burn outcomes were collated from FireWeb in June 2013, and from updated fire history mapping in September 2013. Fire mapping methods varied, with fire cover and severity being mapped by detailed aerial image interpretation for six burns, by ground observation for seven burns (e.g. Fig. 4), and by arbitrary full-cover polygons for three burns.

**Figure 3:** Example of hollow-bearing tree collapse from a trial of this study in Gippsland 2012. The photographed hollow contains nesting materials, most likely those of Superb Lyrebird *Menura novaehollandiae*.

## Post-treatment surveys

### Design

The design of the study was reviewed once planned burn outcomes were known, in order to maximise the ability of the study to inform management decisions, given the remaining project funding. Five types of plot were designated (Table 2): plots in areas mapped as burnt within ignited burns (type A); plots in areas not mapped as burnt, but within ignited burns (B); control plots with no burns planned or ignited (C); post-fire-only plots within ignited burns (D); and plots in scheduled burns that were not ignited in Autumn 2013 (E). Effort was targeted at the primary comparison groups A and C, with these plots receiving full pre-treatment and post-treatment surveys. The key revision was that type E plots were considered redundant (given the sample of type C) but inferentially subordinate (as the choice of which scheduled burns to ignite was not randomised), and accordingly they were not revisited. Similarly, plot types B and C were overlapping in their ability to act as a comparison group with A, except that the location of mapped fire within ignited burns was likely to be non-random. Hence, type B was given lower post-treatment survey effort (collapsed tree scans only), except in a minority of cases where fire had in fact extended to these plots (in which case full assessments were conducted). Reductions in effort across plot types B and E created savings that were used to conduct post-treatment assessments at type D plots. These comprised 80 plots across three planned burns where fire severity had been mapped from high-resolution aerial imagery (courtesy Luke Smith, Greg McCarthy and Gary Carr). Type D plots were stratified evenly into each of the following fire severity categories: unburnt, understorey burnt only, partial crown scorch, and full crown scorch. This provided an extended and more balanced dataset for understanding the effects of fire severity on overall tree collapse, with the limitation that the 80 new plots necessarily lacked pre-treatment identification of HBTs.

**Table 2.** Summary of pre-treatment field surveys, planned burn outcomes and post-treatment surveys at 230 plots across Gippsland

| | | PRE-TREATMENT | | TREATMENT | | | POST-TREATMENT | | |
|---|---|---|---|---|---|---|---|---|---|
| **Type** | *n* | HBT survey | Fuel hazard | Burn planned | Ignited | Mapped as burnt | HBT re-survey | Collapsed tree scan | Fire severity |
| **A** | 34 | Y | Y | Y | Y | Y | Y | Y | Y |
| **B** | 32 | Y | Y | Y | Y | N | N* | Y | N* |
| **C** | 24 | Y | Y | – | – | – | Y | Y | N |
| **D** | 80 | – | – | Y | Y | Y | – | Y | Y |
| **E** | 60 | Y | Y | Y | N | N | N | N | N |

Plot types were classified after treatment outcomes were known; 90 of 150 original plots (types A/B/C) received some form of survey in the post-treatment round. The 60 non-repeat-sampled plots (type E) were in scheduled burns that were not ignited. An additional 80 plots (type D) received post-treatment surveys only. The typology of plots was as follows:

A: plots in areas mapped as burnt within ignited burns

B: plots in areas not mapped as burnt, but within ignited burns

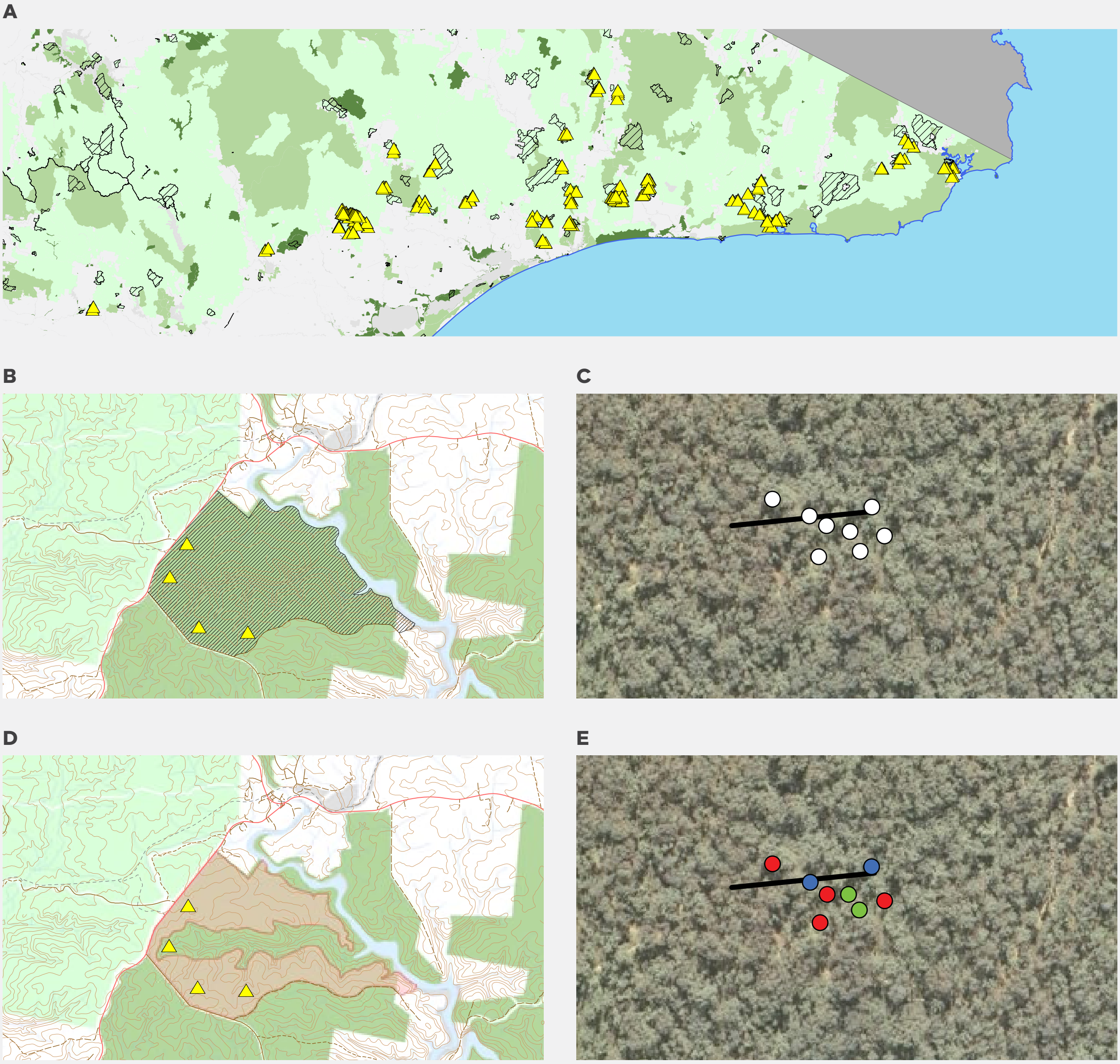
C: control plots with no burns planned or ignited

D: post-fire only plots within ignited burns

E: plots in scheduled burns that were not ignited.

*Type B plots were in ignited burns but outside of the mapped fire area. However, in a small minority of cases (n = 8), fire did in fact extend to these plots, in which case plots had full HBT re-surveys and fire severity assessments.

**Figure 4:** Spatial representation of survey effort at landscape, burn, plot and tree level A Spatial representation of survey effort at landscape, burn, plot and tree level




A: Location of 150 pre-treatment plots (yellow triangles) across 30 burns and 6 non-burn control areas in East Gippsland, Victoria. The spatial extent of the survey area was ~350 km east to west, and ~90 km north to south. Fuel treatments that were planned for Autumn 2013 are shown as black lines or hashed polygons.

B: Extent of a single 678 ha planned burn (black hashing) from the Autumn 2013 Fire Operation Plan, with the locations of four plots.

C: Survey plot (100 m central axis shown) with eight HBTs (white circles) identified in pre-treatment surveys.

D: Post-burn mapped extent of fire cover (red area) within the example Autumn 2013 planned burn, with the locations of four plots.

E: Survey plot with post-burn outcomes for individual HBTs. Four HBTs collapsed (red circles), two HBTs were structurally damaged but did not collapse (blue circles), and two HBTs were not damaged and did not collapse (green circles).

## Field work

Post-treatment field work was conducted between 21 October and 26 November 2013, under a second contract to Ecosystems Management Australia. The majority of field assessors had been involved in pre-treatment data collection, and all assessors were trained in the field on post-treatment methods prior to data collection. Plots were accessed and laid out as before, with additional reference to flagging tape where this remained from pre-treatment surveys. All plots that experienced fire had fire severity assessments conducted at the 25 m and 75 m intervals on the measuring tape that defined the plot axis. Fire severity was assessed using a simplified version of the standard DELWP protocol (DSE 2013b), which involved quantifying the area of three fuel strata (surface, elevated, canopy) in three fire severity states (unburnt, scorched, burnt). However, the default radius for this assessment was increased slightly, from the standard 20 m to 25 m, to more closely match the dimensions of the plot. For all type A ($n$ = 34) and C plots ($n$ = 32) and all type B plots exposed to fire ($n$ = 8), HBTs from pre-treatment surveys were searched for individually using GPS coordinates (and aluminium tags if present) and a subset of their pre-treatment characteristics (e.g. species, DBH, alive/dead, crown state, intact base) were re-recorded. A total of 9 variables and two photographs were collected for each HBT (Table 3). All plots (types A/B/C/D) were surveyed for collapsed trees, with 13 variables collected and two photographs collected for each instance (Table 4). Previously identified HBTs found to have collapsed were recorded in both collapsed tree and existing HBT data entry forms.

**Table 3.** Variables collected in post-treatment assessment of HBTs

| VARIABLE | VALUES | DEFINITION |
|---|---|---|
| Match | Yes/no/maybe | Yes if tree can be matched with confidence to its pre-fire location and characteristics. Desktop assessment was conducted for all 'maybe' and 'no' cases – see text. |
| Fire to base | Yes/no | Yes if fire has touched base of tree. |
| Fire height (m) | Numeric (one decimal place) | Highest mark from recent fire on trunk. |
| Status | Undamaged;<br>Damaged;<br>Collapsed; | Undamaged: no evident structural difference in last 12 months.<br>Damaged: tree has become structurally weaker in last 12 months and is at higher risk of collapse.<br>Collapsed: at less than 45-degree angle from horizontal, even if held up. |
| DBH | Integer | As per Table 1 |
| Intact base | Integer (1–100) | As per Table 1 |
| Species type | As per Table 1 | As per Table 1 |
| Living? | Alive/dead | As per Table 1 |

**Table 4.** Variables collected in post-treatment assessment of all collapsed trees, including collapsed HBTs

| VARIABLE | VALUES | DEFINITION |
|---|---|---|
| Existing HBT | Yes/no/maybe | Yes if tree can be matched with confidence to its pre-fire location and characteristics. Desktop assessment was conducted for all 'maybe' and 'no' cases – see text. |
| Collapse type | No fire;<br>Before fire;<br>With fire;<br>After fire (contributing);<br>After fire (non-contributing);<br>Human intervention;<br>Unsure | Tree fell in last 12 months and fire absent;<br>Tree fell in last 12 months but before fire;<br>Tree fell during fire;<br>Tree fell after fire, fire contributed to fall;<br>Tree fell after fire, fire didn't contribute;<br>Evidence for bulldozer or chainsaw;<br>Fell in last 12 months but can't decide between above categories. |
| Completely consumed? | Yes/no | Yes if there are insufficient remains to make any further assessment. |
| Consumed base (%) | Integer (0–100) | Proportion of base consumed by fire. Base was defined as the section of the main trunk from ground level to below first major canopy branch. Identifying the first major canopy branch was an arbitrary judgement distinguishing the lower starting point of the canopy, including comparison with the canopy structure of surrounding trees if necessary. |
| Consumed crown (%) | Integer (0–100) | Proportion (by mass) of main trunk and large branches consumed by fire, starting at the first major canopy branch (defined above). |
| DBH | Integer | As per Table 1; best equivalent to standing DBH if possible. |
| Species Type | As per Table 1 | As per Table 1 |
| Hollows present | Yes/no/insufficient remains | As per Table 1 |
| Basal hollow | Yes/no | As per Table 1 |
| Hollows 5 cm to <10 cm | Integer | As per Table 1 |
| Hollows 10 cm to <20 cm | Integer | As per Table 1 |
| Hollow ≥20 cm | Integer | As per Table 1 |

## Analysis

### Data curation

A Microsoft Access database was created, with relationships based on unique plot codes (e.g. joining pre- and post-treatment data on plots, and joining plots and trees), and unique tree codes (e.g. joining pre- and post-treatment data on trees) (Fig. 5). All cases where field workers could not confidently match a pre-treatment HBT to a post-treatment HBT (*n* = 58 of 666) were reviewed individually, with reference to GPS coordinates, pre- and post-treatment tree photographs, and pre- and post-treatment data characteristics. This was done on a conservative basis with regard to the probability of tree collapse; pre-treatment HBTs that could not confidently be matched to post-treatment outcomes were deemed not to have collapsed (*n* = 13 of 58).

Overall fuel hazard scores were compiled from individual fuel hazard component scores (Hines et al. 2010), initially on a five-point integer scale (Low = 1 to Extreme = 5). Scores were averaged across plots for plot-level analysis, creating non-integer values. These values were treated as continuous predictor variables (rather than ordered factors) in analyses, which rely on unvalidated assumptions, but (i) is commonplace for fuel modelling within DELWP, and (ii) comprises only a minor input to analyses in this report.

Fire severity assessment data were converted from a set of eight interrelated variables into a one-dimensional 'relative fire severity' variable as follows. The sum of [percentage surface fuel burnt + percentage elevated fuel scorched x 2 + percentage elevated fuel burnt x 4 + percentage canopy fuel scorched x 4 + percentage canopy fuel burnt x 8] was divided by the highest possible score of 1300. For example, 100% surface fuel burnt with no other fuels scorched or burnt would produce a relative severity of 0.077, whereas 100% burn of all fuel layers equates to 1. In practice, this metric produced an intuitive scaling of severity level and performed well in articulating existing fire severity categories (e.g. see Fig. 7).

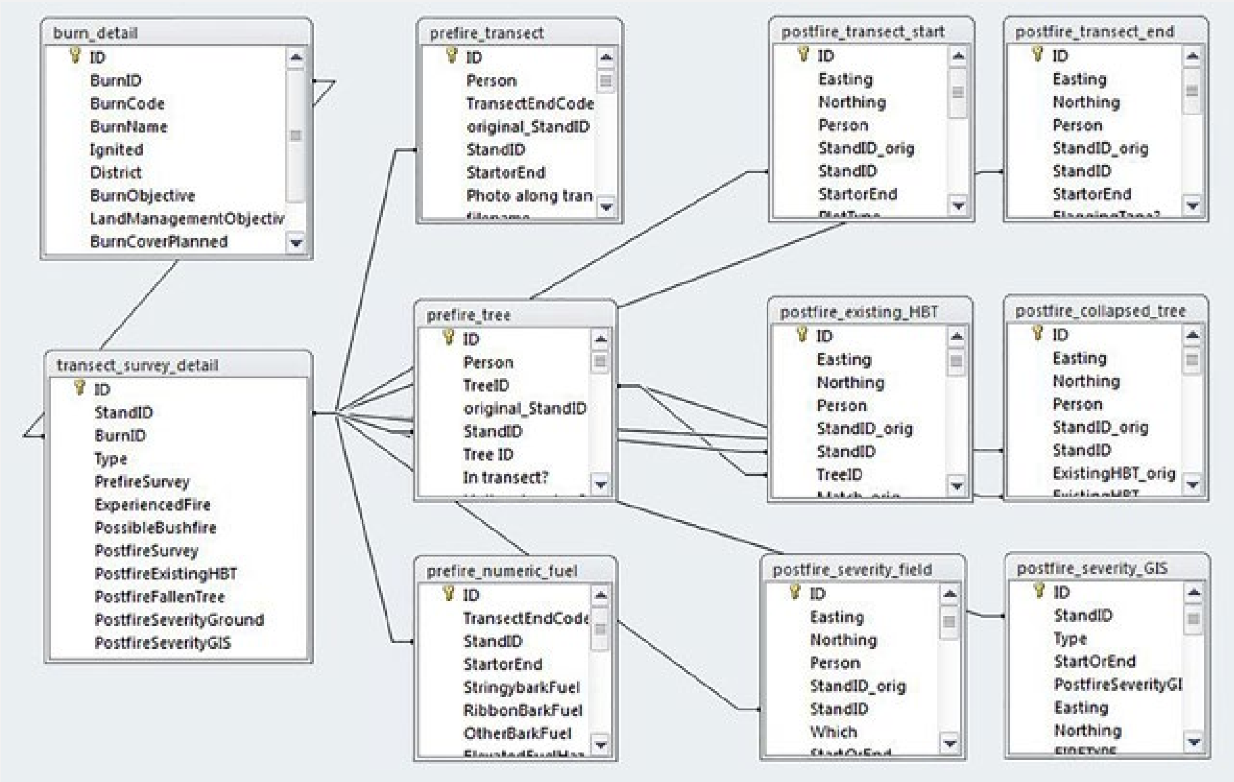
A data-collection software bug resulted in partial data loss for two important tree-level variables during pre-treatment surveys (crown score and counts of tree hollows within size classes). This only affected tree-level analysis, as described further below.

### Plot audits

For the 18 sites at which plot audits were conducted, HBTs were matched between replicate assessments as described above. Trees were then classified into one of three categories: identified as a HBT by assessor A but not assessor B (AX); identified as a HBT by assessor B but not assessor A (XB), and identified as a HBT by both assessors (AB). A simple, double-count method (Caughley 1974) was used to estimate the total number of HBTs per plot [((AB+AX) x (AB+XB))/AB], and HBT detectability was expressed as the number of HBTs detected per plot assessment, divided by the estimated total number of HBTs. This was repeated for subsamples of trees (those with a hollow >10 cm diameter, and those with a hollow larger than 20 cm diameter), and Generalised Linear Models (GLMs) were used to test for the effect of the first observer's identity on plot-level HBT detectability. Pearson correlations were used to evaluate consistency in the reported number of HBTs per plot between first and second assessments. Known HBT matches between assessors (AB) were used to estimate repeatability of tree-level variables in order to inform repeat identification of trees across pre- and post-treatment datasets.

**Figure 5.** Structure of project database in Microsoft Access

Vertical groupings of tables correspond to (from left to right): properties of burns and plot surveys; pre-fire assessments; post-fire assessments. Horizontal groupings correspond to (from top to bottom) plot properties; tree properties; fuel and severity assessments.



### Statistical analysis of HBT collapse rate

The project was designed for analysis with hierarchical methods [e.g. Generalised Linear Mixed Modelling (GLMM)] that allow partitioning of variance at multiple levels (e.g. tree, plot and burn). However, the level of imbalance and extreme contingency of HBT outcome on fire reaching individual trees (see Fig. 6) made a fully-structured, whole-dataset analysis difficult to implement. Accordingly, separate sets of analyses were conducted at the three levels: overall rate of HBT collapse, plots-level outcomes for all trees (HBT and non-HBT) and predictors of individual HBT collapse. These levels contribute complementary information and use different comparison groups and analysis techniques, as described below. All analysis was conducted in R 3.1.0 (R Core Team 2014), with the threshold for significance set at $\alpha = 0.05$ and two-tailed *P*-values reported by default. Model fit and assumptions were assessed for simple linear models using standard diagnostic plots.The Akaike Information Criterion (AIC) and a variant corrected for small sample sizes (AICc) were used to assess model parsimony. Models within three AIC of the most parsimonious model (i.e. delta-AIC < 3) were deemed to have some support; the values traditionally adopted for this cut-off range between two (i.e. the AIC penalty attached to a single additional parameter) and four.

### Overall rate of HBT collapse

The intent of treatment-level analysis was to summarise outcomes for the main effect of the pseudo-experiment — how does collapse rate of HBTs differ between burnt areas and non-burnt areas? The relevant contrast was between HBT outcomes in type A plots (in the area mapped as burnt within ignited burns) versus type C plots (control plots outside of planned burns). Non-ignited burns and areas not mapped as burnt were not used as comparison groups because both ignition, and fire spread within ignited areas, are potentially non-random with regard to HBT outcomes. Data were pooled to calculate an overall rate of collapse in each comparison group together with the associated 95% binomial confidence interval. The relative risk associated with the treatment was calculated directly from the HBT collapse rate in type A plots, divided by the HBT collapse rate in type C plots. Because of known variations in fire mapping practice, a second and more generalisable collapse rate was calculated for trees directly exposed to fire (i.e. those that experienced surface fire to their base). Here the above process was repeated, except the comparison was between directly exposed HBTs in type A plots and non-exposed HBTs (the remainder of trees in type A plots and all trees in type C).

### Plot level predictors of all-tree collapse

Analysis across replicated plots was conducted to examine associations between plot-level tree collapse outcomes and plot-level predictor variables (pre-treatment fuel hazard, post-treatment fire cover, and severity). Two simple linear models were constructed, sharing a similar structure but differing slightly in the available predictors and appropriate datasets. Backwards model selection was conducted on the basis of AIC, starting with full models including interaction terms. The first analysis tested for an association between the count of all collapsed trees >20 cm DBH per plot (HBT plus non-HBT) and relative fire severity and/or fire cover (as above), using a dataset combining type A and type D plots. The second analysis used a response variable of all collapsed trees per plot (as above), but compared the effectiveness of relative fire severity score and aerial image–interpreted fire severity categories as predictor variables. In this case, the dataset was restricted to plots with available aerial image–based fire severity mapping (type D, and three plots in type A).

### Individual HBT level

This level of analysis examined whether outcomes for individual HBTs (i.e. collapsed or remaining standing) were associated with the trees' particular characteristics or immediate surrounds – what factors may predict collapse of single HBTs that are exposed to fire? The dataset comprised all HBTs directly exposed to fire, including those in plot types A and B, but excluding non-exposed HBTs in type A. Therefore, sample sizes of HBTs at this level do not match sample sizes reported at the treatment and plot levels. Binomial GLMMs were fitted for HBT collapse using R Package 'lme4', with the response variable being coded as collapse = 1 and remaining upright = 0. Selection of predictor variables and models required judgement, given the large number of potentially explanatory variables collected, relative to the sample size of HBTs. The approach was to (i) reduce the fixed-effect predictor variables to a subset with the strongest a priori expectation of influence ($n$ = 12 of 25), (ii) include plot ID as the only random effect, (iii) fit a global model based on main effects rather than full interaction terms, and (iv) run all subsets of the global model and use an AICc-based model-averaging approach to identify meaningfully contributing variables. Predictors comprised all variables in Table 1, with the following adaptations:

- The closer of the two fire severity assessments (per plot) was the basis for the relative severity score of each individual tree. (Field-assessed severity data were used in preference to GIS-based fuel severity classification.)
- Fuel hazard data collected for individual trees (in a 2 m radius from the trunk) were used rather than plot-level fuel hazard assessments.
- The percentage of the tree's original cross-section still intact was converted into an 'index of basal defect' as ln(101-percentage intact).
- Missing data (due to a software bug) for crown score ($n$ = 45) was dealt with by allocating the mid-point score of 4.5 to trees missing a crown score.
- Missing data in any of the three hollow size categories ($n$ = 51) was deemed more problematic, and these trees were excluded from further analysis.
- A metric of potential relative HBT habitat value to fauna ('habitat index') was derived from the counts of hollows per HBT in different hollow size classes, relative to the abundance of those classes across all relevant HBTs. The basis for this was the association between fauna use and both the counts of hollows per tree, and the size of individual hollows (Koch 2008). The habitat index was calculated as the natural logarithm of the sum of weighted hollow counts for each tree. Weighted hollow counts were the raw counts of hollows in each size class for a tree, multiplied by the relative frequency of that size class among all hollows on all trees in the sample. The factors applied to small : medium : large hollows, respectively, were 1.4 : 4.6 : 14.6. For example, trees with single small hollows had habitat index values of ln(1.4) = 0.33, whereas the tree with the highest habitat index in the sample had three small hollows, two medium hollows and two large hollows, giving a score of 3.75.

# Results

## Overview

Pre-treatment field work was conducted at 150 plots, of which 126 were distributed across 30 planned burns scheduled for Autumn 2013, and a further 24 across 6 non-treatment 'pseudoburns'. Of these burns, a total of 15 were actually ignited, with 66 plots located in these ignited burns. A total of 34 plots across 13 burns were in areas mapped as burnt. The mean time elapsed between pre-treatment and post-treatment assessments was 337 days, and the mean time elapsed between treatment and post-treatment assessment was 216 days. In total, 1575 HBTs were located and had their characteristics assessed in pre-treatment surveys (Table 1, Appendix 1). Of these, 666 were individually revisited in post-treatment surveys, while the remainder were located in plot types where repeat surveys of individual HBTs were not conducted (see Table 2). Within the boundaries of pre-treatment plots (excluding 125 opportunistically sampled HBTs outside plots), the average pre-fire count of HBTs per plot was 9.67, equivalent to 19.33 HBTs per hectare.

## Audits

Replicate pre-treatment surveys were completed at 18 plots. Using a double-count method, HBT detectability was estimated at 0.567 ± 0.031 (mean and standard error of the mean (SEM)) for all HBTs (i.e. having at least one hollow of any size), rising to 0.767 ± 0.046 for HBTs with at least one medium-sized hollow. Detectability estimates of HBTs did not differ significantly among the three initial assessors ($F_{2,15}$ = 0.404, $P$ = 0.675). Counts of HBTs per plot were moderately correlated between independent assessments ($r$ = 0.486, $P$ = 0.020). However, HBT counts per plot were better correlated for trees with at least one medium-sized hollow ($r$ = 0.674, $P$ = 0.001), or at least one large hollow ($r$ = 0.750, $P$ < 0.001). For the sample of 84 trees determined as HBTs by both assessors, mean (± SEM) divergence between repeat measures of key characteristics was: 1.36 ± 0.18% of DBH, 4.31 ± 0.81% of intact base, 1.20 ± 0.16 units for crown score, 6.40 ± 0.49 m (Euclidean distance) in GPS coordinates and 97.6% consistency of classification as alive or dead. These measures of repeatability subsequently informed decisions when matching pre-treatment and post-treatment samples of HBTs, both in the field and during post hoc desktop classification of difficult cases

## Overall rate of HBT collapse

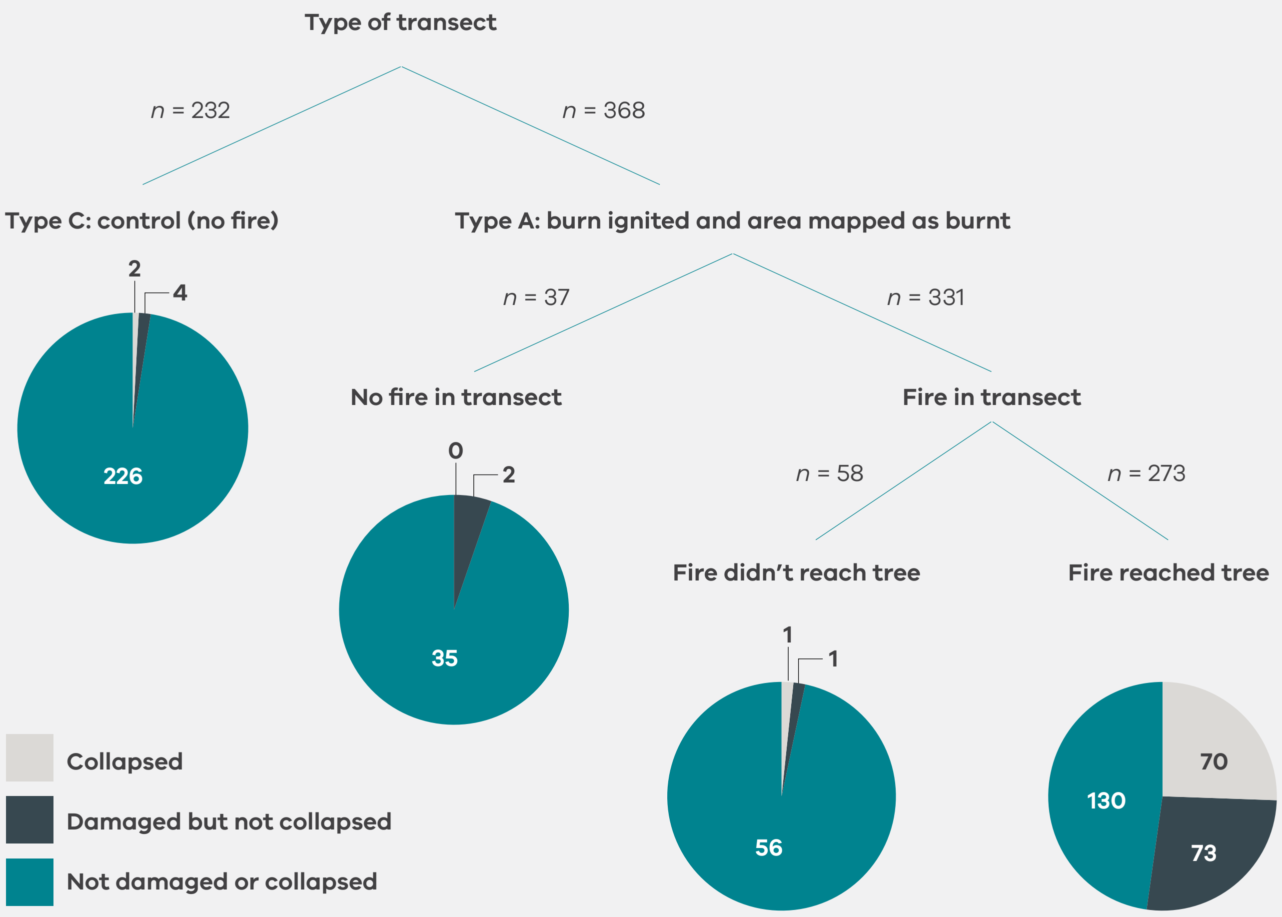
Exposure to fire was unambiguously associated with increased occurrence of collapse among HBTs (Fig. 6). From the sample of 273 HBTs that were directly exposed to fire, 70 collapsed and a further 73 were structurally damaged, whereas these outcomes rarely occurred among HBTs not exposed to fire. Note that all other results consider collapse only, pooling damaged and undamaged trees as 'not collapsed'. The relative risk of collapse depends on which groups of HBTs are compared, with further details provided below. A substantial number of collapsed HBTs (22 of 70) were completely consumed by fire, leaving ash-beds.

The overall rate of HBT collapse across all plots mapped as burnt was 19.3% (95% CI: 15.4–23.7%), compared with 0.9% (0.1–3.1%) in control plots. Accordingly, HBTs within areas mapped as burnt were on average 22.4 times more likely (relative risk) to collapse than HBTs in control plots. This figure does not encompass the occurrence of fire outside mapped areas (i.e. accounts for type I error but not type II error).

The generality of the above results is expected to be constrained by the spatial accuracy of the burn mapping, and this is known to have varied considerably over time and to a lesser extent between DELWP Districts and Regions. A more robust statistic would be the collapse rate of HBTs directly exposed to fire (surface fire to the base of the tree), compared with those not directly exposed to fire. The observed rate of collapse of HBTs directly exposed to fire was 25.6% (95% CI: 20.6–31.3%) versus 0.9% (0.2–2.7%) across all HBTs not directly exposed to fire. Accordingly, direct exposure to fire is associated with a 27.9-fold increase in the rate of HBT collapse (relative risk). As the accuracy of burn mapping increases, convergence is expected between estimates of HBT collapse rates (i) in areas mapped as burnt and (ii) of HBTs directly exposed to fire.

**Figure 6.** Outcomes for HBTs as a function of different levels of exposure to fire.

All numbers refer to counts of individual HBTs. The first split distinguishes HBTs in type C plots (left side) from type A plots (right side). The second division distinguishes HBTs in type A plots in which no fire entered the plot (left) from plots where at least some fire occurred within the plot (right). The third split distinguishes, of all HBTs in type A plots in which fire did enter the plot, those HBTs that didn't directly experience fire (left) from those that did (right). The occurrence of HBT collapse (grey) and damage (dark green) is clearly associated with fire reaching the base of the HBT.



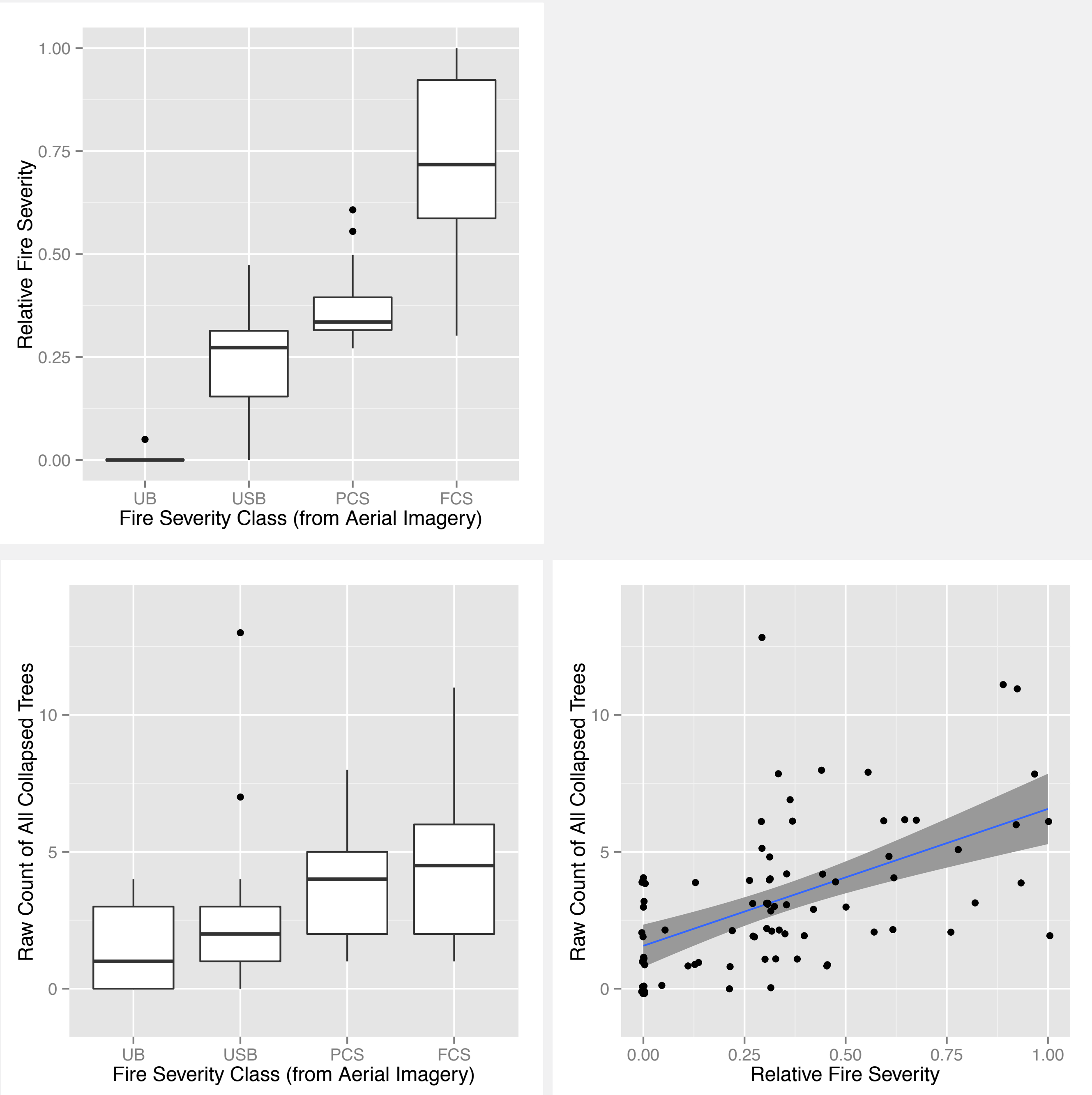
## Plot level predictors of all-tree collapse

The inclusion of type D plots (which were stratified by mapped fire severity classes) together with type A provided a stronger dataset ($n$ = 114 plots) for disentangling severity and burn cover as predictors of collapse. However, because pre-treatment HBT data were lacking for these plots, analysis was constrained to overall counts of all trees >20 cm DBH collapsed per plot (HBTs and non-HBTs). The final model for count of trees collapsed was significant overall ($F_{2,111}$=10.5, $P$ < 0.001) and included a marginally non-significant positive effect of relative fire severity($P$ = 0.056) and a non-significant positive effect of percent burn cover ($P$ = 0.137).

Restricting the dataset to include only plots with both GIS-mapping of categorical fire severity and on-ground relative severity assessments ($n$ = 3 type A plots and $n$ = 80 type B) allowed these two severity measures to be compared as predictors of tree collapse. In this case, the most parsimonious model included only the positive effect of fire severity on the count of collapsed trees per plot ($F_{1,81}$ = 31.47, P < 0.001) (Fig. 7). While GIS-mapped categorical fire severity was a significant predictor of tree collapse if included as the only model term ($F_{3,79}$ = 6.356, $P$ < 0.001) (Fig. 7), it was a poorer performer in terms of overall variance explained (adjusted $r^2$ = 0.164 vs 0.271) and was displaced by relative severity in AIC-based model selection (delta-AIC = 13.297).

**Figure 7.** Top, on-ground relative fire severity as a function of mapped fire severity class (UB = unburnt, USB = understorey burnt only, PCS = partial crown scorch, FCS = full crown scorch)

Boxplots show that relative severity scores were clearly distinguished between severity classes, with the exception of overlap between understorey burnt and partial crown scorch classes. However, as alternative predictors of the count of all collapsed trees, fire severity class (bottom left) was outperformed by relative fire severity (bottom right).



## Predictors of individual HBT collapse

The dataset for individual HBTs directly exposed to fire comprised 235 trees identified in pre-treatment surveys, of which 61 subsequently collapsed and 174 did not. This number included all fire-exposed HBTs in plot types A and B, but excluded trees with missing hollow count data. Binomial GLMMs were fitted for HBT collapse, with the global model including the main effects of 12 predictor variables (that were a selection from ~25 tree-level variables collected) and the random effect of plot ID. Weighted model averaging across subsets of the global model with AICc < 3 identified three tree-level variables with support for a positive association with the likelihood of HBT collapse (Table 5). The model-averaged coefficients were converted to give log-odds scores for individual factors as follows. A dead HBT had on average 6.60-fold higher odds of collapse than a live HBT. A single unit increase in the ln(Base Damage) score (equivalent to the transition from a 100% intact base to a 98% intact base, or a 98% intact base to a 93% intact base) was associated with a 1.35-fold increase in the odds of collapse. Finally, a unit increase in Habitat Index increased the odds of HBT collapse by a factor of 1.76. Converting Habitat Index scores back to hollow counts, either of the following comparisons were associated with an approximately doubling in the odds of HBT collapse: a tree with a single medium hollow versus a tree with a single small hollow; or a tree with a single large hollow versus a tree with a single medium hollow.

**Table 5.** Test statistics for 12 tree-level variables fitted as predictors for the probability of HBT collapse, averaged across all models within 3 AICc of the best model, weighted by submodel AICc. Relative importance of each variable was calculated by the sums of Akaike weights among models with AICc < 3. Note that while two-tailed *P*-values are reported, there was an a priori expectation of positive coefficients for all listed variables except species type. The top three variables were therefore deemed to have statistically significant support across the suite of models with AICc < 3. *$P < 0.10$ **$P < 0.05$.

| VARIABLE | IMPORTANCE | N MODELS | COEFFICIENT | SE | *P* | ODDS RATIO | 95% CI OF ODDS RATIO |
|---|---|---|---|---|---|---|---|
| Habitat Index | 1.00 | 29 | 0.57 | 0.24 | 0.018** | 1.76 | 1.10-2.81 |
| Living (dead) | 1.00 | 8 | 1.89 | 0.49 | 0.000** | 6.60 | 2.55-17.11 |
| ln(base damage) | 0.70 | 32 | 0.30 | 0.17 | 0.082* | 1.35 | 0.96-1.89 |
| Drywood (yes) | 0.53 | 10 | 0.80 | 0.51 | 0.121 | 2.22 | 0.82-6.04 |
| Crown score | 0.45 | 60 | 0.17 | 0.13 | 0.191 | 1.19 | 0.92-1.54 |
| Termites | 0.38 | 11 | 0.66 | 0.52 | 0.208 | 1.93 | 0.70-5.37 |
| Woody fuel (yes) | 0.14 | 7 | 0.29 | 0.42 | 0.498 | 1.33 | 0.58-3.06 |
| Hollow butt (yes) | 0.14 | 40 | -0.01 | 0.74 | 0.989 | 0.99 | 0.23-4.20 |
| Fuel hazard | 0.15 | 60 | 0.18 | 0.24 | 0.465 | 1.19 | 0.75-1.91 |
| DBH | 0.10 | 25 | 0.00 | 0.01 | 0.713 | 1.00 | 0.98-1.03 |
| Relative fire severity | 0.09 | 10 | 0.18 | 1.65 | 0.916 | 1.19 | 0.05-30.54 |
| Species type | 0 | 0 | - | - | - | - | - |

# Discussion

## Overview

The motivation for this study was the lack of information on the fate of HBTs in planned burns in Victoria. Accordingly, the study's primary goal was to quantify the impact on HBTs of exposure to a single instance of planned fire; the secondary goal was to provide evidence-based options to managers seeking to reduce this impact. The rationale for the study was to identify HBTs in burns scheduled for Autumn 2013 in Gippsland, as well as in matching control areas, and to follow these HBTs in a before-after-control-impact (BACI) design. An additional design target was to achieve replication across as many burns ($n$ = 30), plots (150), and individual trees (1575) as possible, within logistical constraints. As anticipated, not all scheduled burns were ignited, and not all ignited burns carried to study plots. The final datasets included 235 to 273 individual HBTs directly exposed to fire across 13 burns (the exact sample size varied between analyses). While plot audits showed that, as expected with ground-based hollows surveys (Harper et al. 2004), detection rates of HBTs were less than 1 (0.567 to 0.768 depending on hollow size cohorts), the overall reported density of HBTs (~19.3 HBT/ha) approximated previous studies in Gippsland (22.0, Gibbons et al. 2000b; 20.3, Fox et al. 2009).

## Collapse rates

Planned burns unambiguously and substantially increased the collapse probability of HBTs (Fig. 6). The collapse rate of HBTs in areas mapped as burnt was 19.3%, and HBTs in such areas were 22.4 times more likely to collapse than trees in control areas. However, this figure does not account for false positive errors (fire mapped but absent) and false negative errors (fire mapped as absent but present) associated with fire mapping. Of HBTs directly reached by fire, 25.6% collapsed, which represented a 27.9-fold increase in the risk of collapse versus that of HBTs that did not directly experience fire. These rates of collapse were consistent with the only other study estimating HBT collapse rate across more than one planned burn (14–26%, Parnaby et al. 2010). But given that 31.4% of collapsed HBTs in this study were completely consumed by fire, post-fire-only studies of HBT fate (such as Parnaby et al. 2010) would systematically underestimate the true rate of HBT collapse.

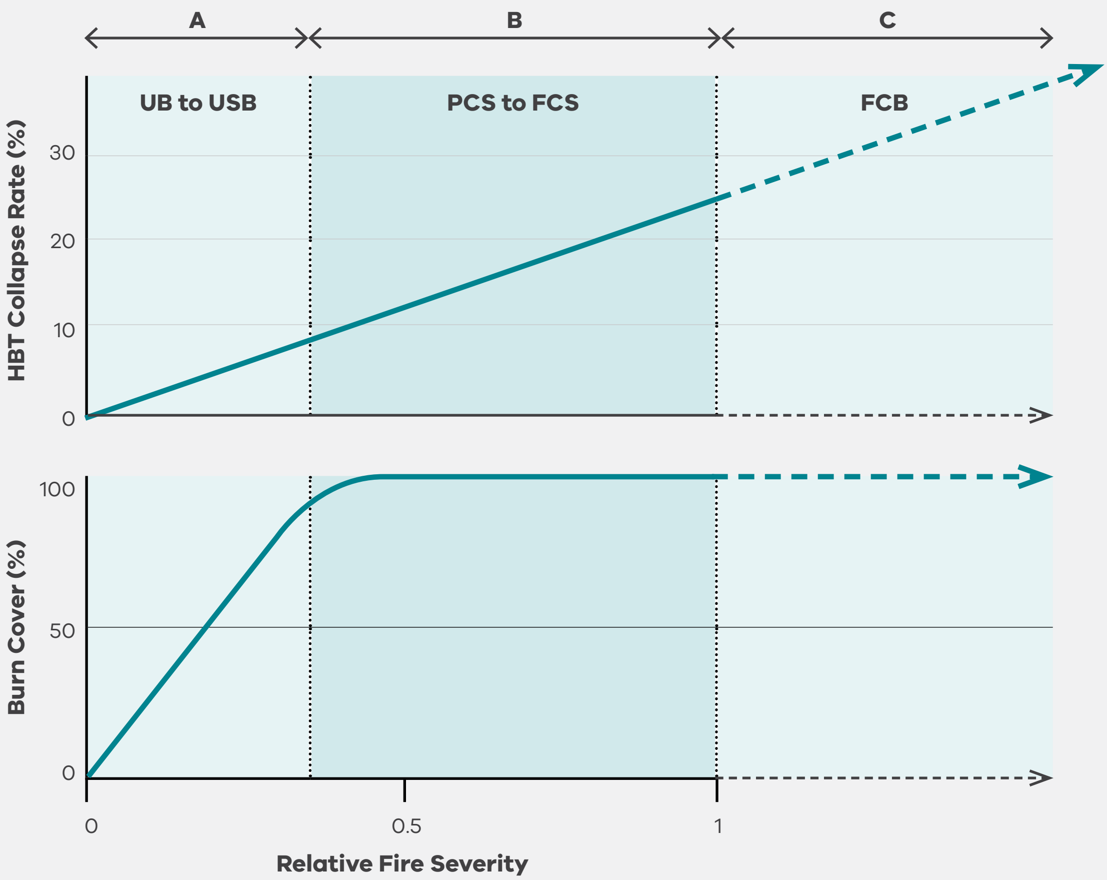
## The relationship between burn cover, fire severity and HBT collapse

Identification of positive relationships between HBT collapse, burn cover and fire severity provides managers with evidence that changing burn prescriptions will reduce the impacts of burns on HBTs. The study provided two relevant lines of evidence. First, collapse of HBTs was clearly contingent on fire carrying to the base of individual HBTs (Fig. 6); on average, reduced burn cover within the burn perimeter will result in proportionally reduced exposure of HBTs to fire, and therefore reduction in the rate of HBT collapse. Secondly, although burn cover and severity are related, higher severity per se was linked to greater numbers of tree collapse events. Using an expanded dataset of post-fire-only plots, it was possible to show that total tree collapse per plot (as a surrogate measure of HBT collapse) was most strongly related to relative fire severity (rather than burn cover) and to on-ground measures of severity (rather than remotely-assessed severity classes). Although relative fire severity was not a significant predictor of collapse in individual HBT models, this may be an issue of spatial scale, i.e. that most relevant variation in severity may occur in close proximity to individual trees rather than the larger scale (25 m radius) at which severity data were collected in this study.

A conceptual model for the interaction of cover, severity and HBT collapse is proposed in Fig. 8. Under this model, the rate of HBT collapse is most strongly associated with burn cover in 'cool burn' conditions, and with severity in 'hot burn' or typical bushfire conditions. The observed relationships and conceptual model can support planners seeking to reduce HBT collapse (see Box 2 for generalised management options); for example the model implies that increasing burn severity beyond the point of full burn coverage is expected to yield continued marginal costs for HBT loss, but decreasing marginal benefits for fuel hazard reduction.

**Figure 8.** Conceptual model for the relationship between fire severity, burn cover and HBT collapse rate in EVDs 3 and 7 in Gippsland

All values are approximate, and curve shapes are arbitrary. Phase A (left): burn cover and fire severity metrics are positively related; however, fire severity metrics are highly spatially variable, and burn cover is the dominant predictor of HBT collapse rate. This phase covers fire severity classes 'unburnt' (UB) through to 'understorey burnt' (USB), has relative fire severity index values (as used in this study) ranging from 0 to ~0.3, and would colloquially be referred to as a 'cool burn'. Phase B: burn cover asymptotes at 100% while fire severity continues to increase, and variation in HBT collapse rate is predicted by severity only (not cover). Here, categorical fire severity ranges from 'partial crown scorch' (PCS) to 'full crown scorch' (FCS), and the relative fire severity index ranges from ~0.3 to 1, corresponding to a 'hot burn'. Phase C: fire severity extending beyond the range observed in this study, but HBT collapse projected to continue increasing. This phase corresponds to full crown burn, exceeds the maximum relative fire severity of 1, and would only be expected in bushfire conditions.



## Predictors of collapse of individual HBTs

By knowing which characteristics most predispose individual HBTs to collapse, it is possible to identify which trees to treat (e.g. potentially by mechanical fuel reduction) to most effectively reduce the overall collapse rate of HBTs in a burn. The factor most strongly influencing the probability of collapse is whether HBTs were alive or dead; dead trees had over six times the odds of collapse. Structural damage to the base of a HBT, i.e. a proportion of the 'natural' cross-section of the tree missing, was also positively associated with increased risk of collapse. Finally, HBTs with more hollows and/or larger hollows were more likely to collapse, with the odds of collapse doubled for, e.g., a tree with one medium hollow compared with a tree with one small hollow. These predictors of collapse are intuitive and consistent with existing opinion on characteristics indicating 'hazardous trees' (DSE 2011). Where on-ground works are prescribed to reduce the overall risk to HBTs, and resources for the task are limited, prioritising HBTs for treatment in the order from largest to smallest effect size will produce the most efficient reduction in HBT collapse rate. The suggested order is (most important first):

1. dead HBTs
2. HBTs with at least one hollow >20 cm
3. HBTs with <80% structural tissue in cross-section at weakest point
4. HBTs with at least one hollow >10 cm
5. HBTs with >80%, but <100%, structural tissue in cross-section.

This sequence could be modified, depending on objectives (e.g. prioritising HBTs matching the hollow requirements of a particular fauna species, see Goldingay 2009), or further simplified for communication to field workers.

*The factor most strongly influencing the probability of collapse is whether HBTs were alive or dead; dead trees had over six times the odds of collapse.*

## Effects of planned burning on hollow-dependent fauna species

The large sample sizes required for this study necessitated ground observation (rather than climbing or felling trees) of mostly canopy-level hollows in forest trees. Collection of detailed data on fauna usage of individual HBTs was unrealistic. However, field assessors noted signs of hollow use (e.g. worn hollow entrance, scat, scratching on bark) at more than 5% of HBTs. This is likely to be a considerable underestimate: studies using felling of trees to examine hollow usage by fauna have found per-tree usage rates from 28% to 57% (Gibbons et al. 2002, Koch et al. 2008). The extent to which hollow availability limits the populations of hollow-dependent species is generally unclear (Koch et al. 2008, Lindenmayer et al. 2011) and is likely to be highly contingent on individual species and location (Newton 1994). Hollows of varying dimensions are required to suit the needs of individual species, and individual animals often use more than one hollow, thereby requiring many more hollows than individuals to support populations. Some ground-dwelling species may hypothetically be advantaged by fire-driven collapse of HBTs, but this seems unlikely in practice given (i) the subset of collapsed HBTs that are fully consumed by fire, combined with (ii) consumption of existing ground-level hollow logs (not investigated here). A small number of opportunistic studies have been able to follow fire-triggered hollow loss on possum species: Inions and colleagues (1989) found that a planned burn in south-western Western Australia removed 38% of trees used by Common Brushtail Possums and Ringtail Possums, but did not examine population impacts. After the 2009 Black Saturday fires burnt an existing Mountain Brushtail Possum study site, Banks and colleagues (2011) observed the loss of 93% of trees previously used by possums, but found no short-term demographic effects.

While field data linking the abundance of HBTs and hollow-dependent fauna are generally lacking (with notable exceptions, e.g. Newton 1994, Lindenmayer et al. 2013), the relationship between the two is likely to be complex, cryptic and interrelated with external factors such as drought, fire and logging (Lindenmayer et al. 2011). This is exemplified by a recent discovery: Swift Parrots suffer exceptionally high mortality at some of their Tasmanian tree-hollow nest-sites due to predation by Sugar Gliders, but the severity of predation is related to limited availability of suitable mature-forest habitat (Stojanovic et al. 2014). In short, it is clear from the current study that planned burning reduces hollow availability in the short term, but it is not clear what longer-term, population-level effects may result for particular hollow-dependent fauna species.

*Hollows of varying dimensions are required to suit the needs of individual species, and individual animals often use more than one hollow, thereby requiring many more hollows than individuals to support populations.*

## Effects of fire regime on HBT abundance

This project was designed to measure the effect of a single planned burn event on HBTs. Longitudinal modelling of HBT abundance is feasible, but would rely on accurate quantification of HBT recruitment rate and feedback effects of sequential fires. For example, it has been suggested (e.g. Adkins 2006) that high-severity fire positively affects post-fire HBT recruitment rate, and there are limited field data supporting this (e.g. Fox et al. 2009, McLean et al. 2015). Planned fire is normally below the severity required to kill upper-storey trees or damage them at canopy level, which are the suggested mechanisms for fire increasing hollow abundance (i.e. post-fire HBT recruitment rates are likely to be higher after bushfire than planned burns). In terms of feedback effects, there is evidence from this study that suggests a positive feedback effect on HBT collapse rate from sequential planned burns: more trees were judged 'structurally damaged' than actually collapsed. That is, preceding fires may increase the subset of HBTs predisposed to collapse in subsequent fires. On the other hand it is conceptually possible that a sequence of fires will quickly remove susceptible trees, but more robust HBTs will not be affected, leading to negative feedback on the HBT collapse rate over a series of fire events. However, no data from this study supported a hypothesis of negative feedback, and indeed tree-level data suggested that HBTs resistant to a series of fires would be a subset of lower value to fauna. Finally, there are only limited, opportunistic data on HBT collapse rate in bushfire (e.g. Banks et al. 2011), and the relationship between extent of planned burning and extent of bushfire is not well understood (Price and Bradstock 2011). Despite these limitations, there is a clear need for longitudinal modelling of HBT abundance (sensu Lindenmayer and Wood 2010, Lindemayer et al. 2011, Manning et al. 2013) under alternative landscape management scenarios, including bushfire effects. The current project has created a widespread network of study plots with identified HBTs, and over the longer term has the capacity to inform longitudinal modelling by intersection with future bushfire events, and/or through sequences of planned burns.

*Planned fire is normally below the severity required to kill upper-storey trees or damage them at canopy level, which are the suggested mechanisms for fire increasing hollow abundance (i.e. post-fire HBT recruitment rates are likely to be higher after bushfire than planned burns).*

## Limitations and further work

- **Geographical and ecological generality.** This work was conducted in particular vegetation types ('Grassy/Heathy Dry Forest' and 'Tall Mixed Forest') typifying the majority of the area treated in planned burns in Gippsland. While it seems likely that some aspects of the project (e.g. predictors of individual tree collapse) are generalisable to other areas and vegetation types, overall collapse rates may well differ according to such factors as: previous disturbance history, operational burning practices, tree species, topography, fuel structure, and moisture levels. The field methods used here were cost-effective and do not require expert assessors, so the work could easily be replicated in other landscapes in Victoria.

- **Spatial effects.** The spatial design component of this project focused on testing whether existing models of HBT abundance are sufficiently informative for management use. This was secondary to the HBT collapse component of the project and was not reported here. As a consequence, the project was not designed to examine co-variation between spatial pattern of fire (e.g. due to fuel moisture gradients or ignition patterns) and HBT collapse rate. A thorough implementation of such a design would involve topographic stratification and experimental burn prescriptions, e.g. to achieve a sufficient distribution of fire presence/absence across gully plots. In areas with a sustained burning history and topography-driven burn pattern, these factors seem likely to influence both the localised density of HBTs and their probability of collapse in planned burns.

- **Sampling bias for HBTs.** Double-count analysis using plot audit data illustrated that HBTs with larger hollows are more detectable. The inference is that trees with small numbers of small hollows were undersampled compared with their abundance in the environment. In combination with the result that trees with more and larger hollows have a higher likelihood of collapse, the overall HBT collapse rates reported here are likely to be overestimates compared with true collapse rates for all qualifying HBTs. Approaches to rectify this could include multiple repeat surveys of all plots, or applying corrective factors to collapse rate estimates, to compensate for sampling bias and differential collapse rates. A counter-argument is that current survey methods, by identifying trees with single 5-cm cavities as hollow-bearing, extended HBT status to many trees of comparatively little value to fauna, distorting the ultimate intent: to guide management of fauna habitat. From this perspective, the HBT collapse rates reported here are underestimates of the impact of planned burning on fauna habitat.

## Fire management and effective mitigation of HBT collapse

A series of generalised options is provided (Box 2) to guide operational and strategic planners seeking to reduce impacts of planned burning on HBTs. The realistic scope for managers to vary fire prescriptions and implementation may be constrained, but the effects of moderate changes on HBT stock would be substantial nonetheless. An average reduction in mapped burn cover of 10% within treated areas across Gippsland's annual planned burning program (~116,000 ha) would result in the annual retention of ~42,000 HBTs. In areas where there is greater scope to vary prescriptions, a reduction from 75% mapped burn cover to 50% cover within a hypothetical 1000-ha burn unit in typical Gippsland forest would result in the retention of ~900 HBTs. In contrast, individual protection of every HBT within 30 m of the same burn unit's perimeter (~750) would be labour-intensive and would result in the retention of fewer than 200 HBTs. However, in smaller burns, protection of individual HBTs would be (relatively) more effective, both in terms of total cost and proportional reduction of HBT loss. It is worth noting that protection of HBTs in burn perimeters addresses both mitigation of human risk (by reducing the frequency of collapse events) and retention of HBTs, whereas removal of hazardous trees only addresses the former. Prescriptions should therefore be relevant to the properties of individual burn units, and also should be stable over time (Box 2, option 1c). Short-term fluctuation of prescriptions (e.g. across FOP planning cycles) might undo within a single burn several cycles of careful fire application.

A hierarchy of hypothetical control measures for HBT collapse risk can be envisaged (Table 6), analogous to the hierarchy of risk controls in occupational health and safety risk assessment. However, the analogy with OHS practice is imperfect: it has an implicit operational focus and underestimates the capacity of strategic planning to reduce the impact of planned burning on HBTs.

**Table 6.** Hierarchy of hypothetical measures to control the risk of HBT loss in a burn unit (analogous to risk controls in occupational health and safety risk assessment)

| EFFECTIVENESS | CONTROL TYPE | HYPOTHETICAL RISK CONTROL MEASURES |
|---|---|---|
| Highest | Risk elimination | Do not burn the area. If fuel treatment is essential, conduct mechanical (slasher) fuel reduction. |
| | Risk substitution | Reduce the area burnt or burn an alternative area with lower HBT values. |
| | Engineering | Mineral earth breaks to stop spread of fire into HBT areas.<br>Ignition patterns that reduce cover and severity of fire in high-density HBT areas. |
| | Administrative | Change burn prescriptions to reduce burn cover, severity and frequency. |
| Lowest | Direct protection | Conduct risk-treatment measures (e.g. rake-hoeing) on individual HBTs. |

# Conclusion

This study has demonstrated that planned burns in Gippsland increase the collapse risk of HBTs significantly and, by implication, are likely to cause loss of habitat for hollow-dependent fauna in areas where hollows are needed.

The outcomes for fauna of such loss of hollows were not the subject of this study but will be influenced by the combined effects of losses from bushfire, planned burning and other disturbances as well as by creation of hollows through natural processes, including fire. The rate of HBT collapse associated with a fire regime focussed on reducing risk to life and property (i.e. fire frequency sufficient to result in sustained reduction of fuel hazard) appears likely to far exceed the natural rate of tree hollow recruitment. In such circumstances, land managers have options to deploy fire in an informed and evidence-based manner in order to retain HBT stocks where possible. This report provides a set of clear management options and opportunities, based on the evidence from the most rigorous study conducted in Australia to date, enabling managers to (i) reduce HBT loss by changing fire prescriptions where this will still achieve the objectives of the Code, and (ii) in areas where human risk requirements and fauna needs coincide, to identify which HBTs to target for direct protection works to reduce overall HBT loss.

## Box 2: Management options

For increased retention of hollow-bearing trees

### Operational level

1) In order to minimise HBT collapse when applying fire to individual burn units:

  a. Consider HBT values in burn planning, particularly where burn units contain known or modelled habitat for hollow-dependent species.

  b. Limit burn severity and cover to the minimum required to achieve burn cover target.

  c. Maintain consistent prescriptions and implementation methods within the same burn units over time.

2) In order to minimise HBT collapse when using risk-treatment measures for individual trees (e.g. rake-hoeing), where resources are limited:

  a. To reduce overall collapse rate, prioritise HBTs for treatment, starting with the top of the following list:

  - dead HBTs
  - HBTs with at least one hollow >20 cm
  - HBTs with <80% structural tissue in cross-section at weakest pointHBTs with at least one hollow >10 cm
  - HBTs with >80%, but <100%, structural tissue in cross-section.

  b. Adjust this set of priorities if needed (e.g. to address specific hollow characteristics required by local high-priority fauna species).

### Strategic planning level

1) In areas where planned burning is necessary to reduce human risk, options are to:

  a. Reduce burn cover and severity prescriptions to the minimum extent sufficient to achieve management objectives.

  b. Maintain consistent burn prescriptions over time for particular burn units.

  c. Where local hollow-dependent fauna species are identified as values within burn units, consider risk-treatment to individual trees as described above.

2) Implement landscape-scale, long-term planning for the needs of hollow-dependent fauna:

  a. Identify areas of comparatively high importance to hollow-dependent fauna and with low contribution to human risk.

  b. Ensure management objectives within these areas achieve the retention of HBT stocks by minimising exposure to planned fire.

  c. Consider past disturbance effects of logging, bushfire and planned burning on HBT stocks, and the time scale of HBT development.

3) Monitoring and research needs:

  a. management effectiveness monitoring to improve the link between burn prescriptions (especially burn cover) and realised outcomes

  b. trial of mechanical fuel removal methods to maximise the cost-effectiveness of HBT risk treatment (e.g. to identify the optimum distance to rake-hoe around the base of HBTs in order to minimise overall HBT collapse rate)

  c. an evidence-based tool to assist field staff in the identification of individual trees with potential (i) habitat value and (ii) human risk

  d. improvement in spatial modelling and remote assessment (e.g. aerial imagery) of (i) habitat importance for hollow-dependent fauna species, and (ii) human risk

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# Appendix 1: Hollow-bearing tree survey protocol

## Project aims

- To quantify the rate of hollow-bearing tree collapse in prescribed burns, by pre- and post-fire ground-based surveys.
- To test for significant predictors of hollow-bearing tree collapse at the scale of individual trees, of forest stands, and of entire burns.

## Definitions

Hollow: an opening 5 cm or greater in its smallest dimension, and at least as deep as its smallest aperture dimension. Fissures are excluded.

Hollow-bearing tree (HBT): any tree containing at least one hollow.

Strip transect: area of 50 x 100 m (0.5 Ha) within which all trees are searched for hollows.

Forest stand polygon: a polygon unit classified (via aerial photo interpretation) conducted as part of the Statewide Forest Resource Inventory program. Stands are areas composed of similar trees, ranging from 1 to 60 hectares. Each stand polygon will contain one HBT survey strip transect.

Burn polygon: a polygon unit defined by the Fire Operation Plan. Each burn polygon will contain two or more forest stand polygons.

## Equipment required

- Trimble Nomad running TerraSync with correct data dictionary loaded
- Navigational GPS with stand polygons and transect point maps loaded
- Binoculars (8 x 40 or higher)
- 100 m measuring tape
- 5 m diameter tape
- Compass
- Laser rangefinder
- Laminated photo guides to fuel hazard, bark char, tree structure
- Clipboard, hard copy datasheets and pencil (backup for Nomad)
- Compact digital camera (backup for Nomad)
- Safety gear including: mobile phone, UHF, trunk radio, personal safety beacon, first aid kit, protective helmet, boots with ankle support, sun protection, food and water.

## Field logistics

Each forest stand polygon will be completed by a single field worker, unless site-specific safety issues override this. Where possible, stand polygons have been located in pairs within burns (i.e. 2/4/6 polygons per burn), so that two or more field workers can operate nearby for logistical convenience and safety. Nearest neighbouring stands are not necessarily contiguous, but should in most cases be within hand-portable UHF transmission distance.

In each stand polygon, the field worker will first survey a strip transect, then search for hollows within the remainder of the stand polygon, then search for hollows in the surrounding area if time permits (see next page). It should be possible to complete two stands per person per day, with a minimum of 3 h spent between starting the strip transect and completing each stand polygon.

**Figure 1: example of a planned burn (red outline) containing four forest stand polygons (yellow and green) targeted for HBT survey. Each stand polygon contains a 50 x 100 m strip transect (black).**

## Steps for completing HBT survey in a forest stand polygon

1. **Establish transect start point.**

- Walk to coordinates of start point.
- Mark with pink flagging tape on nearest eye-level vegetation.
- On Trimble Nomad, open new data file and complete 'Transect Start' form.
- Deploy start of 100 m measuring tape.

2. **Establish transect, including transect end point.**

- While standing at the start point, compare the provided compass bearing with that of the transect end point.
- Walk this bearing, paying out measuring tape and maintaining a straight line.
- Stop at end of 100 m tape (doesn't matter if not exactly at mapped end point).
- Mark with pink flagging tape on nearest eye-level vegetation.
- On Trimble Nomad, complete 'Transect End' form.
- Note: it is optional to use the GPS to navigate between transect start and end points as an alternative to the compass. However, maintaining a straight transect is more important than perfect placement of transect end point.

3. **Complete HBT search in transect.**

- Return along the measuring tape, actively searching up to 25 m either side of the tape for HBTs.
- It is not necessary to walk around every tree, but trees that appear likely to have hollows (e.g. dead/senescent/damaged crown trees) should be inspected closely from multiple sides – not just from the transect centre.
- Use a laser rangefinder to assess whether HBTs are 25 m or less from the transect centre (i.e. tape line).
- Complete a 'Tree' data form on the Trimble Nomad for each identified HBT.
- Keep Nomad under the tree while the GPS is acquiring fixes (beeping noise). Pause acquisition after 50–100 fixes.
- Incidental HBTs more than 25 m from the transect line may be processed now or later – whichever is more time efficient – as long as the 'In transect?' field is correctly filled in.
- Wind the measuring tape in after completing the HBT search in the transect.

4. **Free HBT search in remainder of forest stand polygon.**

- After completing transect, commence a free search for HBTs throughout the forest stand polygon (within boundaries mapped on GPS).
- Avoid trees within 50 m of roads/tracks where possible.
- Continue search until a minimum of 3 h has elapsed since the start of the transect, or when 20 HBTs have been processed, whichever comes first.
- If the forest stand polygon is exhausted before 3 h, continue to search the surrounding area outside the polygon (but inside the burn unit, and not in another survey polygon) for the remaining time.
- Close Trimble data file.

## DETAILS OF 'TRANSECT START' AND 'TRANSECT END' DATA ENTRY FORMS IN TERRASYNC

| FIELD | VALUES | INSTRUCTIONS |
|---|---|---|
| Person | Self-explanatory | If 'Other' is selected, a text field will appear for manual name entry. |
| StandID | Text | 9-digit code for each stand polygon. Should be visible on supplied GPS maps. |
| Please take care to avoid errors in this field. | | |
| Photo along transect | | Take a photo (in landscape orientation) looking down the middle of the transect. |
| **FUEL ASSESSMENT FIELDS** | | **CONSULT DSE STANDARD FUEL ASSESSMENT GUIDE FOR FULL DETAILS** |
| **Canopy fuel 20 m radius** | | |
| Av. Height to top (m) | Integer 0–100 | Assess height at top of canopy within 20 m radius |
| Av. Height to base (m) | Integer 0–100 | Assess height at base of canopy within 20 m radius |
| **Bark fuel 20 m radius** | | |
| Stringybark fuel | L/M/H/VH/E | Consult fuel guide; assess within 20 m radius |
| Ribbon bark fuel | L/M/H/VH/E | Consult fuel guide; assess within 20 m radius |
| Other bark fuel | L/M/H/VH/E | Consult fuel guide; assess within 20 m radius |
| **Elevated fuel 10 m radius** | | **Fine fuels not in contact with surface or canopy (e.g. shrub layer)** |
| % Cover | 0–100% | Assess within 10 m radius |
| % Dead | 0–100% | As above; should be less than or equal to overall percentage cover |
| Fuel av. height (m) | Integer 0–100 | Value in metres; assess within 10 m radius |
| Elevated fuel hazard | L/M/H/VH/E | Consult fuel guide; assess within 10 m radius |
| **Near-surface fuel 10 m radius** | | **Fine fuels in contact with surface but not lying on it** |
| % Cover | 0–100% | Assess within 10 m radius |
| % Dead | 0–100% | As above; should be less than or equal to overall percentage cover |
| WT | Integer 0–100 | Value in metres; assess within 10 m radius |
| Near-surface fuel hazard | L/M/H/VH/E | Consult fuel guide; assess within 10 m radius |
| **Surface fuel 10 m radius** | | **Fine fuels lying on the ground, includes partially decomposed fuels** |
| % Cover | 0–100% | Assess within 10 m radius |
| Av. litter depth (mm) | Integer 0–1000 | Assess by poking stick in litter; value in mm |
| Surface fuel hazard | L/M/H/VH/E | Consult fuel guide; assess within 10 m radius |
| **Comments** | **Free text** | **e.g. unusual features of plot, or reasons for changing transect location** |

### DETAILS OF 'TREE' DATA ENTRY FORMS IN TERRASYNC

| FIELD | VALUES | INSTRUCTIONS |
|---|---|---|
| **Person** | Self-explanatory | If 'Other' is selected, a text field will appear for manual name entry. |
| **StandID** | Text | 9-digit code for each stand polygon. Should be visible on supplied GPS maps. Please take care to avoid errors in this field. |
| **In transect?** | Yes/no | Only 'yes' if tree 25 m or less from transect middle line |
| **Hollow bearing?** | Yes/no | Only 'yes' if one or more qualifying hollows identified |
| **Comments** | Free text | e.g. unusual features of tree |
| **Hollow parameters** | | **Category only appears if 'Hollow bearing?' = 'yes'. Fissures are not assessed as hollows.** |
| Hollows 5 to <10 cm | Integer 0–100 | Count of qualifying hollows from 5 cm to <10 cm minimum aperture. Hollow must appear to be at least as deep as its minimum aperture. |
| Hollows 10 to <20 cm | Integer 0–100 | Count of qualifying hollows from 10 cm to <20 cm minimum aperture. Hollow must appear to be at least as deep as its minimum aperture. |
| Hollows 20 cm+ | Integer 0–100 | Count of qualifying hollows of 20 cm or greater minimum aperture. Hollow must appear to be at least as deep as its minimum aperture. |
| Hollow in use? | Yes/no | Only 'yes' if at least one hollow has visible smoothing, gnawing, scratching or faeces around it, indicating past or present fauna use. |
| Basal hollow | Yes/no | Any qualifying hollow within 2 m of the ground. These hollows are also counted in the fields above. |

| TREE PARAMETERS | | |
|---|---|---|
| **SpeciesType** | Box<br>Gum<br>Ironbark Peppermint Silvertop Stringybark<br>Other | Preliminary classification of Eucalypt species. All options generate further menus, except 'Ironbark' or 'Silvertop'. |
| **BoxSpecies** | E. polyanthemos subsp. vestita | Menu available if SpeciesType = 'Box'.<br>Species given in order from most common to least common in focal EVDs in Gippsland. |
| | E. goniocalyx s.l. | |
| | E. polyanthemos | |
| | E. baueriana | |
| | E. bosistoana | |
| | E. bridgesiana s.s. | |
| | E. goniocalyx s.s. | |
| | E. angophoroides | |
| | E. nortonii | |
| | E. melliodora | |
| | Eucalyptus sp. | Use if tree is a Box but species ID uncertain. |
| **GumSpecies** | E. cypellocarpa | Menu available if SpeciesType = 'Gum'.<br>Species given in order from most common to least common in focal EVDs in Gippsland. |
| | E. mannifera subsp. mannifera | |
| | E. globulus subsp. bicostata | |
| | E. globulus | |
| | E. globulus subsp. maidenii | |
| | E. globulus subsp. pseudoglobulus | |
| | Eucalyptus sp. | Use if tree is a Gum but species ID uncertain. |
| **PeppermintSpecies** | E. dives | Menu available if SpeciesType = 'Peppermint'.<br>Species given in order from most common to least common in focal EVDs in Gippsland. |
| | E. croajingolensis | |
| | E. radiata subsp. radiata | |
| | E. elata | |
| | Eucalyptus sp. | Use if tree is a Peppermint but species ID uncertain. |

| TREE PARAMETERS | | |
|---|---|---|
| **StringybarkSpecies** | E. globoidea | Menu available if SpeciesType = 'Stringybark'<br>Species given in order from most common to least common in focal EVDs in Gippsland. |
| | E. macrorhyncha | |
| | E. consideniana | |
| | E. muelleriana | |
| | E. obliqua | |
| | E. baxteri s.s. | |
| | E. mackintii | |
| | E. conspicua | |
| | E. agglomerata | |
| | Eucalyptus sp. | Use if tree is a Stringybark but species ID uncertain. |
| **OtherSpecies** | C. gummifera | Menu available if SpeciesType = 'Other'<br>Species given in order from most common to least common in focal EVDs in Gippsland. |
| | E. botryoides | |
| | Eucalyptus other | Use if species is known but not available in menus. This should not occur often. Put species name in Comments field near top of screen. |
| | Eucalyptus sp. | Use if species ID is completely uncertain! |
| **Living?** | Alive/dead | 'Dead' if no visible green leaves or clearly living tissue. |
| **Crown score** | Integer 1–10 | Refer to pictorial guide for scores of senescence (if tree is alive) or dead branch order (if tree is dead). |
| **Crown photo** | | Take photo looking up at the crown, standing north of the tree (or elsewhere if necessary to get a clear view). |

| TREE PARAMETERS | | |
|---|---|---|
| **Base parameters** | | **By default, these fields are judged within 2 m of the ground.** |
| DBH 130cm | Integer 1–300 | Diameter in centimetres, measured at 130 cm above the ground, over bark and perpendicular to the axis of the trunk |
| Intact base % | 1–100% | The percentage of the original cross-sectional area of the trunk that is still occupied by structurally sound wood. This percentage is assessed where there is the least cross-sectional area remaining, within 2 m of the ground. |
| Hollowbutt | Yes/no | Cavity/hole in the trunk, e.g. due to disease, fire or physical damage? Does not need to qualify according to full hollow definition. |
| Charred hollowbutt | Yes/no | Is there evidence of past fire reaching the inside of the basal cavity? (Field only available if Hollowbutt = 'yes'.) |
| Dry wood | Yes/no | Is any dead/dry wood exposed within 2 m of the ground? |
| Charred dry wood | Yes/no | Is there evidence of past fire reaching the dead/dry wood? (Field only available if Dry wood = 'yes'.) |
| Termites | Yes/no | Is there evidence that the tree is or has been occupied by termites, e.g. frass or dirt mounds? |
| Bark char | Integer 1–10 | Refer to pictorial guide to bark charring. Assess average state in bottom 1 m of trunk. |
| Base photo | | Take photo looking at the most structurally compromised aspect of the trunk, or take the northern aspect if trunk is uniform. Include 1 m scale bar by hanging diameter tape off trunk; try to get whole 2 m zone of base in photo. |
| **Fuel Hazard** | | **Assessed visually within a 2 m radius of the trunk** |
| Bark fuel | L/M/H/VH/E | Fuel hazard on focal tree.<br>Refer to compiled photo guide to fuel level scores. |
| Elevated fine fuel | L/M/H/VH/E | Refer to compiled photo guide to fuel level scores. |
| Near-surface fine fuel | L/M/H/VH/E | Refer to compiled photo guide to fuel level scores. |
| Surface fine fuel | L/M/H/VH/E | Refer to compiled photo guide to fuel level scores. |
| Woody fuel | Yes/no | Is there dead woody fuel >5 cm in diameter, within a 1 m radius of the trunk, where the radius of the fuel is greater than its distance from the trunk? |
| Woody fuel diameter (cm) | Integer 5–200 | Largest diameter (in centimetres) of woody fuel that qualifies according to the above definition. |

## Data management protocol

### Initial

- Establish a new project in GPS Pathfinder Office.

### Daily (after field work)

- Using GPS Pathfinder Office on a laptop, upload daily data from each Nomad to the project folder. Photos should be automatically included in this data transfer.
- Retain original files on Nomads unless running out of space.
- Back up a copy of project folder to portable hard drive.
- Charge Nomad batteries.

### Weekly

- Send a copy of project folder to Project Leader.

# Appendix 2:

## List of reports in this series

1. 1977. A study of the distribution of aerially applied fire retardant in softwood plantations. R. Rawson.
2. 1978. Low-intensity prescribed burning in three Pinus radiata stand types. D.S. Thomson.
3. 1978. Fuel properties before and after thinning in young Radiata Pine plantations. D.F. Williams.
4. 1979. Using fire to reduce fuel accumulations after first thinning in Radiata Pine plantations. P.R. Billing.
5. 1979. Some of the effects of low-intensity burning on Radiata Pine. P.R. Billing.
6. 1980. A low-intensity prescribed burning operation in a thinned Radiata Pine plantation. P.R. Billing.
7. 1980. Some aspects of the behaviour of the Caroline Fire of February 1979. P.R. Billing.
8. 1981. Changes in understorey vegetation in Sherbrooke Forest following burning or slashing. R. Rawson and B. Rees.
9. 1981. Hazard-reduction burning in the Big Desert. P.R. Billing.
10. 1981. The effectiveness of fuel-reduction burning: five case histories. P. Billing.
11. 1982. A fire tornado in the Sunset Country January 1981. P. Billing and R. Rawson.
12. 1982. A summary of forest fire statistics, 1972-73 to 1980-81. R. Rawson and B. Rees.
13. 1982. Fuel moisture changes under Radiata Pine. M. Woodman.
14. 1982. Fuel-reduction burning in Radiata Pine plantations. M. Woodman and R. Rawson.
15. 1982. Project MAFFS/HERCULES: the Modular Airborne Fire Fighting System in Victoria. R. Rawson, B. Rees, E. Stuckey, D. Turner, C. Wood, and M. Woodman.
16. 1982. Using fire to reduce aerial fuels in first thinned Radiata Pine. P.R. Billing and J.V. Bywater.
17. 1982. Fuel properties before and after second thinning in Radiata Pine. M. Woodman.
18. 1983. Retardant distributions from six agricultural aircraft. B. Rees.
19. 1983. The Bright plantation fire: November 1982. N. Watson, G. Morgan and D. Rolland.
20. 1983. Otways Fire No. 22 – 1982/83: aspects of fire behaviour. P. Billing.
21. 1983. Otways Fire No. 22 – 1982/83: a case study of plantation protection. P. Billing.
22. 1984. Forest fire statistics, 1974-75 to 1983-84. B. Rees.
23. 1985 The Avoca Fire, 14 January 1985. P. Billing.
24. 1985. Fuel management in Radiata Pine following heavy first thinning. P. Norman.
25. 1985. Effectiveness of fuel-reduction burning: 10 case studies. R. Rawson, P. Billing and B. Rees.
26. 1986. Operational aspects of the Infra-Red Line Scanner. P. Billing.
27. 1987. Heathcote fire: Bendigo Fire No.38 – 1986/87. P. Billing.
28. 1987. Monitoring the ecological effects of fire. F. Hamilton (ed.)
29. 1990. Fire behaviour and fuel-reduction burning – Bemm River. A.J. Buckley.
30. 1991. Fire hazard and prescribed burning of thinning slash in eucalypt regrowth forest. A.J. Buckley and N. Corkish.
31. 1992. Assessing fire hazard on public land in Victoria: fire management needs and practical research objectives. A.A.G. Wilson.
32. 1992. Eucalypt bark hazard guide. A.A.G. Wilson.
33. 1992. Fuel reducing a stand of eucalypt regrowth in East Gippsland: a case study. A.J. Buckley.
34. 1992. Monitoring vegetation for fire effects. M.A. Wouters.
35. 1993. Elevated fuel guide. A.A.G. Wilson.
36. 1993. Wildfire behaviour in heath and other elevated fuels: a case study of the 1991 Heywood fire. M.A. Wouters.
37. 1993. The accumulation and structural development of the wiregrass (Tetrarrhena juncea) fuel type in East Gippsland. L.G. Fogarty.
38. 1993. A case study of wildfire management in the Byadlbo and Tingaringy Wilderness Areas. A.G. Bartlett.

39. 1993. Developing fire management planning in Victoria: a case study from the Grampians. M.A. Wouters.

40. 1993. Fuel reducing regrowth forests with a wiregrass fuel type: fire behaviour guide and prescriptions. A.J. Buckley.

41. 1993. The effect of fuel-reduction burning on the suppression of four wildfires in western Victoria. S.R. Grant and M.A. Wouters.

42. 1994. Fire behaviour and fire suppression in an elevated fuel type in East Gippsland: Patrol Track wildfire, February 1991. A.J. Buckley.

43. 1996. Fuel hazard levels in relation to site characteristics and fire history: Chiltern Regional Park case study. K. Chatto.

44. 1998. Effectiveness of fire-fighting first attack operations by the Department of Natural Resources and Environment from 1991/92-1994/95. G.J. McCarthy and K.G. Tolhurst.

45. 1997. The development and testing of the Wiltronics T-H Fine Fuel Moisture meter. K. Chatto and K. Tolhurst.

46. 1997. Analysis of fire causes on or threatening public land in Victoria 1976/77 – 1995/96. C. Davies.

47. 1998. Overall fuel hazard guide. G.J. McCarthy, K. Chatto and K. Tolhurst.

48. 1999. Development, behaviour, threat and meteorological aspects of a plume-driven bushfire in west-central Victoria: Berringa Fire February 25-26, 1995. K. Chatto, K. Tolhurst, A. Leggett and A. Treloar.

49. 2000. Assessment of the effectiveness and environmental risk of the use of retardants to assist in wildfire control in Victoria. CSIRO Forestry and Forest Products.

50. 2001. Effectiveness of broadscale fuel-reduction burning in assisting with wildfire control in parks and forests in Victoria. G.J. McCarthy and K. Tolhurst.

51. 2003. Effectiveness of aircraft operations by the Department of Natural Resources and Environment and Country Fire Authority 1997-98. G.J. McCarthy.

52. 2003. Modelling transport, dispersion and secondary pollutant formation of emissions from burning vegetation using air quality dispersion models. O.D. Valianatos, K. Tolhurst, S. Seims and N. Tapper.

53. 2003. Determination of sustainable fire regimes in the Victorian Alps using plant vital attributes. G.J. McCarthy, K. Tolhurst and K. Chatto.

54. 2003. Prediction of fire-fighting resources for suppression operations in Victoria's parks and forests. G.J. McCarthy, K. Tolhurst, M. Wouters.

55. 2003. Ecological effects of repeated low-intensity fire in a mixed eucalypt foothill forest in south-eastern Australia. Summary report (1994-99).

56. 2003. Effects of repeated low-intensity fire on the understorey of a mixed eucalypt foothill forest in south-eastern Australia. K. Tolhurst.

57. 2003. Effects of a repeated low-intensity fire on fuel dynamics in a mixed eucalypt foothill forest in south-eastern Australia. K. Tolhurst and N. Kelly.

58. 2003. Effects of repeated low-intensity fire on carbon, nitrogen and phosphorus in the soils of a mixed eucalypt foothill forest in south-eastern Australia. P. Hopmans.

59. 2003. Effects of repeated low-intensity fire on the invertebrates of a mixed eucalypt foothill forest in south-eastern Australia. N. Collett and F. Neumann.

60. 2003. Effects of repeated low-intensity fire on bird abundance in a mixed eucalypt foothill forest in south-eastern Australia. R.H. Loyn, R.B. Cunningham and C. Donnelly.

61. 2003. Effects of repeated low-intensity fire on terrestrial mammal populations of a mixed eucalypt foothill forest in south-eastern Australia. M. Irvin, M. Westbrooke and M. Gibson.

62. 2003. Effects of repeated low-intensity fire on insectivorous bat populations of a mixed eucalypt foothill forest in south-eastern Australia. M. Irvin, P. Prevett and M Gibson.

63. 2003. Effects of repeated low-intensity fire on reptile populations of a mixed eucalypt foothill forest in south-eastern Australia. M. Irvin, M. Westbrooke and M. Gibson.

64. 2003. Effects of repeated low-intensity fire on tree growth and bark in a mixed eucalypt foothill forest in south-eastern Australia. K. Chatto, T. Bell and J. Kellas.

65. 2003. A review of the relationship between fireline intensity and the ecological and economic effects of fire, and methods currently used to collect fire data. K. Chatto and K. Tolhurst.

66. 2003. Effects of fire retardant on vegetation in eastern Australian heathlands: a preliminary investigation. T. Bell.
67. 2003. Effects of fire retardant on heathland invertebrate communities in Victoria. N. Collett and C. Schoenborn.
68. 2003. Effects of fire retardant on soils of heathland in Victoria. P. Hopmans and R. Bickford.
69. 2004. Analysis of wildfire threat: issues and options. A.A.G. Wilson.
70. 2004. Surface fine-fuel hazard rating – forest fuels in East Gippsland. G. J. McCarthy.
71. 2004. An evaluation of the performance of the Simplex 304 helicopter belly-tank. H. Biggs.
72. 2004. Operational performance of the S-64F Aircrane Helitanker – 1997/98 fire season. H. Biggs.
73. 2008 Underpinnings of fire management for biodiversity conversation in reserves. M. Gill.
74. 2008. Flora monitoring protocols for planned burning: a user's guide. J. Cawson and A. Muir.
75. 2008. Flora monitoring protocols for planned burning: a rationale report. J. Cawson and A. Muir.
76. 2010. Adaptive management of fire: the role of a learning network. C. Campbell, S. Blair and A.A.G. Wilson.
77. 2010. Understanding, developing and sharing knowledge about fire in Victoria. S. Blair, C. Campbell, A.A.G. Wilson and M. Campbell.
78. 2010. Developing a fire learning network: a case study of the first year. C. Campbell, S. Blair and A.A.G. Wilson.
79. 2010. A case study of a strategic conversation about fire in Victoria, Australia. S. Blair, C. Campbell and M. Campbell.
80. 2012. Guiding principles: facilitating, learning, understanding and change through relationships. C. Campbell, M. Campbell and S. Blair.
81. 2010. Fire Boss amphibious single engine air tanker: final report, November 2008. H. Biggs.
82. 2010. Overall fuel hazard assessment guide. 4th Edition July 2010. F. Hines, K.G. Tolhurst, A.A.G. Wilson and G.J. McCarthy.
83. 2010. Growth stages and tolerable fire intervals for Victoria's native vegetation datasets. D.C. Cheal.
84. Forthcoming. Fuel hazard assessment guide: a rationale report. F. Hines and A.A.G. Wilson.
85. 2012. Guide to monitoring habitat structure. S.M. Treloar.
86. 2012. Guide to monitoring habitat structure: a rationale report. S.M. Treloar.
87. 2011. A literature review on the social, economic and environmental impacts of severe bushfires in south-eastern Australia. C. Stephenson.
88. 2011. The impacts, losses and benefits sustained from five severe bushfires in south-eastern Australia. C. Stephenson.
89. 2011. Establishing a link between the power of fire and community loss: the first step towards developing a bushfire severity scale. S. Harris, W. Anderson, M. Kilinc and L. Fogarty.
90. 2012. Review of resilience concepts and their measurement for fire management. M. McCarthy.
91. 2012. Relationships between disturbance regimes and biodiversity: background, issues and approaches for monitoring. J. Di Stefano and A. York.
92. 2014. Verification of time-since-fire in Gippsland from charring retained on stringybark trees. L. Bluff.
93. 2016 (unpublished). Science and its policy impacts: establishing a monitoring, evaluation, reporting and improvement (MERI) framework, K. Bosomworth and E. Ashman
94. 2016 (unpublished). Assessing the economic value and vulnerability of nature based tourism in the Ovens and Alpine area of NE Victoria, J.Pyke, M. Jiang, T. de Lacy, P. Whitelaw, and R. Jones
95. 2016 Reducing the effect of planned burns on hollow bearing trees. L. Bluff

## Supplementary reports

1. 1992. Ecological effects of fuel reduction burning in a dry sclerophyll forest: a summary of principal research findings and their management implications. Department of Conservation and Environment, Victoria. K Tolhurst, D.W. Flinn, R.H. Lyon, A.A.G.Wilson and I.J. Foletta.

2. 1992. Ecological effects of fuel-reduction burning in a dry sclerophyll forest: first progress report. Department of Conservation and Environment, Victoria. K. Tolhurst and D. Flinn (eds.).

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