Department of
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Environment

Effects of the Black Saturday fires on Sambar Deer occupancy and abundance

Black Saturday Victoria 2009 – Natural Values fire recovery program

David Forsyth, Andrew Gormley, Luke Woodford and Tony Fitzgerald

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Sambar Deer occupancy and abundance

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Front Cover photograph: Sambar Deer photographed by a remote camera during our occupancy survey, 21 July 2010.

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Summary

'Reduction in biodiversity of native vegetation by Sambar Deer (*Cervus unicolor*)' has been listed as a threatening process under the *Flora and Fauna Guarantee Act 1988*, and there is concern that native vegetation may be vulnerable to impacts of Sambar Deer immediately post-fire. However, little is known about the impacts of fire on the population levels of Sambar Deer, except that deer are sometimes killed. The objective of this project was to evaluate the effects of the Black Saturday fires on occupancy and abundance of Sambar Deer using pre- and post-fire data from burnt and unburnt habitat.

The effects of the Black Saturday fires on Sambar Deer abundances were assessed using repeated annual counts of faecal pellets along 30 150-m transects in part of Kinglake National Park, which was burnt by the high-intensity Kilmore East fire on Black Saturday (7 February 2009), and in part of Mount Buffalo National Park, which was not burnt in the Black Saturday fires and serves as a comparison. Pellets were counted in spring for two years pre-fire (2007, 2008) and two years post-fire (2009, 2010) in both areas. Sambar Deer pellets increased during the four years of counts in the unburnt Mount Buffalo National Park. In Kinglake National Park, pellets increased in the two years prior to Black Saturday, but no pellets were recorded eight months after the Kilmore East fire and very few pellets were counted 20 months after the fire.

We evaluated the effects of the Black Saturday fires on Sambar Deer occupancy at a larger spatial scale by sampling 15 pairs of 4 km^2 sites in areas burnt by the Kilmore East, Murrindindi, Bunyip, Dargo, and Beechworth fires. One of each pair had been burnt while the other was not burnt but was located within 15 km of the fire edge. Pre-fire data collected in September 2008–January 2009 were available for five burnt and nine unburnt sites. Sampling was undertaken 16–24 months after the Black Saturday fires using three survey methods: sign searches along a 400-m transect, two remote camera traps set for 21 days and faecal pellet counts along three 150-m transects. We found that Sambar Deer occupancy was only weakly reduced in burnt sites 16–24 months after the Black Saturday fires.

We conclude that Sambar Deer abundances were greatly reduced by the large-scale and high-intensity Black Saturday fires, but that nearly all burnt habitat was occupied 16–24 months later. However, it is expected that Sambar Deer populations in some areas (e.g. part of Kinglake National Park) will take many years to reach pre-fire abundances. Continued annual monitoring of pellet transects at Kinglake National Park will enable the recovery of the Sambar Deer population to be evaluated. A key remaining knowledge gap is the impacts of Sambar Deer on post-fire vegetation dynamics, including those of Victorian Rare or Threatened Species (VROTS).

1 Introduction

The Sambar Deer (*Cervus unicolor*) is both the largest (males, c. 250 kg; females, c. 150 kg; Bentley 1998; Leslie 2011) and most widespread deer species in Victoria (Menkhorst 1995; Bentley 1998). Native to India, Sri Lanka and south-eastern Asia (Leslie 2011), Sambar Deer were introduced at four sites in Victoria during the 1860s and have subsequently expanded their distribution to the north, north-east and south-east of Victoria (Downes 1983; Menkhorst 1995; Bentley 1998; Gormley *et al.* 2011). Sambar Deer occupy wet forest habitats in Victoria (Downes 1983; Gormley *et al.* 2011), with highest abundances recorded in low elevation areas where forest abuts grassland (Forsyth *et al.* 2009).

Sambar Deer in Victoria are generalist herbivores, utilising browse and grass opportunistically (Forsyth and Davis 2011), and there is concern about the negative impacts of Sambar Deer on native biodiversity and water quality (Peel *et al.* 2005; McDowell 2007; Department of Sustainability and Environment 2009). 'Reduction in biodiversity of native vegetation by Sambar Deer (*Cervus unicolor*)' was listed as a threatening process under the *Flora and Fauna Guarantee Act 1988* (Department of Sustainability and Environment 2009). A recent study of the diets of 102 Sambar Deer harvested in Victoria revealed that shrubs/trees dominated their diet (c. 50%), and that ferns (20%) and grasses (20%) were significant components (Forsyth and Davis 2011). Sambar Deer can ingest large numbers of seeds of the weed Blackberry *Rubus fruticosus* agg. (Forsyth and Davis 2011), and may be dispersers of this and other weeds (Eyles 2002).

There is particular concern that native vegetation may be especially vulnerable to Sambar Deer immediately post-fire (Department of Sustainability and Environment 2009), but although many studies have assessed the impacts of fires on small mammals in Australia (e.g. review in Sutherland and Dickman 1999; Lindenmayer *et al.* 2008) the effects of fire on the distributions and abundances of large introduced mammals, such as Sambar Deer, have not been quantified.

The effects of a fire on fauna depend largely on the fire's intensity and scale (i.e. how extensive each fire is and the patchiness of the burnt and unburnt mosaic) (Gill 1975, 1997; Whelan 1995; Friend 2004). A low-intensity fire moves slowly and causes impacts primarily on the ground-layer and understorey plant species, whereas the highest-intensity fires move rapidly and defoliate the canopy as well as removing the understorey (Gill and Catling 2002; Department of Sustainability and Environment 2009). A patchy fire provides refugia for animals (e.g. in moist gullies

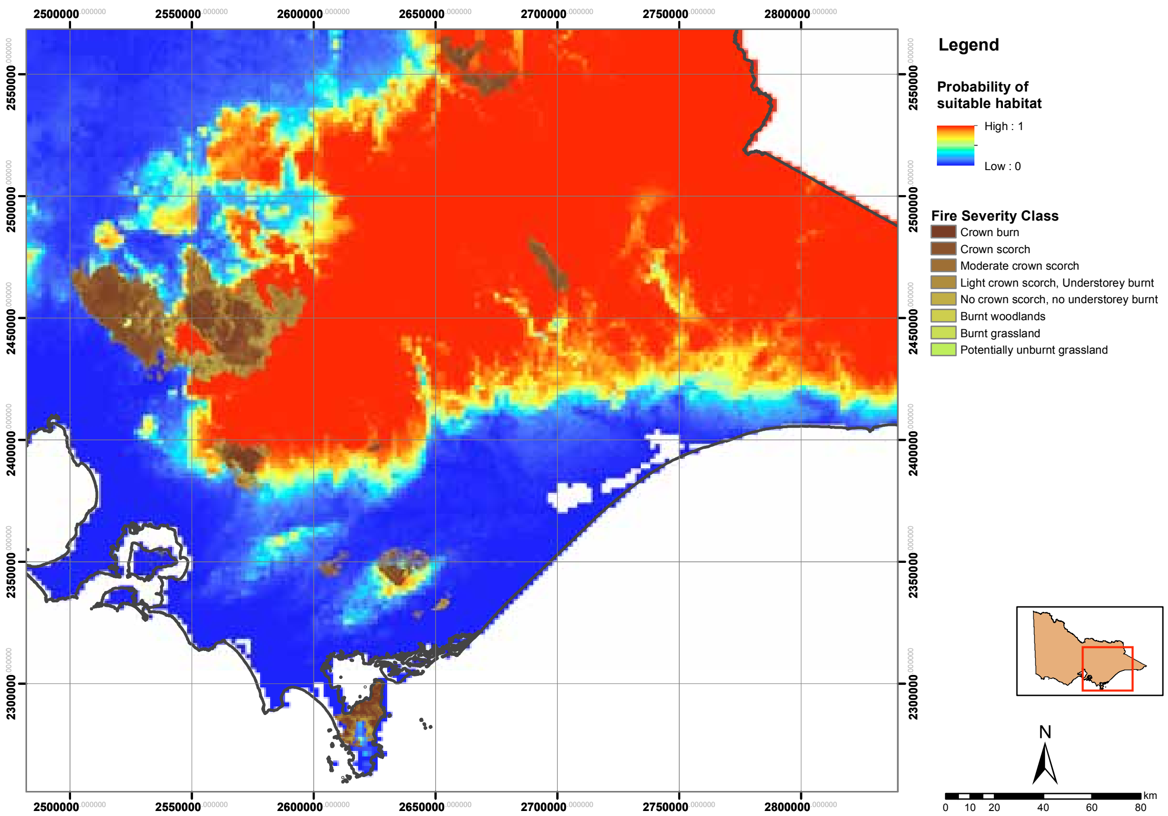
Figure 1. Sambar Deer killed by the Bunyip fire in Bunyip State Park, photographed 21 February 2009 (© Greg Young). This was a crown burn (i.e. the highest fire severity classification).

and creeks) to survive the fire (Whelan 1995) and recolonise burnt habitat. Sambar Deer have commonly been found dead following bushfires (e.g. Mason 2008) and large-scale and high-intensity fires, such as the Black Saturday fires that burnt c. 430 000 ha on and after 7 February 2009 (Teague *et al.* 2010), are thought to kill many Sambar Deer (Mason 2008; Harrison 2010; Greg Young, Parks Victoria, personal communication; Figure 1). However, some Sambar Deer are likely to survive even high-intensity and large-scale fires 'by seeking refuge in unburnt pockets' (Mason 2008: 111).

The effects of fires on fauna populations are typically estimated using changes in abundance or relative abundance pre- and post-fire and/or differences between burnt and unburnt areas (Whelan 1995; Clarke 2008). Parks Victoria began monitoring the abundances of Sambar Deer at high-priority sites in 2006 and 2007, partly in response to concerns about the impacts of Sambar Deer on vegetation communities following the bushfires of 2002–2003 (Forsyth 2006). Estimating the abundance of deer in forest with a closed canopy is difficult (Thompson *et al.* 1998; Mayle *et al.* 1999), and faecal pellet counts have been used as an index of deer abundance in such habitats since the 1930s (Bennett *et al.* 1940). Parks Victoria monitors deer by counting faecal pellets along randomly located 150-m transects (Parks Victoria 2005; Jameson and Forsyth 2008). Counts of faecal pellets using this method have been shown to be linearly and positively related to known abundances of deer (Forsyth *et al.* 2007). Parks Victoria has monitored Sambar Deer annually since 2007 in two areas: Kinglake National Park and Mount Buffalo National Park; the former was burnt by the high-intensity Kilmore East[1] fire on 7 February 2009 (Teague *et al.* 2010) whereas the latter was not burnt, although it was burnt by bushfire in January 2003 (Flinn and Wareing 2003) and some of it was subject to controlled burning in December 2006 (C. Pascoe, Parks Victoria, personal communication).

Inference about the effects of large-scale and high-intensity disturbances on fauna populations can also be made using the state variable 'occupancy', which equals 1 if a site is occupied and 0 if a site is unoccupied (Mackenzie *et al.* 2006). To our knowledge, occupancy models have not been used to evaluate the effects of fire on fauna populations in Australia. Gormley *et al.* (2011) developed a model of Sambar Deer occupancy in Victoria using presence–absence data collected in field surveys at 80 4 km^2 cells between July 2008 and April 2009 (Figure 2). Based on that model, much of the public land burnt by the Black Saturday fires had a high predicted probability of being occupied by Sambar

Figure 2. Estimated probability of Sambar Deer occupancy in eastern Victoria (Gormley *et al.* 2011) immediately prior to the Black Saturday fires overlaid with the areas and intensities of the Black Saturday fires.



1 Fire nomenclature follows Teague *et al.* (2010).

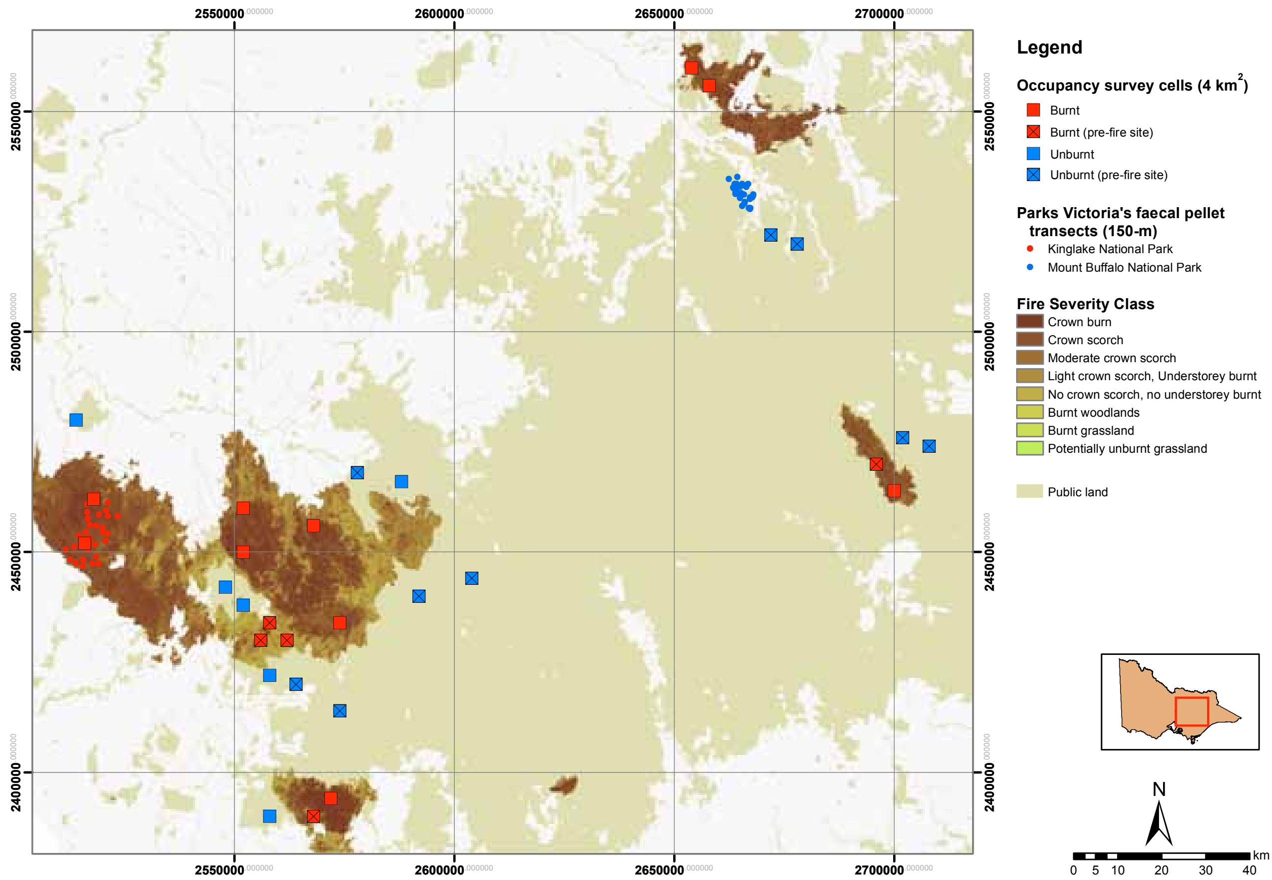
Deer (Figure 2), and some of the cells sampled pre-fire were burnt (Figure 3).

Understanding the impacts of fire, particularly large-scale and high-intensity bushfires, such as the Black Saturday fires, on fauna is widely recognised as being hampered by an absence of robust pre-fire data (e.g. Whelan 1995; Clarke 2008). The pre-fire abundance and occupancy data described above, if compared with post-fire data collected at the same sites with the same methods, provided a unique opportunity to evaluate the effects of the Black Saturday fires on Sambar Deer populations.

1.1 Objective

The objective of this project was to evaluate the effects of the Black Saturday fires on the occupancy and abundance of Sambar Deer using pre- and post-fire data from burnt and unburnt habitat.

Figure 3. Location of the Sambar Deer abundance transects (n = 30) in Kinglake and Mount Buffalo national parks monitored annually from 2007–2010 and the 30 (n = 15 burnt and unburnt) 4 km^2 cells sampled in our post-fire occupancy surveys. The areas and intensities of the Black Saturday fires are also shown.



2 Methods

2.1 Effects of the Kilmore East fire on Sambar Deer abundances in part of Kinglake National Park

Monitoring of Sambar Deer abundances was conducted annually in two areas: part of Kinglake National Park (9965 ha) and part of Mount Buffalo National Park (2499 ha) from 2007–2010 (Figure 3). Hunting was prohibited in both sites. At each site, faecal pellets were counted along 30 randomly located transects using the method described in Parks Victoria (2005) and Forsyth *et al.* (2007). Briefly, a hand-held GPS was used to navigate to the start of each 150-m transect and the number of intact pellets in circular plots of 1 m radius spaced at 5 m intervals (i.e. 30 plots/transect) were counted (Figure 4). The Kinglake National Park site was burnt by the high-intensity and large-scale Kilmore East fire (c. 125 283 ha) on 7 February 2009 (Teague *et al.* 2010; Department of Sustainability and Environment, unpublished data; Figure 5). The monitored area was completely burnt by fire classified as the two highest fire severities (Department of Sustainability and Environment, unpublished data). A 'crown burn' (the most severe fire class) is an intense overstorey burn with 70–100% of eucalypt and non-eucalypt crowns removed and 100% of the understorey burnt (e.g. Figures 1 and 5), and a 'crown scorch' is an intense understorey fire with 60–100% of most eucalypts and non-eucalypts scorched. The Mount Buffalo National Park site was not burnt in the Black Saturday fires (i.e. is a 'non-treatment' area), but had been completely burnt in 2003 and partly burnt in 2006: further details on this area are given in Forsyth (2006). All sampling was conducted in spring. One transect in each study area was not sampled in 2010 due to safety concerns.

The sum of the number of intact pellets (defined in Forsyth 2005) counted in each plot on transect j at time t is the variable of interest, $x_{j,t}$, and is termed the 'Faecal Pellet Index' (FPI; Forsyth 2005, 2006). FPI values in Kinglake National Park and Mount Buffalo National Park were modelled assuming a negative binomial distribution with mean λ_t. A negative binomial distribution is suitable for modelling overdispersed count data, such as faecal pellet counts. The general model is $x_{j,t} \sim NegBin(p_{j,t}, r)$, where $p_{j,t} = r/(r+\lambda_t)$, and r is an overdispersion parameter.

A range of models (Table 1) allowing for different specifications of temporal changes in mean FPI (λ) were fitted independently to the data using Markov chain Monte Carlo as implemented by the software OpenBUGS 3.0 (Lunn *et al.* 2009). Two models were fitted only to the Kinglake National Park data to examine the effects of the Black Saturday fire there (Table 2): one included a constant FPI that differed pre- and post-fire, and another included a time-varying FPI pre-fire and a constant FPI post-fire. We used Bayesian inference requiring specification of priors for all parameters. For the intercept (α) and slope (β) parameters we used vague normal N(0, 10^4) distributions (i.e. mean zero and standard deviation of 100). After discarding a tuning sample of 5000 iterations we sampled two chains each of 50 000 iterations using different starting values.

Figure 4. Thomas Chambers (Parks Victoria) counting Sambar Deer faecal pellets on a transect in Kinglake National Park, October 2010.

Figure 5. Part of the Kinglake National Park study area photographed from the same point in April 2009 (left) and December 2010 (right).

Table 1. Models fitted to temporal trends in Sambar Deer abundances, 2007–2010. Subscripts 'pre' and 'post' denote pre- and post-fire, respectively.

Model	Specification	Description
$\lambda\{.\}$	$\ln(\lambda_t) = \alpha$	Constant FPI each year
$\lambda\{t\}$	$\ln(\lambda_t) = \alpha + (\beta \times \text{year})$	Log-linear relationship between FPI and year
$\lambda\{a_t\}$	$\ln(\lambda_t) = \alpha_t$	Different mean FPI in each year
$\lambda\{a_{pre}{:}a_{post}\}$	$\ln(\lambda_t) = \alpha_{pre}$ for t = 2007 & 2008, $\ln(\lambda_t) = \alpha_{post}$ for t = 2009 & 2010	FPI is constant but differs pre- and post-fire (Kinglake National Park only)
$\lambda\{t_{pre},\cdot_{post}\}$	$\ln(\lambda_t) = \alpha_{pre} + (\beta \times \text{year})$ for t = 2007 and 2008, $\ln(\lambda_t) = \alpha_{post}$ for t = 2009 and 2010	Time-varying FPI pre-fire, constant FPI post-fire (Kinglake National Park only)

The relative support for each model was compared using the Deviance Information Criterion (DIC; Spiegelhalter *et al.* 2002), which provides an assessment of compromise between model fit and model complexity, and model weights (w_i; Burnham and Anderson 2002). A smaller DIC indicates a 'better' model.

2.2 Sambar Deer occupancy 16–24 months after the Black Saturday fires

A pre-fire model of Sambar Deer occupancy in Victoria was developed by Gormley *et al.* (2011) using field data collected at 80 4 km^2 cells during 2008–2009 (Figure 2). Full details of the field methods and modelling are given in Gormley *et al.* (2011). Briefly, presence/absence of Sambar Deer was assessed in the 80 cells using two or three independent methods. First, faecal pellets were counted along three randomly located transects in each of the 80 cells as described above (*2.1 Effects of the Kilmore East fire on Sambar Deer abundances in part of Kinglake National Park*). Second, we searched for signs of Sambar Deer (i.e. sightings of live or dead deer, tree-rubbings, tracks, cast antlers, wallows and faecal pellets; Bentley 1998) along a 400-m transect (Figure 6). Third, in a randomly selected 40 of the 80 cells, two heat-in-motion remote cameras (Figure 7) were set along the sign survey route for 21 days. Of the 80 cells sampled pre-fire, five were burnt during February 2009 and nine were not burnt but within 15 km of the fire edge. We used the resulting model of Sambar Deer occupancy and a GIS layer of the areas burnt by the Black Saturday fires to subjectively identify additional 4 km^2 cells to achieve a sample size of 15 burnt and 15 unburnt cells. We paired burnt and unburnt cells for probability of occupancy (only cells with a modelled probability of occupancy ≥0.70 were used) and adjacency (i.e. as close as possible so as to minimise unmeasured environmental variation that might affect occupancy). These 30 cells were sampled between July 2010 and February 2011 (i.e. 16–24 months after the fires) using the same methods as were used pre-fire except that two camera traps (TrailMAC Digital [Trail Sense Engineering, Middletown, DE, USA] and PixController DigitalEye™ [PixController Inc., Export, PA, USA]) were set for 21 days in all cells, and the sign survey was repeated when cameras were collected.

The observed presence and absence of Sambar Deer for each survey (pellets, sign or photos) in each cell i was indicated by $y_{ij} = 1$ and $y_{ij} = 0$, respectively, where j indicates the method used, i.e. faecal pellet surveys (j = 1, 2 and 3), sign surveys (j = 4 and 5) and remote cameras (j = 6 and 7). Where a survey was not performed, y_{ij} = NA. Due to imperfect detection using any given method apparent absences may arise if a site is occupied but the species is undetected. Because we performed multiple surveys the data were able to be modelled with a site-occupancy model (MacKenzie *et al.* 2002). This modelling framework enables us to separate the probability of occupancy (ψ) from the probability of detection (p). The model can be expressed as a state–space model that contains two submodels: one for the true state (ecological process; z) and one for the observations, conditional on the true occupancy states (observation process; y). The actual observations depend on both processes (Kéry 2010):

$z_i \sim \text{Bernoulli}(\psi_i)$,

and

$y_{ij} \sim \text{Bernoulli}(z_i \times p_{ij})$,

where z_i is the true occupancy state at site i.

We fitted seven occupancy models that allowed detection to be either constant across methods or differ by method (Table 2). Occupancy was modelled as either being constant across time and treatment (i.e. burnt or unburnt), or by including a time effect, and/or a treatment effect and an interaction effect. For models that included a time effect, the difference in occupancy between pre- and post-fire was estimated directly as a derived quantity, $\psi_{post} - \psi_{pre}$. It was expected that a strong effect of fire on occupancy would be apparent in a model with a significant interaction term between treatment and time (i.e. a decrease in occupancy only on burnt cells). On a logit scale, strong effects would be indicated by

parameter estimates with a 95% credible interval that does not include zero.

We again used Bayesian inference and model selection based on DIC and w_i. We used Beta (1,1) distributions for the priors on the detection probabilities p. Occupancy ψ was modelled on the logit scale. We used vague normal N(0, 10^4) distributions (i.e. mean zero and standard deviation of 100) for all coefficients (i.e. year and treatment effects). The model was fitted using Markov chain Monte Carlo as implemented by the software OpenBUGS 3.0 (Lunn *et al.* 2009). After discarding a tuning sample of 5000 iterations we sampled two chains each of 50 000 iterations using different starting values.

Figure 6. Three types of Sambar Deer sign encountered in our sign surveys: rub tree (left), tracks (centre) and wallow (right).

Figure 7. Example of a heat-in-motion remote camera used in our occupancy survey (left) and set in the field (right).

Table 2. Models fitted to pre- and post-fire Sambar Deer occupancy data.

Model	Description
$\psi\{.\}p\{.\}$	Constant occupancy and detection probability among methods
$\psi\{\text{treat}\}p\{.\}$	Occupancy differs by burnt/unburnt, constant detection probability among methods
$\psi\{.\}p\{\text{method}\}$	Constant occupancy, detection probability differs among methods
$\psi\{\text{treat}\}p\{\text{method}\}$	Occupancy differs by burnt/unburnt, detection probability differs among methods
$\psi\{\text{year}\}p\{\text{method}\}$	Occupancy differs pre- and post-fire, detection probability differs among methods
$\psi\{\text{year+treat}\}p\{\text{method}\}$	Occupancy differs by burnt/unburnt and pre- and post-fire, detection probability differs among methods
$\psi\{\text{year} \times \text{treat}\}p\{\text{method}\}$	Occupancy differs by burnt/unburnt and pre- and post-fire with an interaction, detection probability differs among methods

3.1 Effects of the Kilmore East fire on Sambar Deer abundances in part of Kinglake National Park

Mean FPI at Kinglake National Park increased from spring 2007 to 2008, but eight months after the Kilmore East fire burnt the area (7 February 2009) zero pellets were recorded on all 30 transects (Figure 8). Small numbers of Sambar Deer pellets were counted on two transects in Kinglake National Park in October 2010 (mean FPI = 0.9), 20 months after the fire. Three models of the temporal trend at Kinglake National Park had similar support (i.e. ΔDIC<1.2; Table 3). All three models allowed for the mean FPI to differ pre- and post-fire, and all are far superior to the model that specifies a log-linear temporal relationship, confirming that Black Saturday fire had a substantial negative effect on Sambar Deer abundance at Kinglake National Park.

Mean FPI increased annually in unburnt Mount Buffalo National Park by c. 30 pellets per year per transect, although the confidence intervals are wide (Figure 8). The log-linear model ($\lambda\{t\}$) best explained the temporal trend in FPI in Mount Buffalo National Park, although there was some support for the constant and time-differing models (Table 4). The estimated annual rate of increase (β) from the log-linear model was 0.31 (95% CI; 0.05, 0.58).

Figure 8. Annual trends in the Faecal Pellet Index (mean ± 95% confidence interval) at Kinglake National Park (burnt in the Black Saturday fires) and Mount Buffalo National Park (not burnt). Transects (n = 30) in both areas were sampled in spring.

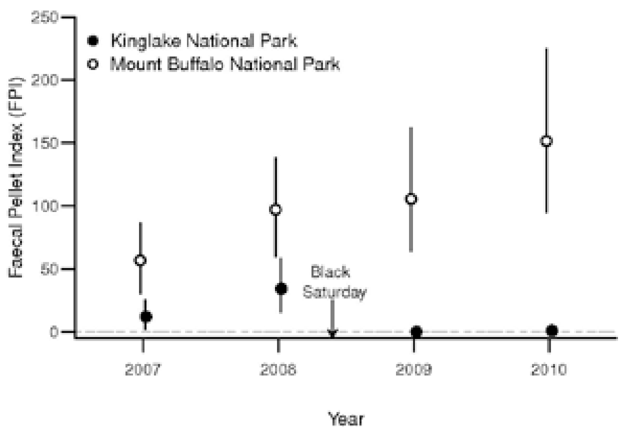


Table 3. Model selection summary for the five models of temporal trends in the Faecal Pellet Index (FPI) in Kinglake National Park, spring 2007–2010. Kinglake National Park was burnt by the Kilmore East fire on Black Saturday. A larger w_i value indicates a better model.

Model	Description	DIC	ΔDIC	w_i
$\lambda\{.\}$	Constant FPI each year	442.6	31.3	0.00
$\lambda\{t\}$	Log-linear relationship between FPI and year	431.2	19.9	0.00
$\lambda\{a_t\}$	Different mean FPI in each year	411.3	0.0	0.47
$\lambda\{a_{pre}:a_{post}\}$	FPI is constant but differs pre- and post-fire	412.4	1.1	0.27
$\lambda\{t_{pre}, \cdot_{post}\}$	Time-varying FPI pre-fire, constant FPI post-fire	412.5	1.2	0.26

Table 4. Model selection summary for the three models of temporal trends in the Faecal Pellet Index (FPI) in Mount Buffalo National Park, spring 2007–2010. Mount Buffalo National Park was not burnt during this period. A larger w_i value indicates a better model.

Model	Description	DIC	ΔDIC	w_i
$\lambda\{.\}$	Constant FPI each year	1277	4.0	0.11
$\lambda\{t\}$	Log-linear relationship between FPI and year	1273	0.0	0.78
$\lambda\{a_t\}$	Different mean FPI in each year	1277	4.0	0.11

3.2 Sambar Deer occupancy 16–24 months after the Black Saturday fires

Sambar Deer were detected in all 14 sites sampled pre-fire. Eleven sites (79%) had detections of faecal pellets on at least one of the pellet transects, all sites (100%) had evidence of Sambar Deer on the sign survey, and Sambar Deer were detected by remote cameras in two of the seven sites (28%). Sambar Deer were detected on 26 of the 30 sites (87%) sampled post-fire, with detections on 80% of the burnt sites and 93% of the unburnt sites. Of the 26 sites with detections, 18 (69%) had detections of faecal pellets on at least one of the pellet transects, all 26 sites (100%) had evidence of Sambar Deer on the sign survey, and 13 (50%) had detections on the remote cameras (e.g. Figures 9 and 10). The efficacy of the cameras was poor, with 17 of the 60 cameras failing after setup, and both cameras failing at two cells. No Feral Goat (*Capra hircus*), Feral Pig (*Sus scrofa*), or deer species other than Sambar Deer were detected in our post-fire occupancy surveys.

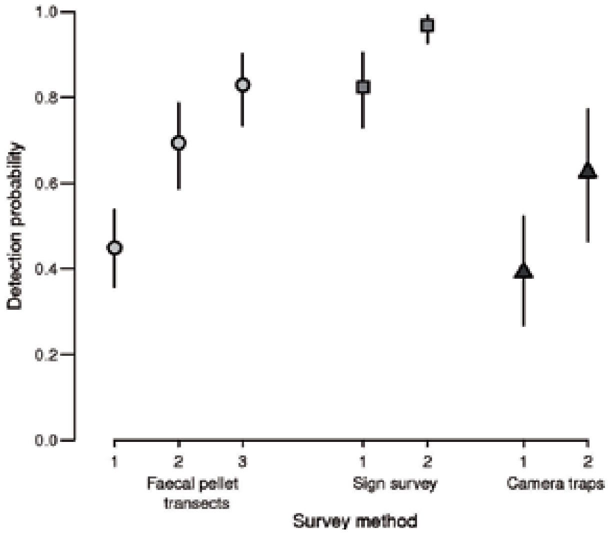
Models that allowed detection probability to vary by detection method (p\{method\}) consistently outperformed models that assumed a constant detection probability for all survey methods (p\{.\}) (Table 3). The probability of detecting Sambar Deer was 0.45 (95% CI = 0.36, 0.54) using one faecal pellet transect, 0.82 (0.73, 0.90) using one sign survey, and 0.39 (0.26, 0.52) using one remote camera (Figure 11). The cumulative probabilities of detecting Sambar Deer from multiple devices were 0.83 (0.73, 0.90) for three transects, 0.96 (0.92, 0.98) for two sign surveys, and 0.62 (0.46, 0.77) for two remote cameras (Figure 11).

Table 5. Model selection summary for the seven models of Sambar Deer occupancy. Models are defined in Table 2. A larger w_i value indicates a better model.

Model	DIC	ΔDIC	w_i
ψ\{year+treat\}p\{method\}	333.4	0.0	0.31
ψ\{year\}p\{method\}	333.7	0.3	0.27
ψ\{.\}p\{method\}	334.2	0.8	0.21
ψ\{treat\}p\{method\}	334.9	1.5	0.14
ψ\{year × treat\}p\{method\}	336.5	3.1	0.07
ψ\{.\}p\{.\}	367.1	33.7	0.00
ψ\{treat\}p\{.\}	367.7	34.3	0.00

Figure 9. Sambar Deer photographed by a remote camera in our post-fire occupancy survey, 21 July 2010. This cell was burnt by the Murrindindi fire.

Figure 11. Probabilities of detecting Sambar Deer, conditional on presence, for our three field survey methods. Cumulative probabilities are shown for one, two or three faecal pellet transects, and one and two sign surveys and camera traps. Vertical bars are 95% credible intervals.



Models that allowed detection to differ by survey method had similar support (Table 5). The model that would have been expected had there been a strong interaction between treatment and time was one of the least supported by the data once we allowed detection to differ by method, although ΔDIC was low (<4). The model with the lowest DIC allowed for occupancy to differ by treatment and by pre- and post-fire, but with no interaction term (i.e. occupancy decreased similarly at burnt and unburnt sites, and was overall lower on the burnt sites). Other models had similar DIC values and subsequently relatively high levels of support, including the model that assumes no difference in occupancy due to time or treatment ($\psi\{.\}p\{\text{method}\}$). Given the similarity in DIC values and hence uncertainty as to which was the best model, we used the model weights to average parameters across all models (see Gormley *et al.* 2011; Table 2). From these model-averaged parameter estimates, there were weak negative effects of the Black Saturday fires and time on occupancy (Figures 12 and 13).

Figure 10. Male Sambar Deer photographed at a wallow by a remote camera in our post-fire occupancy survey, 19 July 2010. This cell was not burnt by the Black Saturday fires.

Table 6. Model-averaged parameter estimates (on the logit scale) from our seven occupancy models (Table 2). SD is the square root of the unconditional variance estimator.

Parameter	Mean	SD	2.5%	97.5%
Intercept	5.65	4.18	-2.70	14.01
Time	-3.67	4.31	-12.30	4.96
Treatment	-1.95	3.58	-9.10	5.21
Time×Treatment	-0.04	0.52	-1.07	1.00

Figure 12. Pre- and post-fire probability of Sambar Deer occupancy (median ± 95% credible interval) at sites burnt and not burnt by the Black Saturday fires.

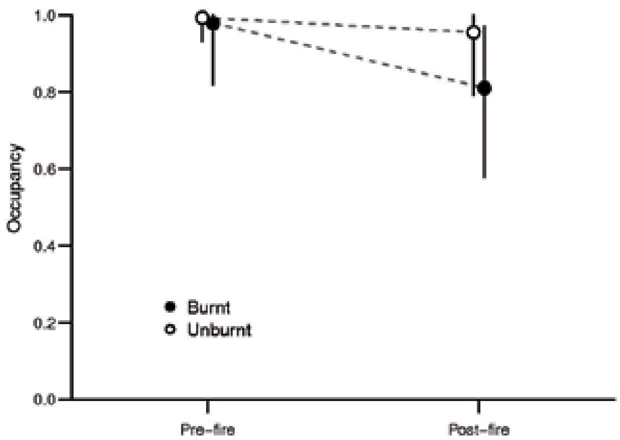


Figure 13. Changes in Sambar Deer occupancy (posterior median ± 95% credible interval) pre- and post-fire on burnt and unburnt sites.

4 Discussion

Understanding the impact of fire on fauna, particularly large-scale and high-intensity bushfires, such as occurred on Black Saturday, is frequently hampered by an absence of robust pre-fire data (Clarke 2008; Whelan 1995). We utilised information from two large-scale pre-fire studies, one of abundance (Forsyth 2006) and one of occupancy (Gormley *et al.* 2011), to estimate the impacts of the Black Saturday fires on Sambar Deer. Annual monitoring of Sambar Deer faecal pellets in Kinglake National Park indicated that the large-scale and high-intensity Kilmore East fire reduced Sambar Deer to very low abundances (Figure 8), a finding in accordance with field observations (e.g. Mason 2008; Harrison 2010) that many deer can be killed in fires, such as occurred in February 2009 (e.g. Figure 1). Our post-fire occupancy survey, using multiple methods to account for imperfect detection of Sambar Deer, indicated that occupancy was only weakly reduced 16–24 months after the Black Saturday fires (Figures 12, 13). These data indicate that Sambar Deer abundances were greatly reduced by the large-scale and high-intensity Black Saturday fires, but that nearly all burnt habitat was occupied 16–24 months later.

Several factors are likely to be responsible for only a very small reduction in Sambar Deer occupancy being observed post-fire.

1. Our post-fire occupancy surveys were conducted 16–24 months after the Black Saturday fires and it is likely that there had been recolonisation of at least some cells from unburnt, or less intensively burnt, habitat. Interestingly, no Sambar Deer pellets (or other sign; T. Fitzgerald, personal observation) were observed during the Kinglake National Park faecal pellet monitoring undertaken in late October 2009 (i.e. the area was unoccupied), eight months after Black Saturday, but in October 2010 (i.e. 20 months post-fire) pellets were counted on two transects and one Sambar Deer was seen. Sambar Deer were also detected in both cells at Kinglake National Park (Figure 2) during our post-fire occupancy survey in July 2010. It is likely that Sambar Deer occupancy rates would have been much lower immediately post-fire.
2. Even within intensively burnt cells there may have been refugia in which some Sambar Deer survived the fire (Mason 2008). Sambar Deer preferentially use wet gullies and swamp/riparian habitats (Lo 1985; Lewis *et al.* 1990; Bentley 1998) that would be less likely to burn relative to many other parts of the landscape (Whelan 1995). There is no information on dispersal rates and/or distances of Sambar Deer in south-eastern Australia.
3. In our occupancy analyses a time × treatment interaction was not supported by the data (mean = -0.04, 95% CI = -1.07, 1.00), but this does not necessarily mean there was no interaction. Rather, the model adequately fitted the data without the interaction term because: (i) the estimated pre-fire occupancy probabilities are near one, and (ii) the data were modelled on the logit scale. On the logit scale, the time effect (-3.67) decreased the burnt and unburnt sites by the same amount: from 5.65 to 1.98 on the burnt sites, and from 7.60 to 3.93 on the unburnt sites. This corresponds to a decrease in occupancy probability from 0.99 to 0.88 and from 0.99 to 0.98 on the burnt and unburnt sites, respectively (i.e. decreases of 0.11 and 0.01).
4. Occupancy is scale-dependent. We used a sampling unit of 4 km^2 (i.e. 400 ha) because this was the scale at which the pre-fire occupancy survey was conducted (Gormley *et al.* 2011). A cell size of 4 km^2 was chosen by Gormley *et al.* (2011) because it approximated estimates of Sambar Deer home range size in other introduced populations (Lewis *et al.* 1990; Fraser and Nugent 2005) and was a practical unit size for conducting field surveys. Using a different cell size would likely have resulted in different estimates of pre- and post-fire occupancy.

Previous studies of the effects of fire on fauna in Australia have used estimates of absolute or relative abundance (e.g. Whelan 1995; van der Ree and Loyn 2002; Lindenmayer *et al.* 2008), but occupancy better describes large-scale temporal changes in distribution (MacKenzie *et al.* 2006). Our results highlight the need to carefully consider detection probability in the design of presence–absence surveys (MacKenzie *et al.* 2002, 2006). Although all three occupancy survey methods had detection probabilities <1 (Figure 11), the use of multiple methods and spatial replication of two of those methods (faecal pellet transects and camera traps) reduced the overall probability of false negatives in sampled cells (see also Gormley *et al.* 2011). Sambar Deer are cryptic, being largely nocturnal and spending daylight hours in dense forest (Bentley 1998). If multiple methods and spatial replication of those methods within cells were not used, then the rate of false negatives would have been much greater. Camera traps are commonly used to detect animals in occupancy studies (reviews in O'Connell *et al.* 2011), but it was unfortunate that 17 of the 60 (28%) remote camera traps in our study failed. Many of these failures were attributed to a batch of poor quality batteries, and highlights the need to use multiple detection methods and spatial replication of those methods when practical.

It is widely accepted that successional changes in vegetation following fire drive the dynamics of small mammal populations in south-eastern Australia (e.g. Fox 1982, 1996; Friend 2004; Lindenmayer *et al.* 2008). Downes (1983) suggested that post-fire successional changes in vegetation affect Sambar Deer through changes in cover and the quality and quantity of food. In North America, early successional plant species are often very palatable to deer (e.g. Pearson *et al.* 1995), leading to increased use of burnt areas by ungulates (e.g. Bailey and Whitham 2002). Hence, although the abundances of Sambar Deer in south-eastern Australia are initially reduced by large-scale and high-intensity fires, in the medium-term vegetation succession may provide higher quantities of high-quality forage, as well as dense cover for shelter, and abundances may become greater than if the forest had not burnt (Downes 1983; Bentley 1998; Mason 2008). Mason (2008) suggested that it would take at least a decade for Sambar Deer populations to recover to pre-fire abundances from the large-scale and high-intensity 2006–2007 fires in eastern Victoria. The post-fire population-level responses of large herbivores, such as Sambar Deer, will play out over much longer time-scales than small mammals due to lower maximum annual population growth rates and larger generation times of the former relative to the latter. The Mount Buffalo National Park study area was burnt by bushfire in January 2003 (Flinn and Wareing 2003) and some of it was subject to controlled burning in December 2006 (C. Pascoe, Parks Victoria, personal communication) and the observed increase in the Sambar Deer population there during 2007–2010 (Figure 8) may be a consequence of post-fire vegetation succession. However, no information on the direct effects of the 2003 fire on Sambar Deer in Mount Buffalo National Park is available. Continued annual monitoring of Sambar Deer abundances in Kinglake National Park provides a unique opportunity to evaluate the population dynamics of Sambar Deer following a large-scale and high-intensity fire.

The FPI used in our study has been shown to be positively and linearly related to known deer densities in 20 enclosures in New Zealand (Forsyth *et al.* 2007). It is desirable to have an accurate and precise estimate of Sambar Deer density rather than an index of relative abundance, but such methods are currently unavailable for Sambar Deer in Victoria. Ground-based direct surveys (Mayle *et al.* 1999) are unreliable because Sambar Deer actively avoid people, and the terrain makes these techniques impractical to implement. Live-capture and photographic mark–recapture methods would be extremely expensive and therefore limited in spatial scale. One recent development that has potential for providing accurate and precise estimates of Sambar Deer density is mark–recapture using DNA from faecal pellets: this method has been successfully applied to Sitka Black-tailed Deer (*Odocoileus hemionus sitkensis*) in the temperate coastal rainforest of Southeast Alaska (Brinkman *et al.* 2011) and we have successfully identified individual Sambar Deer in Victoria from faecal DNA (D.M. Forsyth and D. Gleeson, unpublished data). Further work is required to test whether Sambar Deer abundances can be usefully estimated using faecal pellet mark–recapture.

4.1 Management implications

Although occupancy rates and abundances of Sambar Deer were reduced by the Black Saturday fires, Sambar Deer were using recovering vegetation communities 16 months after the fires (Figure 9). Our study did not investigate the impacts of Sambar Deer on post-fire vegetation recovery, but North American studies show that deer can alter the post-fire successional trajectories of plant communities (e.g. Bailey and Whitham 2002; Royo *et al.* 2010). A risk-averse approach to minimising the post-fire impacts of Sambar Deer would be to exclude them from high-priority areas (e.g. by fencing). Annual faecal pellet monitoring at Kinglake National Park suggests that it is at least eight months before Sambar Deer recolonise areas burnt by a large-scale and high-intensity fire, but a risk averse approach would be to erect fences sooner.

4.2 Future directions

Given the interest in minimising the impacts of Sambar Deer on post-fire vegetation recovery (Department of Sustainability and Environment 2009), future work should investigate the impacts of Sambar Deer on priority plant species and communities, and how these impacts change with fire intensity and management actions, such as fencing and other forms of deer removal. The best way to address this would be by monitoring plant communities post-fire with and without Sambar Deer (and other sympatric herbivores, such as Black Wallaby (*Wallabia bicolor*)). Differential exclusion plots (10×10 m) have been developed for Sambar Deer and Black Wallaby by Bennett and Coulson (2008), and have been constructed in parts of Kinglake National Park to evaluate the impacts of these herbivores on several Victorian Rare or Threatened Species (VROTS). It would be desirable to estimate the relative abundance of deer in the sites where exclosures are located using the Faecal Pellet Index (FPI).

Knowing which plant species (e.g. VROTS) are being eaten by Sambar Deer (and hence most likely to be negatively impacted) during post-fire vegetation succession is also desirable. Analysis of rumen contents is the least biased way to evaluate Sambar Deer diet (Forsyth and Davis 2011), but this method involves killing animals. Analysis of plant material in Sambar Deer faecal pellets is likely to be a non-invasive but less accurate method of estimating Sambar Deer diet than from rumen samples (e.g. Anthony and Smith 1974).

Finally, continued annual counting of faecal pellets along the 30 transects in both Kinglake National Park and Mount Buffalo National Park would enable the long-term recovery of a Sambar Deer population following a large-scale and high-intensity fire to be evaluated. Continued monitoring of the existing photo-points in Kinglake National Park (Figure 5) would provide qualitative information on vegetation succession that would assist with interpreting the post-fire population dynamics of Sambar Deer there.

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