Biodiversity response and recovery supplementary report: bushfire impacts on species in Victoria

August 2022

Environment, Land, Water and Planning

OFFICIAL

Cover Photo
Female Glossy Black-Cockatoo (*Calyptorhynchus lathami*) feeding on seeds of Green She-oak (*Allocasuarina paradoxa*), The Pines Flora Reserve, Frankston North, June 2020 (photo: P. Menkhorst)

Edited by Jeanette Birtles, Organic Editing

Citation
DELWP. (2022). *Biodiversity response and recovery supplementary report: bushfire impacts on species in Victoria.* Department of Environment, Land, Water and Planning, Melbourne, Victoria.

Example chapter citation
Macak, P. & Rowe, K. (2022). Broad-toothed Rat. In DELWP. *Biodiversity response and recovery supplementary report: bushfire impacts on species in Victoria.* Department of Environment, Land, Water and Planning, Melbourne, Victoria.

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Acknowledgement

We acknowledge and respect Victorian Traditional Owners as the original custodians of Victoria's land and waters, their unique ability to care for Country and deep spiritual connection to it. We honour Elders past and present, whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

We are committed to genuinely partner, and meaningfully engage, with Victoria's Traditional Owners and Aboriginal communities to support the protection of Country, the maintenance of spiritual and cultural practices, and their broader aspirations in the 21st century and beyond.

ISBN 978-1-76105-185-2 **(pdf/online/MS word)**

Accessibility

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Acknowledgements

This report is a compilation of activity reports prepared by many people across a number of organisations [including the Arthur Rylah Institute for Environmental Research (ARI), Biodiversity, Strategy and Knowledge (BSK), Environment and Community Programs (ECP) and Forest, Fire and Regions (FFR), all within DELWP; Parks Victoria; Museums Victoria; Royal Botanic Gardens Victoria (RBGV); the University of Melbourne] and by several other scientists. The collaborative approach adopted and the enthusiasm shown by the teams to work together and deliver meaningful outcomes for biodiversity following the 2019–2020 bushfires demonstrate the high quality of people working in Victoria's biodiversity sector.

Thank you to all the supporters and teams of people who contributed to the Bushfire Biodiversity Response and Recovery (BBRR) Theme 1 immediate reconnaissance program, and particular thanks to the following people, who led the early development and delivery of the program: Tim O'Brien (ARI Theme 1 Lead), Mark Whyte (DELWP BBRR Program Lead), Christie Boyle (DELWP BBRR Project Officer), Marc Perri and Jo Andrews (both FFR Gippsland), Jane Roots and Glen Johnson (both FFR Hume), Garry Peterson (FFR Barwon South West), and Ella Loeffler and Anne Buchan (both BSK). Tim O'Brien (ARI) led the compilation of this report with significant editorial support from Michele Kohout, Geoff Brown, Josephine Machunter and Lindy Lumsden (all ARI), Ella Loeffler and Will Sowersby (both BSK) and Jeanette Birtles (Organic Editing), and also Peter Menkhorst, Jenny Nelson, Danny Rogers, Michael Scroggie, Dan Stoessel, Steve Sinclair, Nick Clemann, Lyndsey Vivian and Bryan Mole, who reviewed various sections of the report.

Key participants in this program were the assessment leads and chapter authors listed below:

Phoebe Macak (ARI) and Kevin Rowe (Museums Victoria): Broad-toothed Rat

Willow Bourke (FFR Gippsland): Spot-tailed Quoll

Jemma Cripps, Jenny Nelson, Phoebe Macak and Louise Durkin (all ARI): arboreal mammals and large forest owls

Peter Menkhorst (ARI), Martin Schulz (consultant) and Kasey Stamation (ARI): Glossy Black-Cockatoo

Peter Menkhorst (ARI): Eastern Ground Parrot

Matt West (the University of Melbourne) and Glen Johnson (FFR Hume): Spotted Tree Frog and Booroolong Frog

Jeremy Tscharke (Parks Victoria) and Geoffrey Heard (Australian National University and ARI): Threatened and non-threatened frogs in East Gippsland

Nick Clemann (ARI) and Zak Atkins (Snowline Ecology): reptiles and other frogs

Tarmo Raadik (ARI), Glen Johnson (FFR Hume), Zeb Tonkin (ARI), Shea Rotumah, Jodie Honan and Nicky Hudson (all Gunditj Mirring Traditional Owners Aboriginal Corporation): aquatic species (fish, mussels and crayfish)

David Bryant and Matthew Bruce (both ARI): invertebrate traits database

Matthew Bruce and David Bryant (both ARI), and Ken Walker (Museums Victoria): native bee assessment

Arn Tolsma, Annette Muir and Judy Downe (all ARI), Andre Messina and Neville Walsh (both RGBV): threatened flora species, vegetation types, rainforests, and Limestone Pomaderris Shrubland

Arn Tolsma: Post-fire assessment of Alpine Bogs (reported separately in Tolsma 2020).

These projects were largely funded by the Victorian Government's Bushfire Biodiversity Response and Recovery program and the Australian Government's Bushfire Recovery Package for Wildlife and Their Habitat. Several other organisations, including those listed above, provided significant in-kind and financial support as well as important data and knowledge.

Contents

Introduction

Protecting Victoria's Environment – Biodiversity 2037 (Biodiversity 2037) outlines Victoria's plan to achieve overall biodiversity improvement over the next 20 years. Within this, the Department of Environment, Land, Water and Planning (DELWP) recognises the importance of being strategic when planning conservation objectives, and acknowledges that there is a trade-off between multiple- and single-species actions. Under the extraordinary influence of climate change, new types of interventions and projects that maintain a single-species focus will still be needed, particularly for endangered and critically endangered species. These single-species management actions will, however, need to be balanced against landscape-scale multiple-species approaches, to maximise the benefit to the most species.

The 2019–2020 bushfire season represented an exceptional threat to native species, populations and individuals. These species and populations were already affected by a range of ongoing threats, such as invasive predators and herbivores. Some of these threats are subject to ongoing or planned actions. In response to the impacts of the 2019–2020 bushfire season, DELWP instigated collaborative workshops and an initial impact assessment with experts and organisations to identify species of concern and potential recovery actions. An initial impact assessment report was published in January 2020 and updated in August 2020 (DELWP 2020). More information and this report are available at the following link: *Victoria's bushfire emergency: biodiversity response and recovery* (wildlife.vic.gov.au).

1.1 Immediate reconnaissance objectives and general approach

The Victorian immediate reconnaissance program was designed to identify and assess fauna, flora and habitats most at risk from post-fire threats. These assessments were then used to inform the prioritisation of management actions to prevent significant decline of species, and species extinctions, and to maximise recovery opportunities for threatened species and ecological communities. The general approach was as follows:

Prioritise target species and assessment locations based on the *Victoria's bushfire emergency: biodiversity response and recovery* report (DELWP 2020), which was informed by fire-severity analysis, species records, Habitat Distribution Models, the reports of Rapid Risk Assessment Teams (RRATs), and local observations post fire.

Assess the fire impacts, status of target species, and habitat status at key locations (using both desktop and field assessments).

Review the status of existing threats and increased threats arising due to the fires.

Provide advice to support prioritisation of potential management actions.

Record on-ground observations in appropriate DELWP information systems, including the Victorian Biodiversity Atlas (VBA; DELWP 2021), as these systems form an integral part of DELWP's management prioritisation process. The recorded data include the data from surveys in which no target flora or fauna were recorded, as both positive and negative records are important for informing management decisions.

Desktop assessment of relative fire impact or threat was a key prioritisation criterion, with the focus for reconnaissance to be on identifying treatable threats to fauna and flora species and habitats. As it was not possible to complete reconnaissance surveys for all impacted species, prioritisation of species was guided by DELWP's decision-making tools (including the Strategic Management Prospects tool (NaturePrint; Thomson et al. 2020) and initial impact assessment reports.

The aim of these reconnaissance activities was to understand the immediate and short-term impacts of the bushfires. They were not intended to establish research and monitoring programs, but they may provide some foundation for any subsequent work. Prioritisation of any potential actions to manage the risks to a species will be undertaken through separate DELWP processes, utilising Strategic Management Prospects for identified landscape-scale actions and Specific Needs analysis for more discrete threats and consequent actions. Any further assessments of impacts or management effectiveness will be guided and prioritised by the approaches in the Biodiversity 2037 Knowledge Management Framework.

This report summarises reconnaissance activities and findings completed between early 2020 and June 2021.

1.2 Extent of the 2019–2020 bushfires

The extent of the Victorian fires was approximately 1,511,000 ha, the majority of which was in eastern Victoria. Figure 1 shows the fire extent for eastern Victoria, with its severity mapped into six classes (Collins et al. 2021). Within this context, information was used to identify areas and species most likely to have been impacted by the bushfires (see DELWP 2020), and to select sites for assessment based on a combination of likely fire impacts, species traits (i.e. likely sensitivity to fire), distribution modelling and data, site accessibility, and field logistics.

Since 2000, multiple large-scale fires have increased the area that has been burnt repeatedly, expanding the context in which assessment and mitigation needs to be framed. Some areas and species not directly impacted by the 2019–2020 bushfires (such as the Silurian Limestone Pomaderris Shrubland community that exists at only one site in East Gippsland) were also assessed, to understand how they have coped with previous fires, and what form of stronghold they might provide for species recovery.

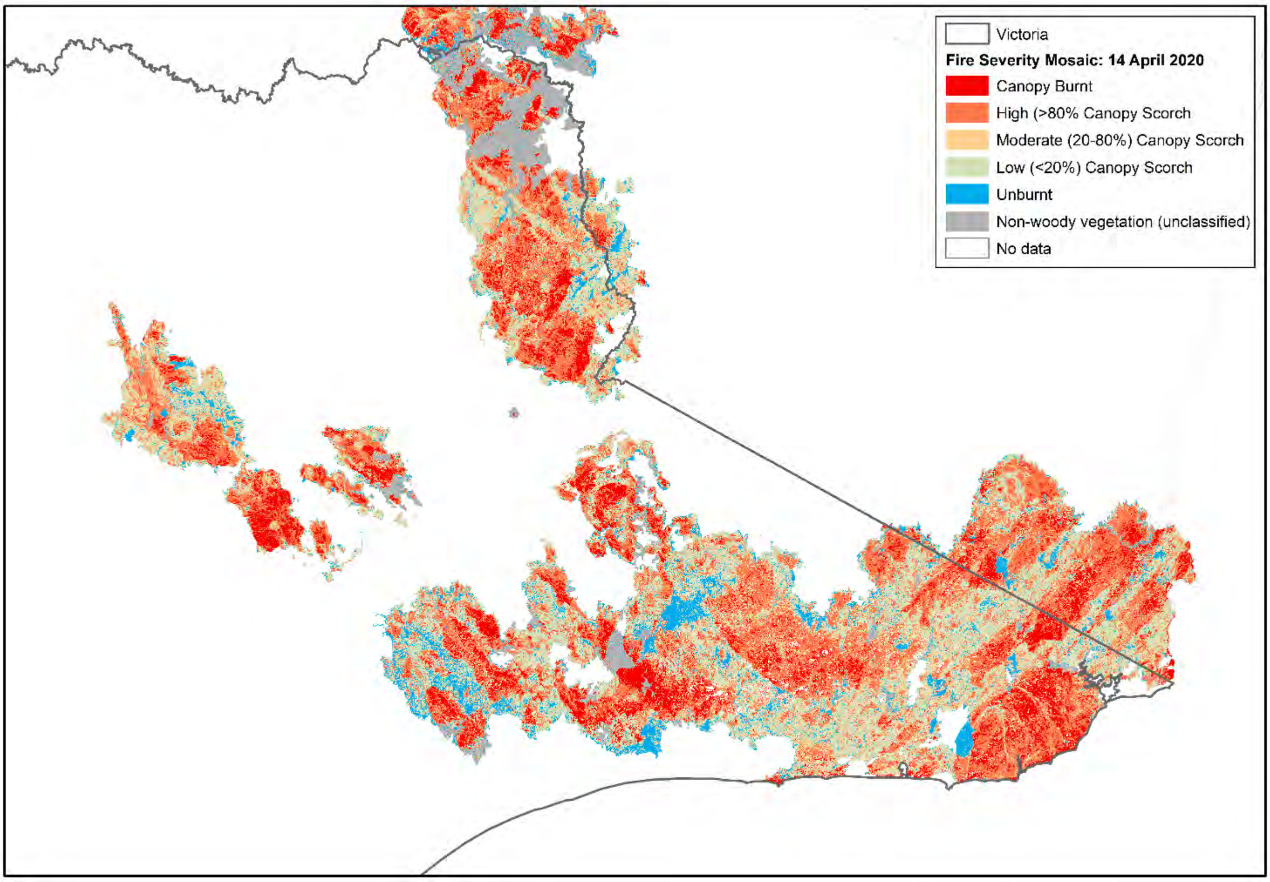

Figure 1. Map of fire severity in north-eastern Victoria and East Gippsland (to 14 April 2020)

In 2019–2020, bushfires also affected over 7000 ha of the Budj Bim World Heritage area. This included a large proportion of the Indigenous Protected Areas, including the catchment of Tae Rak (Lake Condah) and Killara (Darlots Creek). Assessments of bushfire impacts upon several aquatic species were completed at these sites and are reported here.

1.3 Prioritising impact assessments for flora and fauna

Approximately 3000 plant species, nearly 500 species of terrestrial vertebrates, more than 20 species of fish, and a vast number of invertebrate fauna (yet uncounted) are located in the fire-impacted areas. For some threatened species, including the Long-footed Potoroo (*Potorous longipes*), some native freshwater fish species, endemic burrowing crayfish, and extremely localised flowering plants, this region encompasses much of their known worldwide distribution. The affected region also represents critical strongholds for wider-ranging threatened species, such as the Glossy Black-Cockatoo, the Eastern Bristlebird (*Dasyornis* *brachypterus*) and the Eastern Ground Parrot (*Pezoporus wallicus*). While many species impacted by fire in Victoria will also have been impacted by fires in other states, this report focuses on species within Victoria.

Table 1 outlines the fauna of most immediate concern as identified in DELWP's report *Victoria's bushfire emergency: biodiversity response and recovery,* published in August 2020 (DELWP 2020).

Flora species of most concern were initially identified in the same report; however, these species represented only a subset of the threatened flora known to be within the fire-affected area. Further investigation using Habitat Distribution Models identified a total of 688 Victorian Rare or Threatened (VROT) species (vascular plants and ferns only) that may have had a proportion of their distribution burnt.

VBA records for these 688 species were overlain on the fire-severity model to identify those known populations that were within areas burnt at high severity (Crown Burnt or Crown Scorched categories), with the assumption being that these populations would be the most severely affected. This process identified 489 species that had at least one known population in an area that burnt at high severity. To prioritise species for assessment, flora species were identified for which >50% of their total VBA records were from areas that burnt at high severity. In addition, species of particular concern, such as those identified by the Bushfire RRATs, were also targeted for assessment. After combining these groups of species, a provisional shortlist of 155 species was obtained for potential assessment, representing 3464 (VBA) site records.

A total of 287 sites with threatened plant species were assessed on the ground: these sites contained 126 threatened species. Of these, 108 of the species were found to be successfully regenerating from seedlings or resprouts. There were 18 species not found, but it is still too early to determine whether this was due to lack of regeneration, inaccuracy of location records, or simply an insufficient amount of time since the fire to allow detection and positive identification. Table 2 summarises the assessment results for target flora species determined to have had greater than 80% of the locations of their VBA records burnt at high severity.

Table 1. Fauna species of most concern identified in *Victoria's bushfire emergency – biodiversity response and recovery, version 2* (DELWP 2020)
Data presented include percentage of modelled habitat that lay within the 2019–2020 fire extent, percentage of modelled habitat impacted by high-severity fire, genetic risk rating (Kreisner et al. 2020), localised impacts, and reconnaissance status. Reconnaissance results are given for species targeted and reported on in this current report. Localised impacts were determined through consultation with species experts, regional DELWP staff and other regional biodiversity experts from partner agencies. No thresholds or criteria were used to determine localised impacts. Instead, assessment of localised impact was based on whether or not a species had large proportions of their habitat impacted by the fires, and/or whether experts considered that they were especially vulnerable to bushfires.

Common name	Scientific name	Percentage of modelled habitat in Victoria within the fire extent	Percentage of modelled habitat in Victoria impacted by high-severity fire	Genetic risk rating	Comments, including status and localised impacts
Mammals					
Broad-toothed Rat	*Mastacomys fuscus mordicus*	23%	14%	Very high (mainland)	Populations in sub-alpine areas probably affected; greater incidence in unburnt sites
Brush-tailed Rock-wallaby	*Petrogale penicillata*	43%	26%	Very high	Wild Little River Gorge population not directly affected; not assessed under this program
Eastern Bent-wing Bat	*Miniopterus orianae oceanensis*	21%	10%	Moderate	Most important Gippsland cave site is outside burnt area; however, much of the foraging habitat was burnt; not included in this report
Eastern False Pipistrelle	*Falsistrellus tasmaniensis*	26%	13%	Moderate	Not assessed under this program
Eastern Horseshoe Bat	*Rhinolophus megaphyllus megaphyllus*	39%	18%	High	Some cave sites within burnt area and foraging habitat burnt; not included in this report
Eastern Pygmy-Possum	*Cercartetus nanus*	25%	13%	High	Not assessed under this program; a high proportion of the best habitat in East Gippsland has been burnt; some tableland sites have been impacted; most of this species' highest-density sites in East Gippsland (on tableland near Bendoc) not burnt
Feather-tailed Glider species	*Acrobates* spp.	22%	11%	High	Not assessed under this program
Greater Glider	*Petauroides volans*	32%	16%	High	Populations recorded more often in unburnt or moderately burnt forest than in severely burnt areas; most common around Bendoc and Swifts Creek
Grey-headed Flying-fox	*Pteropus poliocephalus*	23%	11%	Low	Major roosting camp near Mallacoota may have been impacted; not assessed under this program
Koala	*Phascolarctos cinereus*	13%	6%	Moderate	Not assessed under this program
Long-footed Potoroo	*Potorous longipes*	79%	41%	Very high	Populations may have been impacted; very high proportion of East Gippsland distribution burnt; evidence of individuals in recently burnt areas
Long-nosed Bandicoot	*Perameles nasuta*	35%	17%	High	Not assessed under this program
Long-nosed Potoroo	*Potorous tridactylus tridactylus*	45%	22%	Very high	Very high proportion of East Gippsland distribution has been burnt; recent (pre-fire) detections of this species have been few; high priority to assess status; to be reported under separate project

Common name	Scientific name	Percentage of modelled habitat in Victoria within the fire extent	Percentage of modelled habitat in Victoria impacted by high-severity fire	Genetic risk rating	Comments, including status and localised impacts
Mountain Pygmy-possum	*Burramys parvus*	7%	4%	Very high	Not assessed under this program
Platypus	*Ornithorhynchus anatinus*	14%	6%	Moderate	Not assessed under this program
Smoky Mouse	*Pseudomys fumeus*	20%	11%	High	Not assessed under this program
Southern Brown Bandicoot	*Isoodon obesulus obesulus*	28%	14%	High	Very high proportion of East Gippsland distribution has been burnt; not assessed under this program
Spot-tailed Quoll	*Dasyurus maculatus maculatus*	36%	19%	Very high	Parts of the key stronghold in the upper Snowy River area were burnt severely. Detected at only 2 of 104 survey sites in the Alpine National Park (NP), both unburnt
White-footed Dunnart	*Sminthopsis leucopus*	36%	18%	High	Not assessed under this program
Yellow-bellied Glider	*Petaurus australis*	35%	17%	High	Populations recorded more often in unburnt or moderately burnt forest compared with severely burnt areas
Birds					
Brown Gerygone	*Gerygone mouki*	52%	26%	Moderate	Impact on East Gippsland population linked to extent of Warm Temperate Rainforest and Riparian Forest burnt; not assessed under this program
Eastern Bristlebird	*Dasyornis brachypterus*	58%	39%	Very high	Fire boundaries very close to key sites; individuals extracted and returned; the population in adjacent Nadgee Nature Reserve has been severely impacted; response activities and assessment was delivered under other programs
Glossy Black-Cockatoo	*Calyptorhynchus lathami*	64%	26%	Moderate	Most of the population in East Gippsland has been affected; effect of fire on food (*Allocasuarina* seeds) likely to be severe
Eastern Ground Parrot	*Pezoporus wallicus*	33%	21%	Very high	Reconnaissance results from the East Gippsland fire area to be reported separately, but related surveys from Wilsons Promontory included in this report
Lewin's Honeyeater	*Meliphaga lewinii*	39%	20%	Moderate	Not assessed under this program
Masked Owl	*Tyto novaehollandiae*	54%	26%	High	Area burnt includes best habitat in Victoria and covers most of the recent records
Powerful Owl	*Ninox strenua*	26%	13%	Moderate	Few records during post-fire surveys; likely affected by fire; impact on species depends on fire severity
Red-browed Treecreeper	*Climacteris erythrops*	31%	16%	High	Not assessed under this program
Sooty Owl	*Tyto tenebricosa*	47%	24%	High	Few records during post-fire surveys; likely affected by fire; impact on species depends on fire severity
Spotted Quail-thrush	*Cinclosoma punctatum*	29%	14%	High	Not assessed under this program

Common name	Scientific name	Percentage of modelled habitat in Victoria within the fire extent	Percentage of modelled habitat in Victoria impacted by high-severity fire	Genetic risk rating	Comments, including status and localised impacts
Reptiles					
Alpine Bog Skink	*Pseudemoia cryodroma*	14%	9%	Very high	Some populations were impacted
Alpine She-oak Skink	*Cyclodomorphus praealtus*	5%	2%	Very high	Habitat on the southern edge of the Bogong High Plains was burnt; extensive impacts in New South Wales (NSW) and from previous bushfires
Alpine Water Skink	*Eulamprus kosciuskoi*	22%	14%	High	Likely that >50% of populations may have been impacted
Copper-tailed Skink	*Ctenotus taeniolatus*	19%	9%	Moderate	Preference for rocky habitat, which may have been less impacted by fires; however, killed animals were found under rock exfoliations. Also important to note that there is a strong temporal element to impacts—immediately after the fire, survivors may have struggled to find food and would only have compromised camouflage and vegetation shelter from predators; in the coming months and years, dense regrowth can shade basking locations and affect foraging success. Because this species uses permanent retreat sites, any effects from dense regrowth could be serious.
Diamond Python	*Morelia spilota spilota*	86%	45%	High	Most of the Victorian population may have been impacted. Likely to be individuals on Howe Flat. Some reports of survivors in burnt areas on the coast west of Mallacoota. So far, these have mostly been in rocky areas, which could help explain their survival. It is also likely that this subspecies has been more visible due to loss of vegetation cover and perhaps shelter sites.
Eastern She-oak Skink	*Cyclodomorphus michaeli*	55%	Unknown	High	The majority of populations may have been impacted; probably shelters among vegetation, which would suggest severe impacts in burnt areas; likely to be individuals on Howe Flat
Gippsland Water Dragon	*Intellagama lesueurii howittii*	42%	20%	High	Some individuals observed, but numbers severely reduced in some areas. Likely oviposition sites in some areas buried by inflow of ash and sediment into streams
Lace Monitor	*Varanus varius*	16%	8%	High	High proportion of East Gippsland distribution has been burnt; this species is likely a more effective coloniser than many other affected reptiles
Red-throated Skink	*Acritoscincus platynotus*	36%	22%	Very high	Likely that all populations may have been impacted; logs and burnt trees that will soon fall are probably a critical factor in the persistence of the small number of survivors; where these shelters are removed or moved, populations that barely survived the fire may be lost
Swamp Skink	*Lissolepis coventryi*	17%	7%	High	Much of its range in East Gippsland (its population stronghold) has been impacted. Few individuals observed at some sites (in burrows). At other sites, burrows were not evident (suggesting the species does not occupy all patches of apparently suitable habitat), burrows were apparently not occupied, or burrows contained other burrowing species (such as White's Skink *Liopholis whitii*).
Yellow-bellied Water Skink	*Eulamprus heatwolei*	39%	20%	High	Numerous sightings since the bushfires; appears to persist where co-occurring species were not detected; it is likely an early and effective coloniser of burnt areas

Common name	Scientific name	Percentage of modelled habitat in Victoria within the fire extent	Percentage of modelled habitat in Victoria impacted by high-severity fire	Genetic risk rating	Comments, including status and localised impacts
Frogs					
Alpine Tree Frog	*Litoria verreauxii alpina*	15%	8%	High	Unburnt breeding ponds containing tadpoles of this subspecies had water pumped in and out of ponds; areas of historically occupied habitat were burnt in north-eastern Victoria
Blue Mountains Tree Frog	*Litoria citropa*	66%	32%	High	Recorded at most known sites, including severely burnt sites, albeit in low numbers
Booroolong Frog	*Litoria booroolongensis*	39%	13%	Very high	Two of three Victorian populations affected; frog numbers reduced
Dendy's Toadlet	*Pseudophryne dendyi*	46%	23%	High	Not assessed under this program
Giant Burrowing Frog	*Heleioporus australiacus*	75%	38%	Very high	Not directly assessed under this program; some survivors and breeding detected in a couple of burnt areas (near Nowa Nowa and close to the NSW border); some animals were found in Mallacoota (in the backyards of burnt properties, the water-treatment plant, etc.); locals also reported them to us from in and near town.
Green and Golden Bell Frog	*Litoria aurea*	53%	24%	High	Populations around Mallacoota may have been affected; some individuals observed in Cape Conran NP since the fires
Keferstein's Tree Frog	*Litoria dentata*	84%	53%	High	Not recorded, though surveys were restricted
Watson's Tree Frog (formerly Large Brown Tree Frog)	*Litoria watsoni*	88%	47%	Very high	All known populations may have been impacted; reconnaissance results to be reported separately
Leaf Green Tree Frog	*Litoria nudidigita*	66%	34%	High	Recorded at most known sites, including severely burnt sites, albeit in low numbers
Martin's Toadlet	*Uperoleia martini*	31%	13%	Very high	Over 30% of Gippsland populations may have been affected; in addition, long sections of stream received enormous inputs of ash and sediment, which buried a lot of shelter and breeding habitat for riverine frogs
Southern Barred Frog	*Mixophyes balbus*	96%	Unknown	Very high	No confirmed records in Victoria since 1982; all known (pre-1982) sites have been impacted
Spotted Tree Frog	*Litoria spenceri*	22%	13%	Very high	Four significant populations affected by fire and by post-fire changes (flooding and increased sediment loads)
Aquatic fauna					
Australian Grayling	*Prototroctes maraena*	Unknown	Unknown	Low	Eastern Victorian populations may have been affected; not assessed under this program
Burrunan Dolphin	*Tursiops australis*	Unknown	Unknown	Moderate	Not assessed under this program
Cann Galaxias	*Galaxias* sp. 17	Unknown	Unknown	Very high	All populations affected in sediment event; individuals extracted; no more located within known range

Common name	Scientific name	Percentage of modelled habitat in Victoria within the fire extent	Percentage of modelled habitat in Victoria impacted by high-severity fire	Genetic risk rating	Comments, including status and localised impacts
Dargo Galaxias	*Galaxias mungadhan*	16%	Unknown	High	All populations affected; fish abundance reduced by ~30%; individuals extracted
East Gippsland Galaxias	*Galaxias aequipinnis*	100%	Unknown	High	All populations may have been affected; fish abundance reduced by ~30%
Flatheaded Galaxias	*Galaxias rostratus*	~25%	Unknown	Very high	Impacts unknown due to difficulty in sampling
Mountain Galaxias complex	*Galaxias olidus* complex	Unknown	Unknown	Moderate	Key population in south of range may have been affected (~85% of populations occur within the recent fire extent)
Gippsland Blackfish	*Gadopsis* sp. SEV	Unknown	Unknown	Very high	Key populations in East Gippsland may have been affected
Macquarie Perch	*Macquaria australasica*	~20%	Unknown	High	Population in Lake Dartmouth and Buffalo River affected; individuals extracted
McDowall's Galaxias	*Galaxias mcdowalli*	77%	Unknown	High	All populations may have been affected; individuals extracted
Moroka Galaxias	*Galaxias* sp. 16	Unknown	Unknown	Very high	Only known population is outside of fire footprint
Mountain Galaxias	*Galaxias olidus*	Unknown	Unknown	Moderate	Key populations in south of range may have been affected
Roundsnout Galaxias	*Galaxias terenasus*	97%	Unknown	Very high	Entire Victorian population may have been affected; no access possible for extraction due to fires
Yalmy Galaxias	*Galaxias* sp. 14	94%	Unknown	Very high	Entire population affected in major post-fire sediment event; fish abundance reduced by 100% in Serpentine Creek, and by ~60% in Yalmy River
Additional species assessed for impacts from the Budj Bim World Heritage Area fires					
Ngeerang Yarram (Glenelg Spiny Crayfish)	*Euastacus bispinosus*			High	Restricted to the Glenelg River system in south-western Victoria and spring-fed coastal streams in south-eastern South Australia; Darlots Creek is at the extremity of its south-eastern range
Yiritja (South-west River Blackfish)	*Gadopsis* sp. SWV			Very high	Victorian endemic species that now occupies a very small range, though thought to have been widespread historically; three small, isolated populations exist in south-western Victoria; the largest of these, at Darlots Creek, was impacted by the 2019–2020 fires; rapidly declining in range and abundance

Table 2. Flora species of most concern identified in *Victoria's bushfire emergency – biodiversity response and recovery, version 2* and/or those species subsequently determined to have had greater than 80% of their VBA record locations burnt at high severity
Data presented include percentage of VBA records impacted by high-severity fire, localised impacts, and reconnaissance status. Reconnaissance results are given for species targeted and reported on in this current report that potentially had 80% or more of their VBA record locations burnt at high severity. Not all species originally identified in *Victoria's bushfire emergency – biodiversity response and recovery, version 2* were searched for. Some species with a high proportion of VBA record locations burnt were ultimately unable to be searched for, as those records proved inaccurate or inaccessible.

Common name	Scientific name	Percentage of VBA record locations impacted by high-severity fire	Localised impacts and reconnaissance status
Green Wattle	*Acacia irrorata* subsp. *irrorata*	100	One population assessed along Cicada Track, Croajingalong NP. Regenerating by seed, with around 1000 seedlings to 50 cm high. Fire severity was high. Threats include deer, road clearing, and another fire before plants reach reproductive maturity.
Woolly Wattle	*Acacia lanigera* var. *gracilipes*	100	Two populations found in riparian scrub among rocks along Genoa River. One population burnt at moderate fire severity, with ~500 seedlings to 20 cm high. Other population of ~50 plants partly burnt, with some seedlings and resprouts and some mature plants dead (but not directly burnt). Moderate amount of erosion noted, but weed cover was low. Main threat would be another fire before plants reached reproductive maturity.
Woolly-bear Wattle	*Acacia lucasii*	100	Two populations found on rocky slope and ridge in woodland on the northern end of Nunniong Plateau (a third population was not found). One population was burnt at very high severity (creating a deep ash bed) and consisted of a few hundred seedlings ~5 cm high. A few larger adults were resprouting. The other population consisted of around 500 seedlings to 10 cm high. Main threats include erosion, possibly feral Horse activity, and another fire before plants reach reproductive maturity.
Phantom Wattle	*Acacia phasmoides*	100	Not assessed for this project. VBA records did not meet dual criteria of accuracy and accessibility.
Net-veined Wattle	*Acacia subtilinervis*	100	Not assessed for this project. VBA records did not meet dual criteria of accuracy and accessibility.
Pink Flannel Flower	*Actinotus forsythii*	100	Two populations assessed in Mallee woodland near Brumby Point, Alpine NP, only one of which was found. Appears to depend on fire for recruitment, and population consisted of more than 10,000 seedlings to 10 cm high over an area of ~1.5 ha. Fire severity was high. Potential threat from feral Horse activity.
Black Stem	*Adiantum formosum*	80	One population searched for in fern gully off Jack Rich Divide Track, but not found. Fire severity was high. Threats to the site include moderate weed infestation. Additional surveys are needed to determine impacts of the fire on this species.
Native Quince	*Alectryon subcinereus*	100	One population assessed in Warm Temperate Rainforest along tributary of Genoa River. A single seedling was found in an unburnt area. No obvious threats observed, but risk to plant exists from browsing or another fire before tree recruits reach reproductive maturity.
Gippsland Banksia	*Banksia croajingolensis*	100	Three populations searched for in heathland in Croajingalong NP, of which two were found (at Shipwreck Creek and Betka River). Fire severity was high, and both populations (of around 90 and 27 individual plants, respectively) were regenerating by resprouts to 50 cm high. Threats include minor activity from deer.
Showy Boronia	*Boronia ledifolia*	82	Two populations searched for near Mount Elizabeth, only one of which was found. Population consisted of hundreds of seedlings clustered in small depressions. Main threats would be deer activity and another fire before seedlings reach reproductive maturity.
Snowy River Daisy	*Brachyscome riparia*	80	One population found in unburnt riparian scrubland along Genoa River. Around 20 plants scattered among rocks along rocky terraces of the river. No obvious threats observed, and location might protect population from fire.
Dwarf Brunoniella	*Brunoniella pumilio*	100	Two populations found in lowland forest in Croajingalong NP, one small (80 plants) and one large (~28,000 plants in a hectare). Fire severity was high, and plants were recruiting profusely from seedlings to 5 cm high. No obvious threats noted.

Common name	Scientific name	Percentage of VBA record locations impacted by high-severity fire	Localised impacts and reconnaissance status
Summer Spider-orchid	*Caladenia aestiva*	100	Not assessed for this project. VBA records did not meet dual criteria of accuracy and accessibility.
Forrester's Bottlebrush	*Callistemon forresterae*	100	Not assessed for this project
Betka Bottlebrush	*Callistemon kenmorrisonii*	100	Two populations located in riparian scrub along Betka River, Wingan SF. Fire severity was high, and populations (of more than 20 individuals each) were regenerating by resprouts to 50 cm high. Two dead plants were observed. Minor weeds and deer activity noted.
Dwarf Bottlebrush	*Callistemon subulatus*	100	Two populations located among rocks in riparian scrub along Genoa River. Unburnt population consisted of only three plants to 150 cm high. Second population of ~500 plants was partially burnt at moderate fire severity, and plants were regenerating by basal resprouts. Obvious threats were not observed, although the smaller population could be at risk from deer activity.
Elegant Cassinia	*Cassinia venusta*	100	One population located in woodland in Mount Mittamatite NCR. Fire severity was moderate (but patchy), and seedlings and resprouts were only observed in burnt road margins. Appears restricted to disturbed areas, suggesting roadworks are not a threat, but the population could be impacted by high plant–plant competition at this site.
Curtis' Colobanth	*Colobanthus curtisiae*	100	Not assessed for this project
Purple Coopernookia	*Coopernookia barbata*	90	Not assessed for this project
Genoa River Correa	*Correa lawrenceana* var. *genoensis*	92	Four populations searched for in riparian scrub along Genoa River but not found (plants were uncommon before fire). Fire severity was high, and the site in Maramingo SF had moderate weed infestation and some deer activity. Additional assessments of other known populations are required to determine impact of fire.
Sheath Rush	*Cyathochaeta diandra*	97	Not assessed for this project
Kydra Dampiera	*Dampiera fusca*	100	Three populations found on stony ridges in sub-alpine woodland on the northern end of Nunniong Plateau. Two populations were burnt at moderate severity and consisted of up to 100 seedlings to ~10 cm high. The other population east of Reedy Track was burnt at high severity and consisted of over 10,000 seedlings across around 10 ha. Minor erosion was noted, and feral Horses are active in the area.
Rock Orchid	*Dendrobium speciosum* var. *speciosum*	100	Not assessed for this project
Small Wax-lip Orchid	*Glossodia minor*	92	Three populations were located in coastal heathland and woodland between Mallacoota and Genoa, all burnt at high intensity. Population size ranged from ~30 to 400 individuals, which were resprouting from tubers. No obvious threats were noted.
Daisy Goodenia	*Goodenia bellidifolia* subsp. *bellidifolia*	86	One population searched for in Marramingo SF but not found. Fire severity was moderate, and there were no obvious threats observed.
Variable Goodenia	*Goodenia heterophylla* subsp. *heterophylla*	83	One population located in Tulloch Ard SF. Site was burnt at high severity, and 23 seedlings were observed, ~5 cm high and in flower. No obvious threats were observed but could include deer activity.

Common name	Scientific name	Percentage of VBA record locations impacted by high-severity fire	Localised impacts and reconnaissance status
Pine Mountain Grevillea	*Grevillea jephcottii*	95	Two populations located in severely burnt patches in Pine Mountain NP. One population on a granite outcrop in montane woodland consisted of ~500 seedlings to 5 cm height, and all adults were dead. The other, larger population consisted of over 10,000 seedlings spread out across ~150 ha, with a small number of adults surviving in sheltered areas. Main threat would be another fire before plants reach reproductive maturity.
Finger Hakea	*Hakea dactyloides*	100	Not assessed for this project
Brown Guinea-flower	*Hibbertia rufa*	82	Two populations searched for in sedgy woodland along Genoa Creek Track, Drummer SF, but were not found. Fire severity was high, but habitat looked wrong for this species. Additional surveys are needed to determine the impact of the fire.
Sour Currant-bush	*Leptomeria acida*	100	Not assessed for this project. VBA records did not meet dual criteria of accuracy and accessibility.
Drupe Bush	*Leptomeria drupacea*	100	Not assessed for this project. VBA records did not meet dual criteria of accuracy and accessibility.
Smooth Tea-tree	*Leptospermum glabrescens*	100	Not assessed for this project. VBA records did not meet dual criteria of accuracy and accessibility.
Stringybark Tea-tree	*Leptospermum jingera*	86	One population was searched for on a rocky slope in Mallee woodland near Brumby Point but was not found. Habitat looked wrong, and additional surveys are needed to determine the impact of the fire on this species. Risks to the site include feral Horse activity.
Prickly Mirbelia	*Mirbelia pungens*	100	Not assessed for this project. VBA records did not meet dual criteria of accuracy and accessibility.
Heathy Mirbelia	*Mirbelia rubiifolia*	100	One fenced population located within plot with star pickets in coastal heathland at Shipwreck Creek, Croajingalong NP. Fire severity was high, and most of the 50 plants were regenerating by resprouts ~6 cm high. Some seedlings were possibly present. Track work was identified as a potential threat. Seedlings at risk if another fire before plants reach reproductive maturity.
Trailing Monotoca	*Monotoca rotundifolia*	100	Four populations searched for on shale soils in Mallee woodland near Brumby Point, but only two were confidently found. Populations found (of 70 and 100 plants, respectively) were in unburnt patches, and no seedlings or resprouts were observed. Additional surveys are required to determine impacts of the fire.
Smooth Geebung	*Persoonia levis*	86	Three populations located in Banksia woodland off Point Hicks Road and Cicada Track, Croajingalong NP. Two sites were burnt at high severity, and populations each consisted of only two resprouting plants to 80 cm high. The other population was burnt at low severity and consisted of 10 plants (both seedlings and resprouts). Obvious threats were not observed but could include deer activity.
Buchan Pomaderris	*Pomaderris buchanensis*	100	Two populations located in rocky riparian scrub near Buchan. One population was unburnt and consisted of ~200 plants ~150 cm high (and in flower). The second population on a steep cliff in a severely burnt patch consisted of only four seedlings. Erosion was noted as a potential threat, along with high cover of weeds. Plant believed to resprout following low- to moderate-intensity fire, but seedlings at risk from another fire before plants reach reproductive maturity.
Sydney Pomaderris	*Pomaderris ledifolia*	100	Not assessed for this project. VBA records did not meet dual criteria of accuracy and accessibility.
Bent Pomaderris	*Pomaderris sericea*	100	Not assessed for this project. VBA records did not meet dual criteria of accuracy and accessibility.
Upright Pomaderris	*Pomaderris virgata*	100	Not assessed for this project
Clustered Poranthera	*Poranthera corymbosa*	88	One population searched for in forest along Bralak Road, Wingan River, but not found. Fire severity was high, but obvious threats at the site were not observed. Additional assessments needed to determine impact of the fire.

Common name	Scientific name	Percentage of VBA record locations impacted by high-severity fire	Localised impacts and reconnaissance status
Fragrant Leek-orchid	*Prasophyllum odoratum*	100	Four populations searched for along Bass Track, Croajingalong NP, but not found. Fire severity at the sites was low to moderate, and the main potential threat would be any road works. Additional surveys needed to ascertain impact of the fires.
Chinese Brake	*Pteris vittata*	100	Not assessed for this project. VBA records did not meet dual criteria of accuracy and accessibility.
Sharp Greenhood	*Pterostylis acuminata*	100	Two populations located in shrubby open forest near Mallacoota. Fire intensity had been high, but plants were resprouting from tubers, some in flower.
Coastal Greenhood	*Pterostylis alveata*	89	Two populations were located in shrubby open forest off Wangarabell Road, Wroxham. Fire severity was moderate, and the populations of up to 50 plants were resprouting from tubers, some in flower. No obvious threats noted.
Granite Greenhood	*Pterostylis tunstallii*	100	Five populations searched for in shrubby open forest between Bruthen and Mallacoota. Two populations in severely burnt area not found. The other three (one unburnt and two moderately burnt) were resprouting from tubers and were flowering.
Parris's Bush-pea	*Pultenaea parrisiae*	100	Not assessed for this project
Lilac Lily	*Schelhammera undulata*	81	Three populations located along Centre Track, Miners Track and Genoa River, Croajingalong NP. Fire severity was high, and plants were regenerating by resprouts ~5 cm high. Population size ranged from ~90 to 200 plants. No obvious threats observed, but the Centre Road population could potentially be at risk from road works.
Black Bog-sedge	*Schoenus melanostachys*	86	One population was searched for in Maramingo SF but was not found, despite low fire severity. No obvious threats noted at the site, but additional surveys are needed to determine the impact of the fire on this species.
Tree Triggerplant	*Stylidium laricifolium*	100	One population located in Banksia forest at Wingan Inlet. Fire severity was low, and ~100 plants were regenerating by seedlings and resprouts to 25 cm high. No obvious threats were observed.
Leafless Pink-bells	*Tetratheca subaphylla*	95	Four populations were searched for in forest near Mount Elizabeth, but only one population on rocky soils off Betts Creek Track was found. Fire severity was moderate, and ~50 plants were regenerating from basal resprouts ~20 cm high. Fire severity at the other sites was high, and there was dense regrowth. No obvious threats were noted.
Lobed Sun-orchid	*Thelymitra longiloba*	100	Three populations found in Banksia forest or wet heath: two off East Wingan Road and one off Sydenham Inlet Road. All populations had been burnt at high severity but were resprouting from tubers and flowering. Population size ranged from 10 to ~150 individuals. No obvious threats noted.
Snowy River Westringia	*Westringia cremnophila*	100	One population was located on a cliff face along the Snowy River. Despite the general area being burnt, the population of ~60 individuals was not burnt. However, many plants appeared heat stressed and were resprouting. Potential threats include erosion and deer.
Lemon Zieria	*Zieria citriodora*	100	Not assessed for this project. VBA records did not meet dual criteria of accuracy and accessibility.

NCR, Nature Conservation Reserve; NP, National Park; SF, State Forest.

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Mammals (and large forest owls)

Spot-tailed Quoll (*Dasyurus maculatus maculatus*) (photo: Andrew Geschke)

The following species were targeted for assessment, and reported on in the following sections:

2.1 Broad-toothed Rat

2.2 Spot-tailed Quoll

2.3 Arboreal mammals and large forest owls

2.1 Broad-toothed Rat

Prepared by Phoebe Macak (ARI) and Kevin Rowe (Museums Victoria)

Summary of bushfire impacts

The Broad-toothed Rat (*Mastacomys fuscus mordicus*) is a native rodent with a patchy distribution in Victoria, found in alpine grassland and heath, sub-alpine woodland, and riparian sedgeland within wet sclerophyll forest at lower altitudes. Surveys across the state conducted prior to the 2019–2020 bushfires found that Broad-toothed Rats were not detected from 53% of Victorian sites at which they had been recorded prior to 1990 (Shipway et al. 2020). Due to their apparent decline, the Broad-toothed Rat is listed as vulnerable in Victoria (*Flora and Fauna Guarantee Act 1988*). Of the species' modelled habitat in Victoria, 23% was within the fire extent, with 15% affected by high-severity fire. The catastrophic loss of habitat, and potentially populations, following the widescale 2019–2020 bushfires has increased concerns about the persistence of the Broad-toothed Rat in Victoria.

Summary of key findings

Feral herbivore impacts have increased due to higher activity in unburnt habitats and delay in recovery of burnt habitats.

Predation threat has increased due to the reduced area of unburnt habitat and the loss of cover in burnt habitat.

Habitat loss in burnt areas, particularly sub-alpine woodland and alpine grasslands/shrublands, is a key threat to the species in eastern Victoria.

The Broad-toothed Rat faces a potential loss of genetic diversity, exacerbated by habitat loss, reduced connectivity, and climate change.

Mount Hotham and surrounds

Broad-toothed Rats were found during targeted searches in 9 (69%) of 13 unburnt sub-alpine woodland and treeless alpine grassland/heathland sites within the study area. None were found at the 8 burnt sites searched.

It is likely that Broad-toothed Rat populations were affected by loss of habitat when sub-alpine woodland and treeless alpine grassland/heathland habitats were burnt in the 2019–2020 bushfires.

It is unknown whether Broad-toothed Rat populations were in forested habitat (e.g. wet forest) pre-fire. However, no suitable Broad-toothed Rat habitat was observed in forested locations post-fire within the fire boundary.

Sites outside the 2019–2020 burn area that had been burnt two to three times in the last 20 years during previous bushfires were structurally similar to recently burnt sites and generally contained no vegetation considered to be suitable Broad-toothed Rat habitat.

Eastern section of the Alpine National Park

Broad-toothed Rats persist in 16 (67%) of 24 unburnt sites surveyed (within the study area) where they had occurred in the last decade with suitable treeless alpine grassland, heathland, and peatland habitats.

Broad-toothed Rats persist in 4 (25%) of 16 burnt sites surveyed (within the study area) where they had occurred in the last decade with suitable treeless alpine grassland, heathland, and peatland habitats.

It is likely that Broad-toothed Rat populations were affected by loss of habitat when treeless alpine grassland, heathland, and peatland habitats were burnt in the 2019–2020 bushfires.

It is likely that persistence of Broad-toothed Rat populations in partially burnt and remaining unburnt habitat is threatened by the impacts of feral herbivores on habitat quality.

Background

The Broad-toothed Rat occurs in a range of environments, including wet forest, coastal and alpine grassland, woodland, and heathland, from the Otway Ranges through the Great Dividing Range to the alpine region.

Characteristics of Broad-toothed Rat habitat include a mean annual rainfall of greater than 1000 mm, and a dense ground layer of grasses, sedges and herbs (Menkhorst 1995). The Broad-toothed Rat is a specialist herbivore, feeding on a small number of plant species, especially grasses and sedges (Green et al. 2014).

The 2019–2020 bushfires potentially affected the higher-altitude habitat of Broad-toothed Rat in the Alps. Post-fire reconnaissance surveys focused on two broad areas: Mount Hotham and surrounds (south of and including the Mount Hotham Alpine Resort), and the eastern section of the Alpine National Park (Davies Plain, Native Dog Flat, Mount Cobberas, to Nunniong Plains and the surrounding areas).

Locations assessed

<u>*Mount Hotham and surrounds*</u> – The study area covered approximately 30 × 20 km and extended from the Mount Hotham Alpine Resort, encompassing an area south and south-west of Dinner Plain, including the Dargo High Plains to just west of Mount Murray on the border of the Alpine National Park (NP) and Tea Tree Range State Forest (SF) (Figure 2).

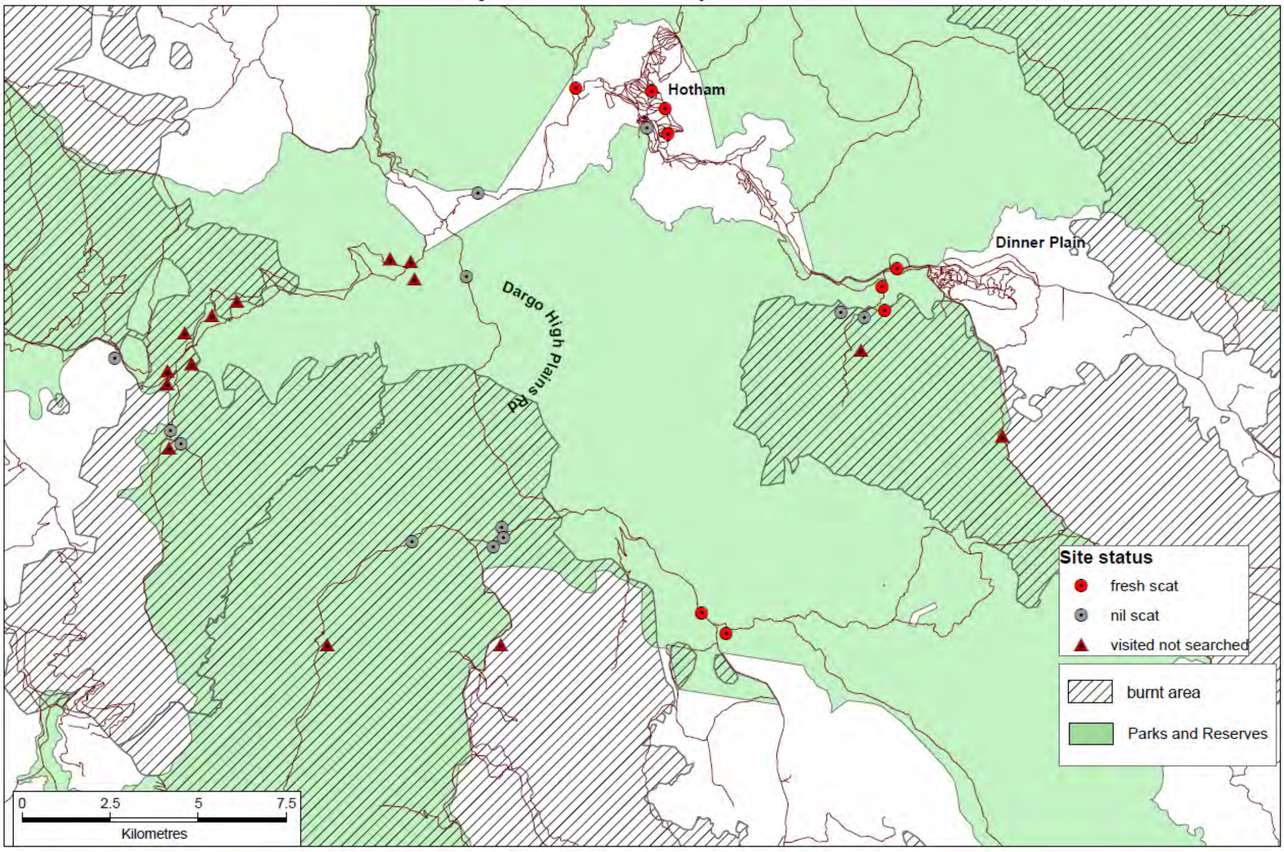

Figure 2. Study area for Broad-toothed Rat in the 2019–2020 post-fire reconnaissance surveys: Mount Hotham and surrounds

Site selection was based on revisiting previous Broad-toothed Rat record locations [from the Victorian Biodiversity Atlas (VBA 2021) and Deakin University] and new sites based on GIS spatial information regarding suitable habitat, topography, fire severity, presence of bogs, and aerial mapping (compiled by Deakin University). Some discretion in the field was used to select survey sites in likely habitat (e.g. wet grassland and heathland with a thick grassy groundcover and a dense low shrub layer). Thirty-five sites were selected in both burnt (2019–2020) and unburnt areas across a range of Ecological Vegetation Communities (EVCs), including Sub-alpine Woodland, Sub-alpine Wet Heathland and Montane Damp Forest.

<u>*Eastern section of the Alpine National Park and surrounds*</u> – The 40 sites visited in the eastern section of the Alpine NP Broad-toothed Rat habitat were distributed over an area of approximately 35 × 60 km north and east of Omeo, Victoria (Figure 3). The sites extended from Donovans Creek in the northwest, to Davies Plain in the northeast, and to the Nunniong Plains in the south. Active searches at these 40 sites covered approximately 80 ha of the suitable habitat for Broad-toothed Rat in the area.

Site selection was based on previous Broad-toothed Rat records (from the VBA 2021, Global Biodiversity Information Facility, Museums Victoria and Deakin University) and GIS spatial information on suitable habitat, topography, fire severity, presence of bogs and aerial mapping (compiled by Museums Victoria and Deakin University). Additional sites were also selected in the field where suitable habitat was observed.

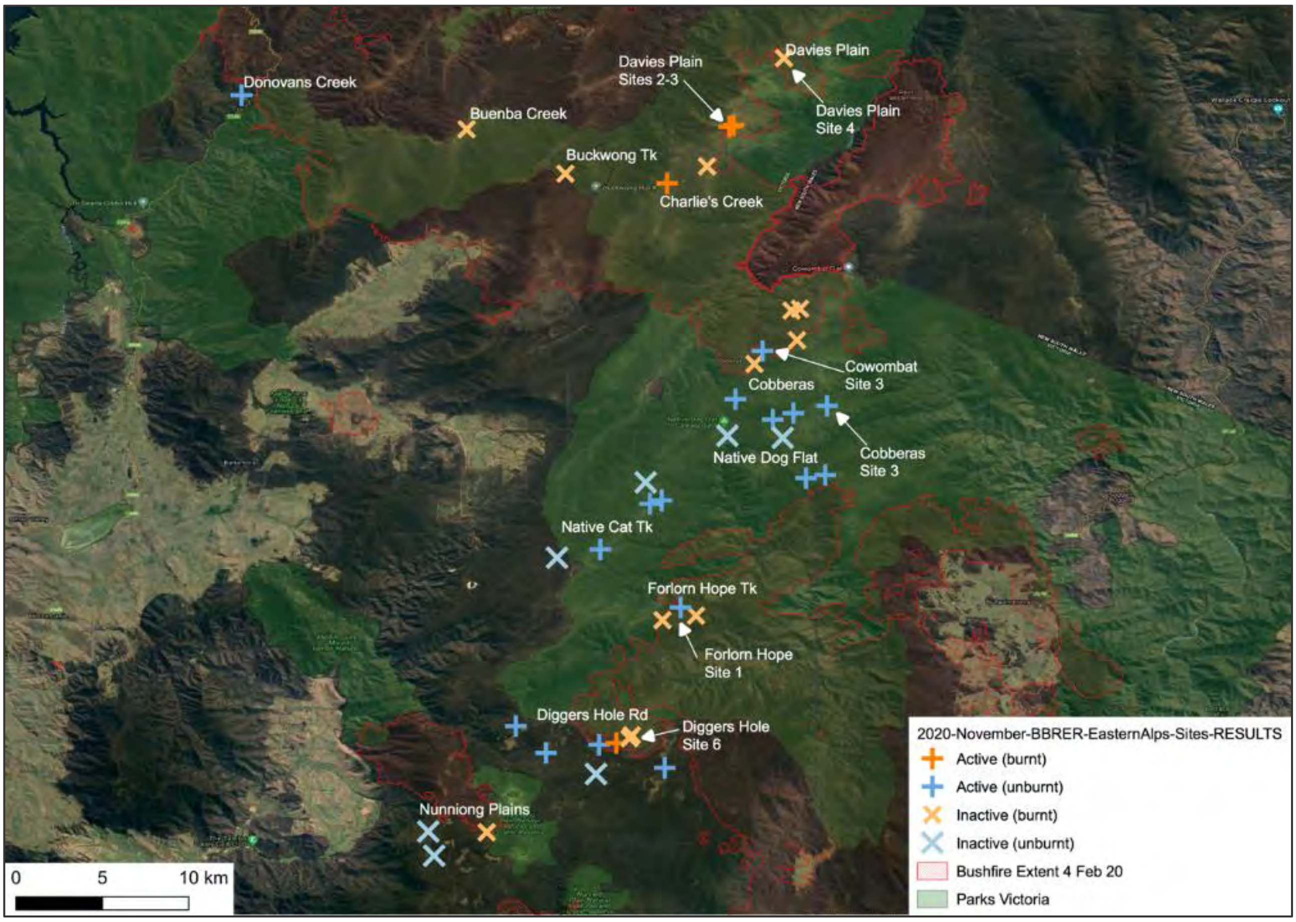

Figure 3. Study area for Broad-Toothed Rat in the 2019–2020 post-fire reconnaissance surveys: eastern section of Alpine National Park and surrounds

Survey methods

<u>*Scat surveys (both study areas)*</u> **–** Survey methods for Broad-toothed Rat were developed in collaboration with Museums Victoria and Deakin University to ensure data were collected consistently throughout the range. A site was deemed active if fresh Broad-toothed Rat scats (faecal pellets) were present, which are characteristically bright green and fibrous (Happold 1989; Figure 4) due to the species' grass-and-sedge–based diet. Active Broad-toothed Rat occurrence was also assumed for sites at which both old scats were identified, and fresh grass clippings were observed in distinct runways. Old Broad-toothed Rat scats, which can persist for up to 5 years (Happold 1989), are readily identified by being characteristically pale yellow to white, fibrous, and often occurring in clusters. The presence of only old scats (without fresh clippings) was used to categorise a site as inactive. Old scats could also be identifiable as being burnt (i.e. deposited prior to the 2019–2020 bushfires). Clippings or runways without identifiable Broad-toothed Rat scats were not counted as detections of Broad-toothed Rat occurrence.

The most suitable habitat at each site was targeted for searches. Observers looked for runways consisting of narrow tracks of flattened groundcover vegetation. If found, these runways were followed as far as possible and searched for scats and signs of fresh clippings. Scats were identified as fresh or old, as described above. Searches were conducted for up to 10 minutes, with a maximum of six searches per site. Timed searches were halted if fresh Broad-toothed Rat scats were found. Two or three observers searched each site simultaneously, with two or three timed searches being conducted per observer.

Figure 4. Fresh, green Broad-toothed Rat scats found at an unburnt site during a survey near Dinner Plain (photo: Phoebe Macak)

Activity and vegetation transects (eastern section of the Alpine National Park and surrounds only) **–** To estimate Broad-toothed Rat abundance and to assess vegetation structure and feral herbivore impacts at each site, 100-m-long transects were installed in collaboration with Museums Victoria and Deakin University. Scat surveys were used to determine the position of transects in suitable habitat. Where fresh or old Broad-toothed Rat scats were detected, transects were positioned to intersect with the locations containing the greatest number of fresh scats or the most abundant scats (in cases where only old scats were detected). Where scats were not detected after six 10-minute searches, transects were positioned in the most suitable and representative habitat. Data were collected at 2-m intervals along the transect, starting at 2 m, using a 100-m tape. Thus, 50 data points were collected for each transect. At each transect point, data were collected on vegetation structure, herbivore activity, and occurrence of Broad-toothed Rat. Vegetation structure was assessed using a 2-m structure pole to record the height of all vegetative life forms. Within a 1-m radius of each transect point, a search for Broad-toothed Rat scats was conducted, the scats being categorised as fresh or old. Broad-toothed Rat abundance was estimated as the percentage of survey points along the transect with detection of Broad-toothed Rat scats. Also recorded were deer and rabbit scats within the same radius. At each transect point, the presence of feral herbivore activity within 4 m either side of the tape was recorded. This was based on signs of trampling/pugging, browsing/grazing, turf compaction, Pig-diggings, tracks, counts of Horse dung piles, and weeds. For this report, a herbivore activity score was calculated as the sum of the proportion of transect points with signs of trampling/pugging, browsing/grazing, turf compaction, and tracks. For the entire transect (8 x 100 m), the percentage of area covered by (1) burnt habitat, (2) each life form, (3) exotic/native plant species and (4) bare ground was estimated. At burnt sites, fire severity was estimated by measuring the tip diameter of three burnt branches from five shrubs along the transect, where greater diameters indicate higher severity burns. Additional analyses of these and other transect data from Deakin University are being undertaken as part of a separate project.

Although not part of this report, each of these sites will be revisited to estimate accumulation of feral impacts, changes in vegetation structure, and Broad-toothed Rat activity. Wildlife cameras deployed at these transects to estimate feral predator abundance will be retrieved in late 2021. At the time of writing this report, only the transects in the eastern section of the Alpine NP had been completed, but extra transects at sites on

Mount Hotham and surrounds and in the west of the state will be completed by mid-2021 in the context of other projects.

Results

Mount Hotham and surrounds

Thirty-five sites were visited and assessed for suitable survey habitat during the study: 17 in unburnt areas and 18 in areas burnt in the 2019–2020 bushfires. Fourteen of these sites were deemed not suitable habitat for Broad-toothed Rat, so were not searched further. Active searches were carried out at 13 unburnt and 8 burnt sites, with the presence of Broad-toothed Rats (fresh scats) confirmed at 9 unburnt sites (Figure 4), but none were found at burnt sites (Table 3, Figure 4). Fresh Broad-toothed Rat scats were found in either Snow Gum (*Eucalyptus pauciflora*) woodland or treeless grassy heathland (Figure 5), which comprised a thick groundcover (including graminoids such as *Poa, Dianella* spp.) and a dense low shrub layer [e.g. Alpine Podolobium (*Podolobium alpestre*), Leafy Bossiaea (*Bossiaea foliosa*)]. The one unburnt site that was in Montane Dry Woodland included a localised area of very thick tussocky grass along a creekline in which runways were present; however, no scats were detected.

Table 3. The number of sites visited, and the number that were searched for Broad-toothed Rat scats within the Mount Hotham and surrounds study area, 9–14 December 2020

Sites	Unburnt	Burnt
Searched	13	8
Fresh Broad-toothed Rat scats found	9	0
No fresh Broad-toothed Rat scats found	4	8
Not searched	4	10
Total number visited	17	18

All burnt sites were similar in terms of understorey vegetation: sparse grassy regrowth, sometimes with scattered burnt (dead) shrubs. Most of the sites selected in Montane Dry Forest and Montane Damp Forest EVCs were in burnt areas. There was only one Broad-toothed Rat record pre-dating the 2019–2020 fires (1997) located in Sub-alpine Woodland within the study area (Figure 6). Broad-toothed Rats were not detected at this site, nor were they detected within an adjacent small patch of unburnt habitat. This unburnt site, and several other Sub-alpine Woodland sites that were not burnt in 2019–2020, have burnt two to three times in the last 20 years during bushfires in 2003, 2006 and 2013. These sites were structurally similar to recently burnt sites, with a very sparse understorey and ground layer. Generally, burnt sites contained no vegetation considered suitable Broad-toothed Rat habitat.

Figure 5. This site on Dargo Plain exemplifies treeless grassy heathland habitat in which fresh Broad-toothed Rat scats were found (photo: Phoebe Macak).

Mount Hotham Alpine Resort appears to be a key area for Broad-toothed Rats, particularly within the dense native vegetation between the ski runs, where there were numerous records from 2017 (Megan Taylor, pers. comm.). Fresh scats were found at four sites within the resort during the current survey, with three of those being adjacent to ski runs. More populations likely occur in the broader area where there is suitable woodland, heathland and grassland habitat (e.g. near Dinner Plain and Dargo Plain).

The presence of deer was apparent at most sites; in places there was severe damage (many droppings, widespread signs of grazing and bogging) and in others little evidence of damage. High-value Broad-toothed Rat sites identified here should be considered for intensive deer control activities. In burnt sites, there was almost no vegetation cover that would provide protection from introduced predators such as the Red Fox (*Vulpes vulpes*).

Figure 6. This site near Mount Murray at the western edge of the Mount Hotham and surrounds study area was searched for Broad-toothed Rat scats. The area had been burnt in the 2019–2020 bushfires and several times previously. The Broad-toothed Rat had been recorded here in 1997, but no scats were found in the current survey (photo: Phoebe Macak).

Eastern section of the Alpine National Park and surrounds

Searches for Broad-toothed Rat scats were conducted at 40 sites (Figure 3): 23 in unburnt areas and 17 in areas burnt in the 2019–2020 bushfires. Burnt sites ranged in burn coverage from 5 to 100% (mean 73%), with average diameters of shrub tips (an estimate of fire severity) ranging from 1.43 to 9.03 mm (mean 3.72 mm). All but one of the sites, the lower-elevation grassy riparian site, Donovan Creek (Figure 3), were in treeless alpine grassland, heathland, or peatland habitats. These habitats exist primarily as islands in the forest matrix, with connectivity along drainages. Active signs of Broad-toothed Rats (fresh scats/clippings) were detected at 16 unburnt and 4 burnt sites (Table 4; Figure 3). Inactive signs of Broad-toothed Rats (old scats) were detected at 6 unburnt and 12 burnt sites. No Broad-toothed Rat scats (fresh or old) were detected at 5 of the sites (2 burnt, 3 unburnt) at which the species was last reported between 2014 and 2017. Sites with active signs of Broad-toothed Rats typically contained a dense cover of mature shrubs and a dense cover of grasses and sedges. Notably, Broad-toothed Rats were not detected at sites without shrubs, even if there was a dense cover of grasses and sedges.

The results of the vegetation and activity transects revealed a wide range of Broad-toothed Rat abundance among sites, as measured by the percentage of points along the transect with a detection of Broad-toothed Rat scats (fresh or old) within 1 m of the transect. Unsurprisingly, active Broad-toothed Rat sites had on average higher densities of scats, whether unburnt (mean = 38% of transect points) or burnt (mean = 29%), than inactive Broad-toothed Rat sites (Figure 7). However, scat densities were higher at inactive burnt sites (mean = 14%) than at inactive unburnt sites (mean = 3%), reflecting the loss of recently suitable habitat due to the 2019–2020 bushfires. The three inactive burnt sites with the highest densities of old scats had similar or higher densities than the mean density of active sites. These sites are identified in Figure 3 and include Davies Plain Site 4 (28%), Forlorn Hope Site 1 (36%) and Diggers Hole Site 6 (48%). The data from these sites reflect the impacts of the 2019–2020 bushfires on previously abundant Broad-toothed Rat populations.

It appears that the 2019–2020 bushfires have exacerbated existing threats to and impacts on Broad-toothed Rats, resulting in further decline of Broad-toothed Rats in the study area. No sign of recent Broad-toothed Rat activity was detected at 30% of unburnt sites, despite detection of Broad-toothed Rats at those sites within the past decade. The impacts of Horse (*Equus caballus*) and deer were apparent at almost every site, with severe impacts at many sites, such as widespread signs of turf compaction, grazing, trampling/pugging and high counts of dung piles, all of which indicated a significant ongoing presence of these introduced herbivores. Furthermore, Pig (*Sus scrofa*) diggings were observed at approximately 20% of sites. Most sites with active Broad-toothed Rat signs contained dense thickets of shrubs that may limit penetration by large herbivores. Across the 100-m transects, inactive sites in unburnt areas had considerably greater herbivore activity, as measured by the proportion of transect points with evidence of trampling/pugging, grazing/browsing, turf compaction, and tracks (Figure 8). In contrast, most inactive sites in burnt areas revealed levels of herbivore activity that were similar to those at active sites, either burnt or unburnt. The exception, Buenba Creek, was a heavily grazed site with extensive soil compaction that may not have provided habitat for Broad-toothed Rat at the time of the fires and was one of five sites without detection of old Broad-toothed Rat scats.

Table 4. Occurrence (active or inactive) of Broad-toothed Rat at burnt and unburnt sites as identified by scat searches within the eastern section of the Alpine National Park and surrounds study area during 9–26 November 2020 (includes three sites in Nunniong Plains without Broad-toothed Rat detections that were searched in May 2020). Broad-toothed Rat occurred at all sites within the last decade, so occurrence is reported as active or inactive.

Sites	Unburnt	Burnt
Total searched	23	17
Active Broad-toothed Rat site (fresh scats/clippings)	16	4
Inactive Broad-toothed Rat site (old scats only)	4	11
Inactive Broad-toothed Rat site (no scats)	3	2

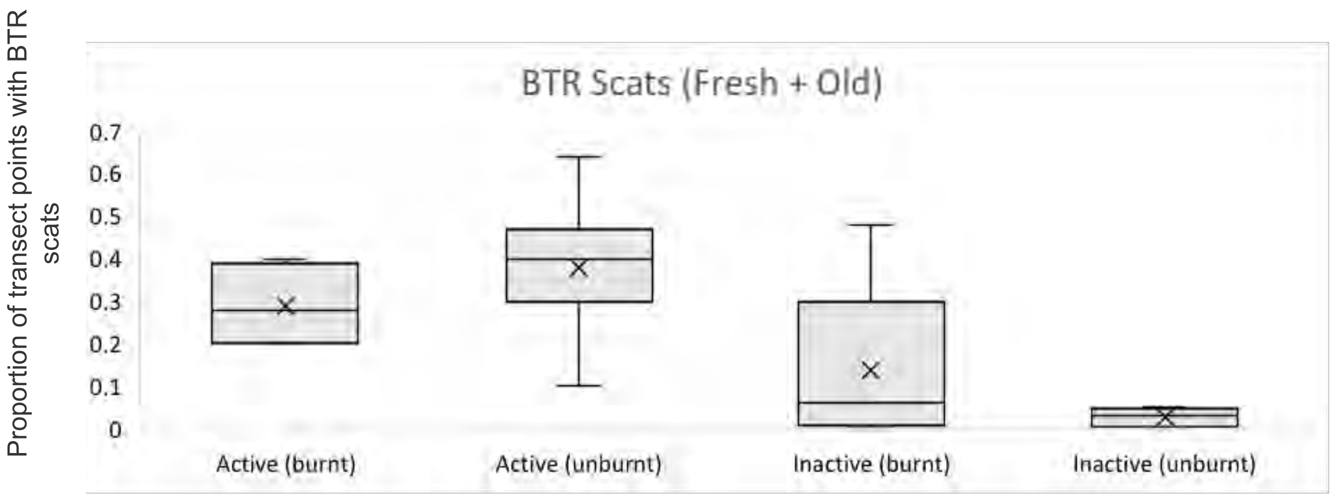

Figure 7. Box-and-whisker plots of densities of Broad-toothed Rat (BTR) scats (active = fresh scats; inactive = old scats) along 100 m transects in active and inactive sites, split into burnt sites and unburnt sites

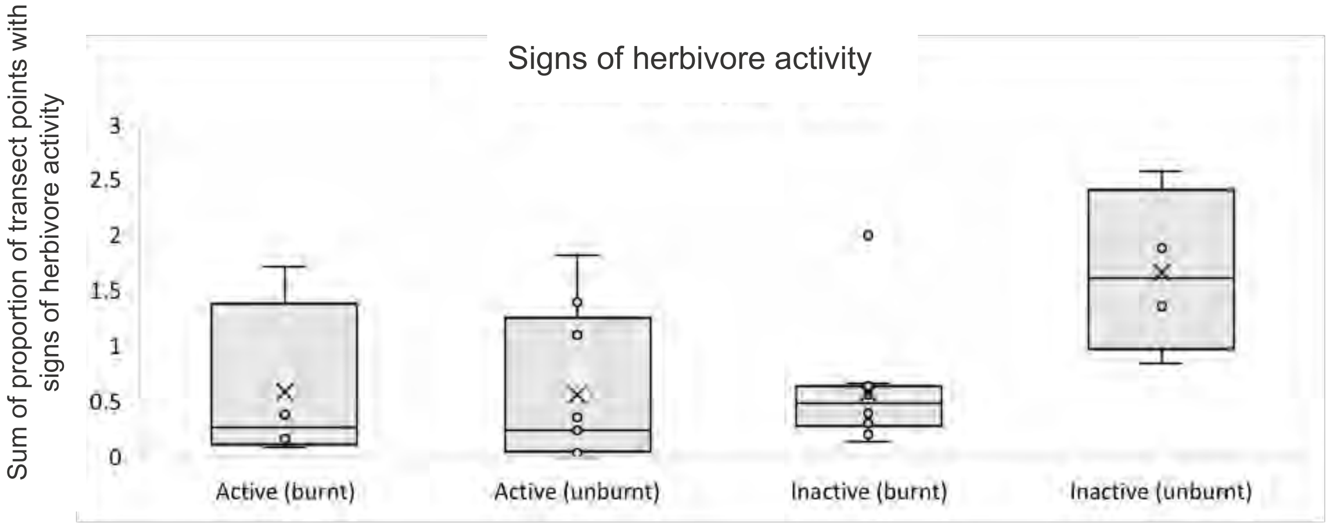

Figure 8. Box-and-whisker plots of herbivore activity scores along 100-m transects in active (fresh scats) and inactive (old scats) sites split into burnt sites and unburnt sites. Herbivore activity was measured by presence of trampling/pugging, browsing/grazing, soil/turf compaction, and tracks

Two sites contained exclusion fencing and had substantially improved grass and shrub cover, with reduced soil compaction and other noticeable impacts. At Native Cat Track Site 5, there were small experimental plots that did not appear to support Broad-toothed Rats (Figure 9). At Cobberas Site 3, abundant and active signs of Broad-toothed Rats were detected by walking the perimeter fence (Figure 10).

In burnt sites, there was almost no vegetation cover that would provide protection from predators.

This study revealed three key areas for Broad-toothed Rat populations in relation to the impacts of the 2019–2020 bushfires in the eastern section of the Alpine NP and surrounds. Two main arms of the bushfires, a northern and a southern arm, covered large portions of suitable Broad-toothed Rat habitat and known populations. The third area, lying between the two main arms of the bushfires, extends from the Cobberas through Native Dog Flat and along Native Cat Track, and was largely unaffected by the fires. This area has key populations of Broad-toothed Rats. However, the impact of Horses in these areas is substantial and is a probable cause for the absence of Broad-toothed Rats at the four unburnt sites where they are no longer active. Herbivore exclusion fencing at Cobberas Site 3 and Native Cat Track Site 5 demonstrates the effectiveness of this method for improving Broad-toothed Rat habitat, especially at Cobberas Site 3, where abundant Broad-toothed Rat activity was detected by walking the perimeter fence. Fire impact was more limited around the Nunniong Plains area, with one Broad-toothed Rat site being partially burnt, and the other two sites being unburnt. Nevertheless, neither active nor inactive signs of Broad-toothed Rats were detected at any of the three sites in the area, suggesting that the impacts of the fire were less obvious than other impacts, such as those from feral herbivores, which were abundant in the area.

The northern arm of the bushfires burnt most sites (11 of 14) from Donovans Creek to Davies Plain and south to Cowombat Flat Track at the northern edge of the Cobberas (Figure 3). Within this burn scar, eight Broad-toothed Rat sites are now inactive, and only three sites within the scar sustain active Broad-toothed Rat populations. Along Cowombat Flat Track, the two sites just outside the margin of the fire retain active Broad-toothed Rat populations, whereas the three burnt sites are now inactive. Within the burn scar, Charlies Creek retains a small number of individuals in isolated unburnt shrubs in the riparian peatland shrub habitat near the campground (Figure 11). Little habitat is left along the creek for more than 100 m downstream, where Broad-toothed Rats would likely have existed in high abundances before the bushfires. Two adjacent peatland sites along Davies Plain Track also have signs of post-fire Broad-toothed Rat activity within the fire extent. The larger of these two sites extends for almost a kilometre to the east of the track and remains largely unburnt, despite fires all around its margins. Abundant inactive signs of Broad-toothed Rat (old scats) were detected in the area, but some limited signs of recent activity in the form of fresh grass clippings in runways were detected, primarily in shrubs at the margin of the peatland. Davies Plain represents an extensive area (~35 ha) of once-prime habitat for Broad-toothed Rats from which the species appears to have disappeared since the bushfires (Figure 12).

Figure 9. Herbivore exclusion fence on Native Cat Track Site 5, showing the strong contrast between the trampled and compacted soil outside the fence and regenerating vegetation within the fence (photo: Museums Victoria)

Figure 10. Herbivore exclusion fence on Cobberas Site 3, where abundant signs of Broad-toothed Rat runways and scats were detected emerging from the protected habitat inside the fence (photo: Museums Victoria)

Figure 11. Burnt Broad-toothed Rat habitat along transect at Charlies Creek. Inset shows a fresh Broad-toothed Rat scat collected at the site (photo: Museums Victoria).

Figure 12. Burnt habitat along transect on Davies Plain Site 4. No signs of active Broad-toothed Rats were detected in the area, but inactive signs of Broad-toothed Rats were common (photo: Museums Victoria).

The southern arm of the fire affected Broad-toothed Rat populations from Forlorn Hope Track to Diggers Hole Road (Figure 3). A complex of three peatland shrub sites on Forlorn Hope Track demonstrated the impact of the bushfires and the persistent threats of feral herbivores. Forlorn Hope sites 1 and 2 burnt entirely, and had abundant signs of burnt and old Broad-toothed Rat scats, but no active signs of Broad-toothed Rats (Figure 13). Forlorn Hope Site 3 (Figure 14) was unburnt and maintains one of the most abundant active populations of Broad-toothed Rats in the study area (44% of transect points with fresh Broad-toothed Rat scats). Horse, deer and wild Dogs (*Canis familiaris*) were encountered at this site, which had the highest herbivore activity score of any active unburnt site (1.82) and among the highest of any site (mean for all sites = 0.74). This high score is consistent with the expected concentration and increased activity of feral herbivores at unburnt sites adjacent to burnt areas. Feral herbivore control measures in the area have removed some individual Horses, but Horses are still abundant.

A second complex of four peatland shrub sites near Diggers Hole Road (Sites 4–7) and connected by Blue Shirt Creek is a prime example of connected habitats in which recovery of burnt sites depends on protection of unburnt and partially burnt sites (Figure 15). A Specific Needs analysis was carried out for Broad-toothed Rats, using these sites as an example to assess the need for feral predator control, feral herbivore control, exclusion fences, and artificial refugia. One site was completely burnt, two were partially burnt, and the fourth was unburnt by the bushfires. The first site, Diggers Hole Site 7 (Figure 16), provided extensive (>5 ha) prime peatland shrub habitat for Broad-toothed Rats prior to the bushfires and had the second-highest number of Broad-toothed Rat detections of any site (48% of transect points). The bushfires burnt 100% of the site area, and the only signs of Broad-toothed Rats were burnt runways and scats. Extensive searches in the area—including an adjacent partially burnt site, Diggers Hole Site 6, and along Blue Shirt Creek to the intersection with Diggers Hole Road—failed to reveal any signs of active Broad-toothed Rats in the area in November 2020. In May 2020, a single active Broad-toothed Rat runway was detected at Diggers Hole Site 6 that is now inactive. Upstream (west) along Blue Shirt Creek, over 90% of Diggers Hole Site 5 was burnt, but a few patches of shrubs persisted with active signs of Broad-toothed Rats, especially close to the creek. The signs of herbivore activity at the site (1.74 activity score) are the highest of any of the active burnt sites and are among the highest for any site (mean for all sites = 0.74). Further upstream (west) along Blue Shirt Creek, Diggers Hole Site 4 lies outside the 2019–2020 bushfire extent. Here, signs of Broad-toothed Rat activity were high (40% of transect points), and signs of feral herbivore activity although present were comparatively low (0.36), most likely because of the dense shrub cover.

Figure 13. Burnt habitat along transect at Forlorn Hope Site 1 (photo: Museums Victoria)

Figure 14. Unburnt habitat at Forlorn Hope Site 3, which had abundant signs of active Broad-toothed Rats but heavy impacts of feral herbivores (photo: Museums Victoria)

Figure 15. Complex of four sites along Blue Shirt Creek near Diggers Hole Road (photo: Museums Victoria)

Figure 16. Diggers Hole Site 7 along Blue Shirt Creek, showing severe burn and old burnt runways previously occupied by Broad-toothed Rats (photo: Museums Victoria)

Risks

Pre-existing risks (i.e. before the bushfires)

Feral herbivores, in particular horses, deer and pigs, are a primary threat to the suitability of habitat for Broad-toothed Rats, through trampling/pugging, soil/turf compaction, browsing, grazing, and digging (Cherubin et al. 2019). The impacts of feral herbivores on vegetation structure and Broad-toothed Rat abundance at sites in alpine environments were obvious, when compared with exclusion fencing plots from which these herbivores had been excluded. In eastern alpine areas of the Alpine NP, Broad-toothed Rats may have already retreated to areas of dense shrub thickets that provide temporary refuge from the impacts of feral herbivores.

Broad-toothed Rats are also vulnerable to predation by introduced species, such as red foxes, dogs and cats (*Felis catus*) (Woinarski et al. 2014). Inappropriate fire regimes may remove or simplify the structure of vegetation close to the ground (Vic SAC 2012), which would otherwise typically provide some cover from predators.

Climate change is predicted to affect Broad-toothed Rats by reducing the extent and connectivity of habitat, and possibly by increasing competition with other species (Green et al. 2008; Shipway et al. 2020).

Lastly, the highly disjunct nature of Broad-toothed Rat distribution across its Victorian range increases its vulnerability to these risks and may lead to further genetic isolation (Kriesner et al. 2020).

Additional risks driven by the 2019–2020 bushfires

Inappropriate fire regimes appear to increase the density of feral herbivores at unburnt sites, reducing the capacity for burnt areas to be recolonised by Broad-toothed Rats from adjacent unburnt sites. Additional threats due to the 2019–2020 fires include:

Increased feral herbivore impacts due to increased activity in unburnt habitats and delay in recovery of burnt habitats

Increased predation threat due to reduced area of unburnt habitat and loss of cover in burnt habitat

Loss of habitat in burnt areas, particularly sub-alpine woodland and alpine grasslands/shrublands or where habitat has not recovered from previous fires

Potential loss of genetic diversity, exacerbated by habitat loss, reduced connectivity and climate change.

Future directions

DELWP's decision-support tool, Strategic Management Prospects (SMP), indicates that broadscale landscape actions such as broadscale herbivore and predator control are likely to assist a broad suite of species such as the Broad-toothed Rat. In addition, Specific Needs analysis has also been carried out for Broad-toothed Rat at the sites along Blue Shirt Creek (Diggers Hole Sites 4–7) as examples of bushfire recovery and connectivity of sites. Several actions were identified for consideration, including targeted control of introduced herbivores and predators, predator and herbivore exclusion fencing, and the installation of artificial refuges from predators in situations where Broad-toothed Rat populations were found to persist in patches of unburnt habitat within fire-affected areas.

Priority actions identified for consideration within DELWP's decision-support tools are as follows:

Feral herbivore control

> Landscape-level, broadscale herbivore control guided by SMP is likely to benefit Broad-toothed Rat populations. Intensified control and suppression may be required to support populations in the eastern section of the Alpine NP. In some localised cases, broadscale suppression may not be sufficient to support Broad-toothed Rat populations, and exclusion fencing may need to be considered as an intensified action. In this study, it was observed that exclusion fencing in the eastern section of the Alpine NP may increase the probability of Broad-toothed Rat persistence at unburnt and partially burnt sites, as well as support the recovery and connectivity of burnt habitats. Exclusion fencing may be a priority action for consideration at the following sites in the eastern section of the Alpine NP and surrounds: (1) Charlies Creek, (2) Forlorn Hope Site 3, (3) Diggers Hole Site 4, (4) Diggers Hole site 5 and (5) Cowombat Site 3.

Feral predator control

> Predator control actions should be considered at partially burnt sites that sustain active Broad-toothed Rat populations, which may require actions beyond broadscale predator control at a landscape level. In the eastern section of the Alpine NP and surrounds, priority sites to be considered for predator management include (1) Charlies Creek, (2) Diggers Hole Site 5 and (3) Davies Plain Sites 2 and 3.

Acknowledgements

Survey methods and approach were developed and informed in collaboration with Deakin University (Zac Walker). Hotham Alpine Resort staff (Georgina Boardman, Aviya Naccarella and Bev Lawrence) provided locality information and ensured access to vegetation alongside ski runs. Megan Taylor (Deakin University) kindly provided the Broad-toothed Rat record locations confirmed during her 2017 Honours study.

Broad-toothed Rat surveys were conducted by Phoebe Macak and Amanda Bush (ARI), Kevin Rowe, Amy Adams and Mohammed Nizar (Museums Victoria), and Zac Walker (Deakin University).

This project was funded by the Australian Government Bushfire Recovery Package for Wildlife and Their Habitat.

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2.2 Spot-tailed Quoll

Prepared by Willow Bourke (FFR Gippsland)

Summary of bushfire impacts

The Spot-tailed Quoll (*Dasyurus maculatus maculatus*) is a carnivorous marsupial found in forest and woodland areas in south-eastern Australia. Spot-tailed Quolls have declined markedly in distribution and abundance since European settlement, and populations have become isolated and fragmented (DELWP 2016).

The Spot-tailed Quoll is listed nationally as endangered under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* and threatened under Victoria's *Flora and Fauna Guarantee Act 1988*.

Just over 40% of modelled Spot-tailed Quoll habitat in Victoria was burnt in the 2019–2020 bushfires. Fifty-seven percent of modelled Spot-tailed Quoll habitat in the Gippsland region was burnt, including parts of the upper Snowy River and tributaries, which is currently the stronghold for the species in Victoria (DELWP 2016).

Summary of key findings

The 2019–2020 bushfires affected 41 of 104 sites chosen for this study. Retrospective analysis of site photos indicates that, of the 41 burnt sites, 33 of these experienced medium- to high-severity fire (i.e. canopy scorched or burnt).

Spot-tailed Quolls were detected at only 2 of 104 sites surveyed in 2020, in the Alpine National Park (NP), north-east of Wulgulmerang East near the New South Wales border (both unburnt). Based on the spot patterns observed on the quolls, it is thought that three individuals were present.

The results from previous surveys in 2009, 2016 and 2017 are not directly comparable with those from the 2020 survey, as several known sites were not accessible in 2020 due to wet weather and snow. This was due to the late timing of the 2020 survey (August), compared with 2017 and 2016 (May).

Pest vertebrate species were frequently detected on cameras, including Cat (*Felis catus*), Red Fox (*Vulpes vulpes*), Pig (*Sus scrofa*), European Rabbit (*Oryctolagus cuniculus*), Horse (*Equus caballus*), and Sambar Deer (*Cervus unicolor*).

Surveys identified a number of key threats, including increased competition for prey and possibly increased predation from introduced predators such as Foxes and Cats, as these species are likely to recover from the direct impacts of the fire more quickly than the Spot-tailed Quoll.

Loss of habitat for small- to medium-sized mammalian prey may lead to reduced resources for the Spot-tailed Quoll.

Loss of individual Spot-tailed Quolls due to the direct impacts of the fire are likely to lead to further contraction of the population.

Background

Historically, the Spot-tailed Quoll had a broad distribution in southern, central, eastern and north-eastern Victoria, at altitudes ranging from sea level to at least 1100 m a.s.l. (Backhouse 2003).

The majority of recent Spot-tailed Quoll records in Victoria (since 1990) originate from East Gippsland, particularly the upper Snowy River and tributaries, which is considered the stronghold of the species in Victoria [(DELWP 2016, 2021 (VBA)].

Recent targeted surveys in parts of their current Victorian range, together with a substantial decline in reporting rates over the past two decades (Mansergh 1995; Nelson 2007; DELWP 2021), indicate that Spot-tailed Quolls are continuing to decline and now occur at extremely low densities.

Nelson et al. (2010) surveyed 129 sites across the Upper Snowy area in 2009, and this study was repeated in 2017 (Bluff, unpubl. data). A similar study was carried out in 2016 (Bluff, unpubl. data) across 100 sites close to the Victoria – New South Wales (NSW) border either side of the Snowy River.

A significant period of drought in recent years, followed by the widespread bushfires in 2019–2020 across East Gippsland, as well as extensive fires over the last two decades, combined with ongoing competition from, and possible predation by, introduced predators has led to concerns about the persistence of the Spot-tailed Quoll in East Gippsland.

Methods

Locations surveyed

The study area (Figure 17) was in the Upper Snowy River area, mainly in the Alpine NP and Snowy River NP, between Bonang, Gelantipy and the Cobberas.

Camera trap surveys carried out in 2020 focused on a subset of sites from the 2009, 2016 and 2017 studies (104 sites), based on previous detections of Spot-tailed Quoll and accessibility. Overall, Spot-tailed Quolls had been detected at 22 of the 104 sites surveyed between 2009 and 2017. Forty-one of the 104 sites were fire-affected. Surveying the full extent of the target area (i.e. Cobberas and Tingaringy) was not achievable due to time and weather constraints.

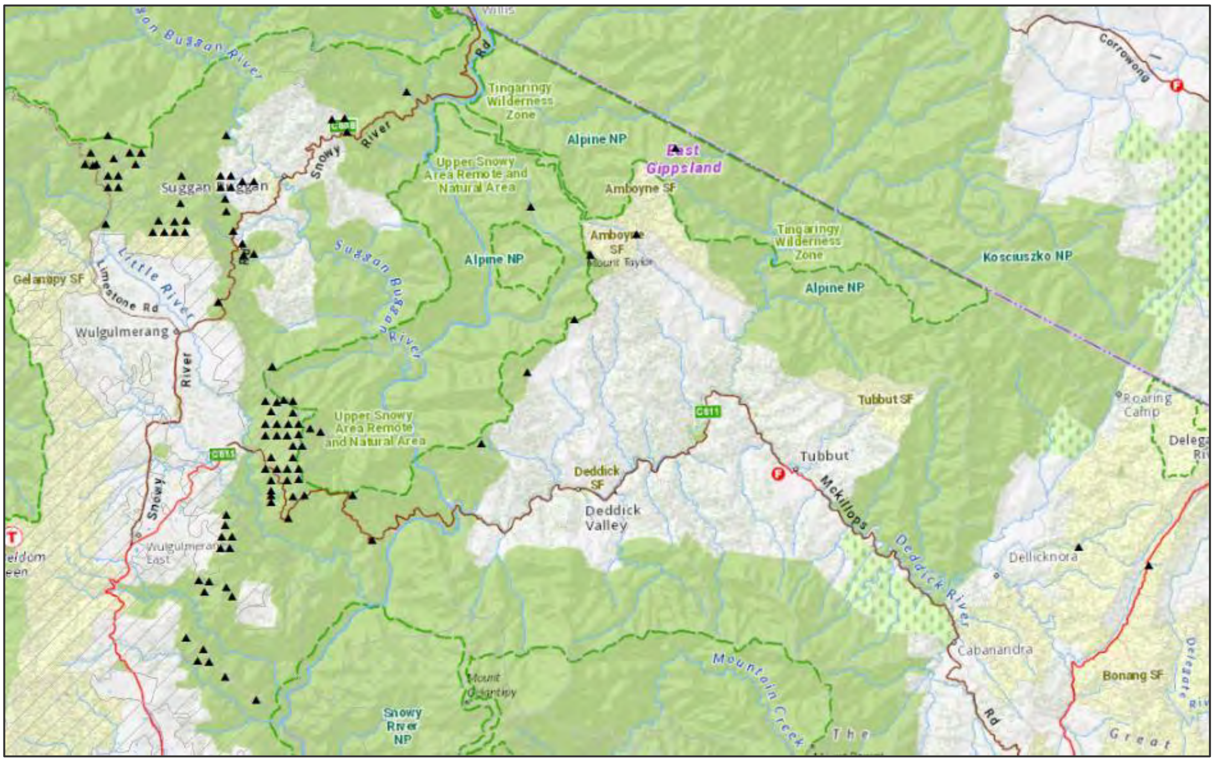

Figure 17. Spot-tailed Quoll survey sites for 2020 (black triangles): Upper Snowy River and the Alpine National Park

Survey methods

At each site, one camera was attached to a tree base, facing due south, at a height of 0.5 m from the ground. Four camera models were used (Reconyx HC500, HC600, HP2W and HF2X), with the model of camera randomly selected for deployment at each site. The lure comprised chicken necks, pilchards and tuna oil in a vented PVC tube, cable-tied to the top of a wooden post at a height of 0.6–0.8 m. The horizontal distance between camera and post was 2.5 m (extended to 3 m as needed to drive the post into the ground).

Camera settings were set to capture five images per trigger, with a 1-second interval between images, a quiet period of 30 seconds, continuous activity (day and night) and high sensitivity. Cameras were deployed between 4 August 2020 and 10 September 2020 and remained on site for a minimum of 27 nights.

Images were identified following established guidelines and tagged in the program ‘ExifPro’. Metadata was extracted in the program ‘ExifTool’ following DELWP Gippsland Natural Environment Programs protocols.

Results

Spot-tailed Quoll detections

Spot-tailed Quoll were detected at only 2 of 104 sites (Table 5), both of which were in the Alpine NP, north-east of Wulgulmerang East near the NSW border (and both were unburnt sites). Based on the spot patterns observed on the quolls, it is thought that three individuals were present.

Table 5. Comparison of the proportion of sampling sites where Spot-tailed Quolls were recorded in surveys from 2009 to 2020

Year	Number of sites sampled	Number (and percentage) of sites where Spot-tailed Quoll were detected
2009	129	9 (6.9%)
2016	99	12 (12.1%)
2017	129	13 (10.0%)
2020	104	2* (1.9%)

*14 sites where Spot-tailed Quoll were detected in 2009–2017 were not surveyed in 2020 due to access constraints (also see Figure 18).

Results from the previous surveys in 2009, 2016 and 2017 are not directly comparable with those obtained in 2020 (Table 5), as several sites were not accessible in 2020 due to wet weather and snow. This was due to the late timing of the 2020 survey (August), compared with the timing in 2017 and 2016 (May). The two sites where Spot-tailed Quolls were detected in 2020 had been surveyed in 2016; Spot-tailed Quolls had been detected at one of these sites. Fourteen of the sites where Spot-tailed Quolls were previously detected remain to be surveyed—these sites could potentially be surveyed in the future (Figure 18).

Study sites affected by the bushfires

The 2019–2020 bushfires directly affected 41 of the 104 sites that were chosen for this study (Figure 18 shows the fire extent across the study area). Retrospective analysis of site photos indicates that, of the 41 burnt sites, 33 of these experienced medium- to high-severity fire (i.e. canopy scorched or burnt) (Table 6, Figure 18).

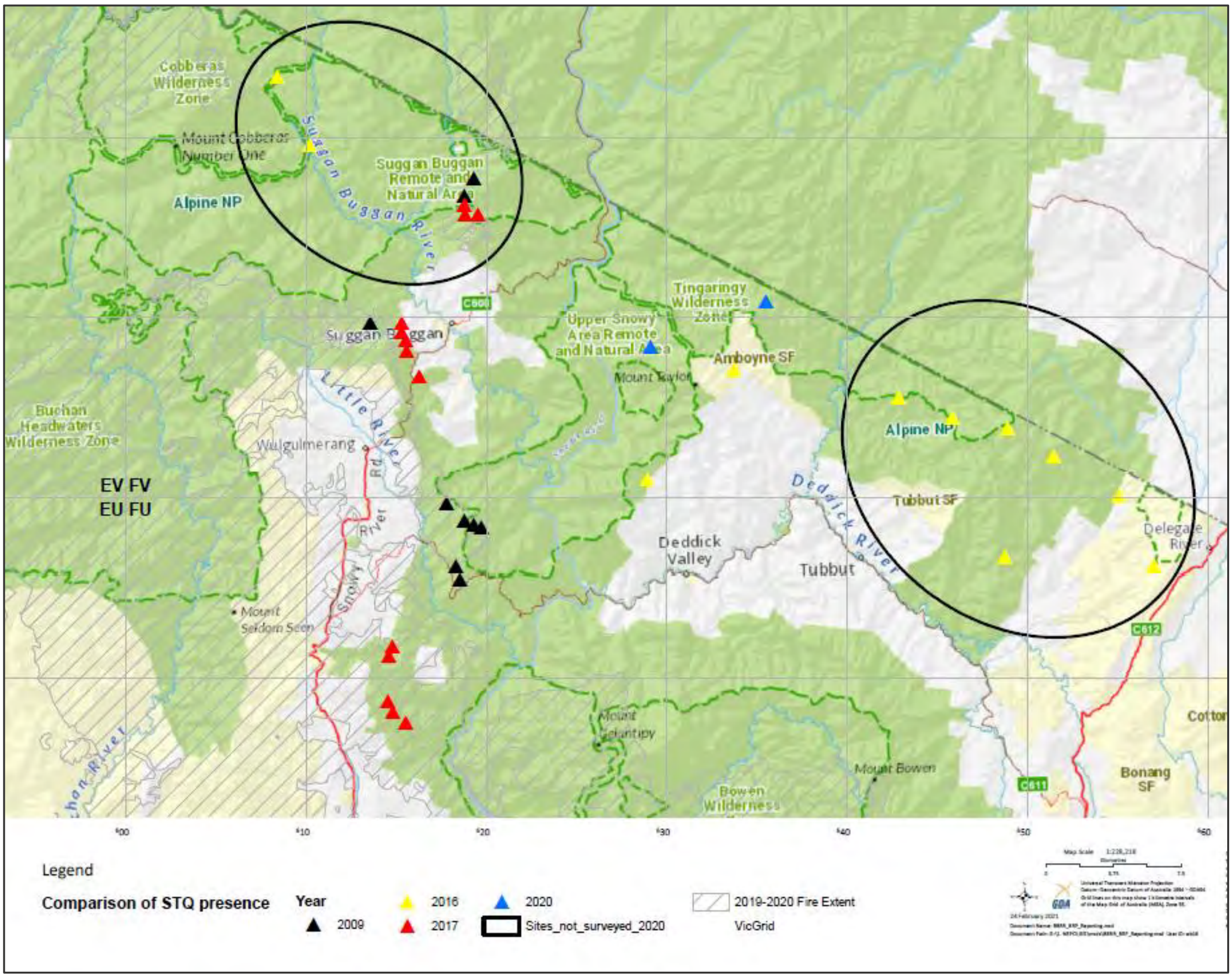

Figure 18. Map of Spot-tailed Quoll records from surveys in 2009–2020 in relation to the 2019–2020 fire footprint (cross-hatch), with the circles showing sites not sampled in 2020. The symbols reflect the most recent years in which quolls were detected.

Table 6. Distribution of fire-severity classes across 104 sites surveyed for Spot-tailed Quolls

Severity class	Number (and percentage) of sites
High	27 (26.0%)
Low	8 (7.7%)
Medium	6 (5.8%)
Unburnt	63 (60.6%)

Figure 19. Examples of high-severity fire impacts at sampling sites

Introduced fauna

Introduced fauna were present at many sites, with Cats, Pigs and Foxes being the most frequently observed introduced species across the study area (Table 7).

Table 7. The number of sites (of the 104 survey sites) at which introduced mammal species were recorded

Species	Scientific names	Number (and percentage) of sites present
Cat	*Felis catus*	29 (27.9%)
Pig	*Sus scrofa*	24 (23.1%)
Red Fox	*Vulpes vulpes*	21 (20.2%)
Horse	*Equus caballus*	19 (18.3%)
European Rabbit	*Oryctolagus cuniculus*	18 (17.3%)
Sambar Deer	*Cervus unicolor*	17 (16.3%)
Dog	*Canis familiaris*	14 (13.5%)
European Brown Hare	*Lepus europaeus*	11 (10.6%)
Cattle	*Bos taurus*	4 (3.8%)
Black Rat	*Rattus rattus*	2 (1.9%)
Deer (unknown species)		2 (1.9%)

Risks

Pre-existing risks (i.e. before the bushfires)

- Habitat loss and modification, and fragmentation of suitable habitat, are thought to be the primary causes of decline of the Spot-tailed Quoll throughout the species range (Belcher 2004; DELWP 2016)
- Competition with and predation by introduced predators, and recent drought leading to widespread high-intensity bushfires, may have compounded impacts on the Spot-tailed Quoll (DELWP 2016)

- Low population viability in small, fragmented populations
- Potential loss of genetic diversity.

Additional risks driven by the 2019–2020 bushfires

- Loss of individual Spot-tailed Quolls due to the direct impacts of the fire, further reducing the viability of this small population
- Loss of habitat for small- to medium-sized mammalian prey, leading to lack of prey resources for Spot-tailed Quolls
- Loss of potential prey due to direct impacts of the bushfires could exacerbate competition for prey resources from introduced predators, such as Foxes and Cats.

Future directions

Projects being implemented to support Spot-tailed Quoll monitoring and recovery aim to address some of the additional risks identified above.

Invasive predator control

Extending Fox control into areas known to contain stronghold Spot-tailed Quoll populations potentially impacted by the 2019–2020 bushfires

Use of remote cameras to assess the effectiveness of targeted Fox control programs

Genetic health and population structure

Targeted on-ground monitoring of Spot-tailed Quoll activity to support genetic sampling and enhance understanding of post-fire population structure

Field searches, remote camera monitoring, and non-invasive genetic sampling of active Spot-tailed Quoll latrines

Ongoing targeted remote camera surveys to supplement existing presence/absence information

Targeted cage trapping to gather further genetic and ecological information

Assessment of all available genetic and ecological information to inform planning and implementation of genetic supplementation and translocation strategies

Investigate the use of non-traditional methods for broad-scale monitoring of Spot-tailed Quolls outside known stronghold populations (e.g. conservation dogs, eDNA).

Acknowledgements

This project was funded by the Victorian Government's Bushfire Biodiversity Response and Recovery program.

This project was delivered in partnership with two other funding sources—Biodiversity Response Planning (Victorian Government) and the Regional Landscape Partnerships (Australian Government).

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2.3 Arboreal mammals and large forest owls

Prepared by Jemma Cripps, Jenny Nelson, Phoebe Macak and Louise Durkin (all ARI)

Summary of bushfire impacts

The 2019–2020 bushfires in south-eastern Australia were of unprecedented size and intensity, and likely resulted in a significant loss of habitat for hollow-dependent species throughout large areas of their distribution. This chapter assesses the impacts of these fires on two glider and three owl species: the Southern Greater Glider (*Petauroides volans*), henceforth referred to as the Greater Glider, the Yellow-bellied Glider (*Petaurus australis*), the Powerful Owl (*Ninox strenua*), the Sooty Owl (*Tyto tenebricosa*) and the Masked Owl (*Tyto novaehollandiae*).

Thirty-two per cent of Greater Glider modelled habitat in Victoria was within the bushfire extent, and 16% of its modelled habitat is estimated to have been impacted by high-severity fire. Yellow-bellied Glider habitat was similarly affected. For the large forest owl species, estimates of the proportion of modelled habitat affected by the bushfires within Victoria range from 26 to 54%. On-ground surveys (via two approaches: targeting habitat refugia, and targeting pre-fire records) found that both of the target glider species (the Greater Glider and the Yellow-bellied Glider) were impacted by the bushfires, with site occupancy declining by about 45% at locations occupied prior to the bushfires. Gliders were less likely to be found in forests affected by high-severity fire. Very few detections of large forest owls occurred, so it is difficult to assess any impacts the fires may have had on these species. However, it is possible that all the targeted owl species have undergone declines due to reductions in key requirements for these species (e.g. prey abundance and hollow-bearing trees).

Summary of key findings

Greater Gliders persist at 17 (57%) of the 30 sites within and adjacent to the bushfire footprint in the highland forests of East Gippsland where they had occurred prior to the fires.

Yellow-bellied Gliders were detected at 48% of habitat refugia sites and 53% of pre-fire record sites.

Greater Gliders and Yellow-bellied Gliders were detected more frequently in unburnt forest or in forest burnt at low or medium severity, than in forest burnt at high severity.

Reconnaissance data highlight the critical importance of protecting remaining unburnt forest habitat for gliders and owls in East Gippsland. Retaining high numbers of prey species in the landscape is also essential for large forest owls.

Based on these findings, additional Specific Needs analysis should be undertaken to assess conservation actions for the recovery of gliders and owls in East Gippsland.

Background

Over the 2019–2020 summer period, bushfires affected a significant proportion of Victoria, with over 1.5 million hectares burnt. Forest-dependent fauna, such as gliders and large forest owls, were highlighted in DELWP's analysis of species of concern following this event (DELWP 2020a). These species depend on tree hollows for their denning and breeding requirements (e.g. Goldingay and Kavanagh 1991; Gibbons et al. 2002). In south-eastern Australia, the fires were unprecedented in the extent of forest they impacted (Collins et al. 2021), potentially resulting in a significant loss of habitat for these hollow-dependent species throughout large areas of their distribution.

In Victoria, the two largest gliders overlap in their distribution through forested areas. The Greater Glider (McGregor et al. 2020) is distributed from Wombat State Forest in western Victoria through the forested parts of eastern Victoria to the New South Wales (NSW) border. The Yellow-bellied Glider is similarly distributed but is absent from the Wombat State Forest and occurs further west, in disjunct populations in the Great Otway, Cobboboonee and Lower Glenelg national parks (NPs) and in other forests in south-western Victoria.

These two glider species vary considerably in their dietary requirements, with the Yellow-bellied Glider exploiting a broader diet of arthropods, pollen, and plant and insect exudates (Goldingay and Kavanagh 1991). The Greater Glider has a specialised diet consisting almost exclusively of eucalypt foliage (Kavanagh and Lambert 1990).

The three forest owl species inhabiting the forests of eastern Victoria are the Powerful Owl, Sooty Owl and Masked Owl. The Powerful Owl and Masked Owl have been observed in a broad range of habitats (Debus 1993; Loyn et al. 2001), whereas the Sooty Owl tends to prefer wetter forest types (Loyn et al. 2001; Bilney et al. 2011). These three owl species are apex predators and occupy large home ranges, which may vary in size depending on the density of prey and hollow availability (Debus 1993; Soderquist and Gibbons 2007; Bilney et al. 2011). Research suggests that the Powerful Owl and Sooty Owl in Victoria now overlap considerably in their diet (Bilney et al. 2006).

For the Greater Glider, 32% of its modelled habitat in Victoria was within the bushfire extent, and 16% of its modelled habitat in Victoria is estimated to have been impacted by high-severity fire. Yellow-bellied Glider habitat was similarly affected. The Greater Glider is listed as vulnerable nationally under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and as vulnerable under Victoria's *Flora and Fauna Guarantee Act 1988* (FFG Act). The large forest owls are also listed under threatened species legislation. The Powerful Owl is listed as vulnerable, the Sooty Owl is listed as endangered, and the Masked Owl is listed as critically endangered under the FFG Act. For large forest owls, estimates of the proportion of their modelled habitat affected by the bushfires within Victoria range from 26 to 54% (see Birds section of Table 1).

The Greater Glider was the key focal species in this survey program due to its significant conservation status at both the state and federal levels, and site selection was based on its distribution and habitat. The Yellow-bellied Glider and the three owl species overlap in habitat requirements with the Greater Glider in many locations in eastern Victoria and were secondary targets of this survey program. Bushfire affects Greater Glider habitat in several ways. Fire can affect hollow dynamics by causing loss of hollow-bearing trees, but it also affects the potential acceleration of hollow development under some circumstances (Adkins 2006). Different fire severities have different impacts on canopy foliage—leaving it unaffected in low-severity-burn areas and completely consumed in high-severity-burn areas. The impact of fire on the canopy likely influenced the distribution of the Greater Glider following the 2009 Black Saturday bushfires. Surveys after 2009 found the occurrence of the Greater Glider was restricted to unburnt forest or areas affected by understorey fire only, which were acting as fire refugia both 2 and 10 years post-fire (Collins, Campbell-Jones and others, pers. comm.). Greater Glider occurrence was associated with areas of high canopy cover (>50%), which did not occur in areas affected by high-severity, canopy-consuming fires (Collins, Campbell-Jones and others, pers. comm.). Other researchers (Lindenmayer et al. 2013; Berry et al. 2015; Chia et al. 2015) have demonstrated similar findings. Therefore, for this species, fire refugia are likely confined to areas where the canopy is predominantly unaffected (i.e. in unburnt or low-severity-burn areas).

Fire refugia for the Greater Glider within the 2019–2020 fire extent are defined as any areas where fundamental resources remain. These include locations where preferred eucalypt food species are present and where eucalypt canopies are intact following the fire (i.e. impacted only by low- or moderate-severity fire), providing for the foraging requirements of this species. Fire refugia also include locations with older forest elements, such as large, hollow-bearing trees that meet the species' denning requirements. If such areas allow for persistence of the species, then these unburnt to moderately burnt sites are also likely to offer the best chance for natural recolonisation of burnt areas as the recovering habitat becomes suitable post-fire.

Methods

Site selection

Sites were selected based on the distribution and habitat requirements of the Greater Glider (due to its recent change in conservation status), but survey data was also collected on Yellow-bellied Gliders and the three large forest owls. The focal landscape for the surveys was in the East Gippsland fire footprint, which encompassed the majority of pre-fire Victorian Biodiversity Atlas (VBA; DELWP 2020a) records for the Greater Glider. The focus was on the Ecological Vegetation Classes (EVCs) most likely to contain suitable foraging habitat for the Greater Glider (i.e. Damp Forest, Wet Forest, Riparian Forest); for locations at which there were no pre-fire VBA records, areas of older forest with hollow-bearing trees able to meet the species' denning requirements were surveyed. DELWP fire-severity mapping, and on-ground assessment of habitat supported site selection in the field. Fire-severity mapping was derived for approximately 1.5 million hectares of forest burnt between November 2019 and March 2020, using high-resolution remotely sensed imagery and machine learning (Figure 20). A detailed description of the methodology can be found in Collins et al. (2020). The classification covers woody vegetation landcover types (including native and non-native forest, woodland and shrubland). There were six fire-severity categories derived from this mapping:

0 – No data (cloud/shadow/smoke, etc.)

1 – Non-woody vegetation (unclassified)

2 – Unburnt: canopy and understorey foliage are largely (>90%) unburnt

3 – Low-severity burn: canopy foliage is largely unaffected (<20% scorched), but the understorey has been burnt

4 – Medium-severity burn: canopy is a mosaic of scorched foliage (20–80%)

5 – High-severity burn: >80% of canopy foliage scorched

6 – Canopy burnt: >20% of canopy foliage consumed.

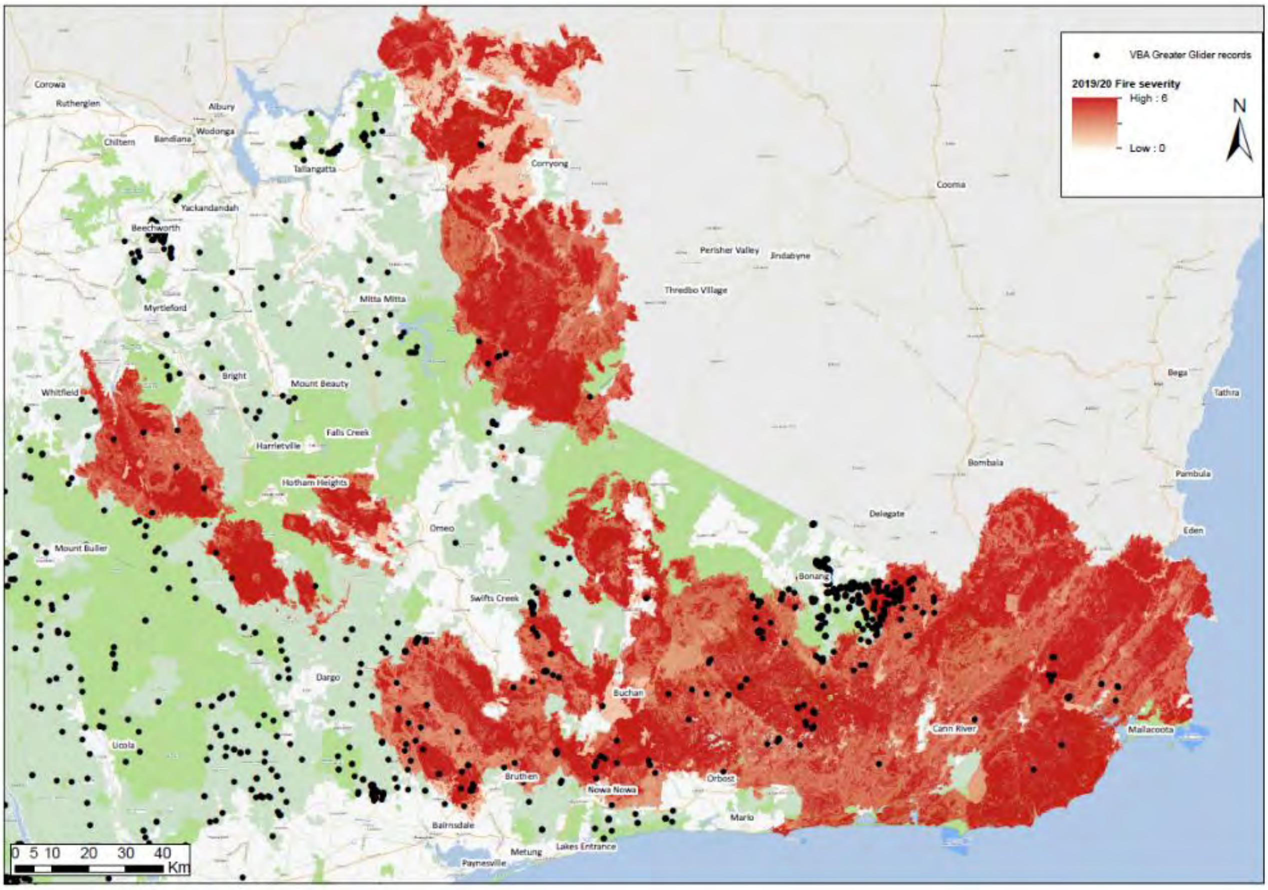

Figure 20. The DELWP fire-severity map of the 2019–2020 bushfires in Victoria, with Greater Glider records from the VBA displayed as black dots. Areas in darker red are more severely burnt. Areas with no data and areas that have non-woody vegetation have been filtered out.

For the purposes of sampling for gliders and owls, areas with no data (category 0) and non-woody vegetation (category 1) were excluded. It was assumed unlikely that Greater Gliders would be found in locations burnt at very high severity (based on Lindenmayer et al. 2013; Berry et al. 2015; Chia et al. 2015), and that fire refuges would be constrained to locations in the landscape that were unburnt or burnt at lower severity. However, a precautionary approach was taken during sampling, and some locations burnt at high severity where there were pre-fire VBA records were included (Assessment 2—see below). Other spatial data were incorporated, such as the Timber Release Plan (which outlines areas available for timber harvesting) and data sources such as the VicForests Rolling Operations Plan (coupe harvesting schedule) to cross-check and eliminate sites that had since been harvested.

Two post-fire assessments for gliders and owls were undertaken within the bushfire extent in 2020–2021. Sites were selected according to different criteria for each assessment.

Assessment 1—habitat refugia (November 2020 – January 2021)

Site selection in this first post-fire assessment was focused on potential glider/owl refugia (unburnt habitat) within East Gippsland. Thirty-one sites were installed in areas in which the burn severity was classified as unburnt, low severity (canopy foliage is largely unaffected, <20% scorched) or medium severity (canopy is a mosaic of scorched foliage, 20–80% scorched). Site selection was additionally limited to locations where there was suitable foraging habitat for the Greater Glider and the presence of older forest containing hollow-bearing trees. These site criteria also satisfied the habitat requirements of the Yellow-bellied Glider, the Powerful Owl and the Sooty Owl. The selected sites were located 30–880 m a.s.l and were predominantly in the lowland forests of East Gippsland, around Cann River and Bemm River. Pre-fire, 3 of these sites had Greater Glider VBA records, 11 sites had Yellow-bellied Glider VBA records, 6 sites had Powerful Owl VBA records, and 2 sites had Sooty Owl VBA records.

Assessment 2—sites with pre-fire Greater Glider VBA records (March–May 2021)

Sampling in the second post-fire assessment was focused on locations that were occupied by Greater Gliders prior to the bushfire (i.e. with recent or historical records), with 30 sites installed in total. By undertaking a desktop GIS analysis, 91 VBA records were identified that overlapped with the fire-severity mapping. These records were then shortlisted, as many of them were collected during DELWP's Forest Protection Survey Program (surveys prior to timber harvesting) or were being concurrently surveyed through survey programs external to DELWP (see below). Twenty-five of these VBA records were included as sites in this assessment. For record locations in which the forest had been disturbed (e.g. by timber harvesting or by previous fire) since the Greater Glider record was collected (*n* = 5), a site was installed in the nearest available suitable habitat. Survey sites were located 660–1220 m a.s.l. and were predominantly in the highland forests of Gippsland, around Bendoc and Swifts Creek. Site selection was prioritised by recency of VBA record date, with sites of records collected from 2010 onwards targeted first. To increase the sample size, sites were then selected based on older records (i.e. from the 1980s). Records were filtered out that had an accuracy of >100 m. This sample of sites encompassed a range of fire severities (Table 8). Pre-fire, 25 of these sites had Greater Glider VBA records, 19 sites had Yellow-bellied Glider VBA records, 6 sites had Powerful Owl VBA records, 8 sites had Sooty Owl VBA records and 1 site had a Masked Owl VBA record.

Table 8. The distribution of sites in Assessment 2 across five different fire-severity classes. Fire severity was assessed in the field at three locations, then averaged to allocate it to a fire-severity class.

Fire-severity class	Number of sites	Percentage of sites
Unburnt	5	17
Low-severity burn (<20% of canopy scorched)	16	53
Medium-severity burn (20–80% of canopy scorched)	2	7
High-severity burn (>80% of canopy scorched)	3	10
Canopy burnt (>20% of canopy consumed)	4	13
Total	30	100

Concurrent post-fire glider surveys

Surveying was conducted in close collaboration with two concurrent glider surveys to avoid overlap in survey effort and site selection. The ARI survey focused on forests surrounding the localities of Swifts Creek, Bendoc, Cann River and Bemm River. In contrast, the World Wildlife Fund (WWF; Rutter and Blake 2020) surveyed 24 sites (between Bairnsdale and Orbost) where there were historic records with more than a single Greater Glider being recorded. Further east, Native Mouse Ecological Consulting and Atkins Ecological Contracting undertook surveys at 30 sites north of Genoa, along the NSW border (Burns and Atkins 2021). The collaboration between researchers at DELWP–ARI and the other ecologists has increased the opportunity to assess the occurrence of, and threats to, the Greater Glider. All organisations generously shared their data and maps of planned survey locations, to avoid overlap, and an effort was made to collect data using comparable field methods. Between these survey programs, most of the pre-fire Greater Glider records in the East Gippsland fire footprint have now been resurveyed post-fire. Many pre-fire Yellow-bellied Glider records have also been resurveyed, but likely to a lesser extent.

Survey methods

Line transects were installed for spotlighting at each site. Transects began at a road edge and were a maximum of 500 m in length, running in a straight line through the forest (usually off road) along a fixed compass bearing. Minor course changes due to terrain and obstacle avoidance occasionally occurred. Some transects (*n* = 15) were established along a road—this occurred where safety concerns precluded installing a transect off road, or where the density of the midstorey vegetation would have greatly reduced visibility during spotlighting. Rapid habitat assessments were undertaken during the day at the start, middle and end points of each transect (three per transect). At each of these points, the following data were collected:

The fire severity within a 30-m radius, using the five categories outlined in the DELWP fire-severity spatial layer (Table 8). These scores were used to calculate an average burn severity for each site and to assign individual sites to an overall burn category.

The presence or absence of hollow-bearing trees.

The estimated proportion of each eucalypt species within an ~50-m radius.

Sixty-one sites were surveyed for Assessments 1 and 2 during several field trips between November 2020 and May 2021 (surveys had been planned for earlier in the season but were delayed due to COVID-19 restrictions). Spotlighting followed a double-observer distance sampling protocol as per Nelson et al. (2018). This involved two observers independently surveying each transect, with the first observer beginning 15 minutes before the second observer (or 10 minutes before if the transect was along a road). Duplicate observations of animals were identified at the end of the survey to determine the number of individual gliders observed (either by sight or sound) by the two observers. Each site was surveyed by spotlighting once during suitable weather (i.e. not during strong wind or rain, as per Wintle et al. 2005), starting at least 1 hour after dusk. The methods used were largely consistent with other post-fire surveys being undertaken for the Greater Glider in East Gippsland (B. Blake and Z. Atkins, pers. comm.).

The surveys aimed to determine whether identified habitat was occupied by Greater Gliders and to measure their relative abundance. Estimates of glider density using distance sampling methods were not possible, due to the non-random selection of survey sites and the low number of animal detections. A GPS waypoint was taken at each location at which nocturnal animals were seen or heard. The double-observer survey protocol increases detection probabilities when gliders are present along a transect line; however, it was not possible to undertake repeated surveys at each site in this time-limited, post-fire survey program. Repeated surveys can account for nights when gliders are using a different part of their home range that, by chance, may not be intersected by a transect line.

To provide data on the presence of large forest owls, a call playback survey was conducted at each of a subset of sites (*n* = 37), at locations along the road approximately 100–200 m from the start of the associated spotlighting transect. Call playback consisted of broadcasting a standard 2-minute recording of calls of each of the Powerful Owl, Barking Owl, Sooty Owl and Masked Owl in turn, via a hand-held megaphone, for a total survey time of 20 minutes. Each owl call was followed by a 2-minute listening period. This call playback survey was followed by 10 minutes of spotlighting, whereby the two observers walked (in opposite directions to each other) up to 100 m away from the playback location. A GPS waypoint was taken for each nocturnal animal that was seen or heard. This method provided additional data on the presence of the Yellow-bellied Glider, as they are known to respond to owl calls (Eyre and Buck 2005). Call playback surveys were undertaken from the vehicle track within the hour immediately following sunset, before each night's spotlight surveys, or (less often) later in the night, following the completion of spotlight surveys. Each site was visited once.

Results

Assessment 1—habitat refugia (November 2020 – January 2021)

Thirty-one sites in total were surveyed during Assessment 1. Spotlighting occurred over 15.2 km of transects, and owl call playback was deployed at 8 sites. Twelve nocturnal mammal and bird species were detected (Table 9), including two of the target species—the Yellow-bellied Glider (48% of sites) and the Sooty Owl

(10%). However, Greater Gliders were not detected during spotlight surveys, despite the presence of apparently suitable habitat at the sites surveyed.

Greater Gliders were not detected at any of the 3 sites where they were present prior to the bushfires. Yellow-bellied Gliders were detected at 6 (55%) of the 11 sites where they were present prior to the bushfires. The remaining 9 sites are new locations for this species. One Sooty Owl detection was from 1 (50%) of 2 sites occupied prior to the bushfires, and this species was detected at 2 additional sites with no prior records. Fire severity varied across the landscape (

Figure 21), but in this assessment sampling occurred predominantly in refugia habitat that had experienced lower-severity fire. Habitat assessments along each transect, when pooled, scored 92% of the sampled points as having experienced low-severity fire (<20% canopy scorch). The understorey vegetation within sites was generally consumed or fire-affected; however, eucalypt canopies were intact. Only 3 sampled points scored as high-severity fire (>80% of canopy scorched) or canopy burnt; these points were collected at the very end of two transect lines. Hollow-bearing trees were observed at 28 (90%) of 31 sites surveyed.

Table 9. Nocturnal species detected during Assessment 1 spotlighting (*n* = 31) and owl call playback (*n* = 8) surveys in East Gippsland, November 2020 – January 2021. Target species are shown in bold.

Species	No. of sites with detections	Percentage of sites with detections
Greater Glider (*Petauroides volans*)	**0**	**0**
Yellow-bellied Glider (*Petaurus australis*)	**15**	**48**
Sooty Owl (*Tyto tenebricosa*)	**3**	**10**
Powerful Owl (*Ninox strenua*)	**0**	**0**
Masked Owl (*Tyto novaehollandiae)*	**0**	**0**
Southern Boobook (*Ninox boobook*)	27	87
Sugar Glider (*Petaurus breviceps*)	16	52
Mountain Brush-tailed Possum (*Trichosurus cunninghami*)	14	45
Australian Owlet-nightjar (*Aegotheles cristatus*)	10	32
Common Brush-tailed Possum (*Trichosurus vulpecula*)	3	10
Eastern Ring-tailed Possum (*Pseudocheirus peregrinus*)	2	6
Feather-tailed Glider species (*Acrobates* spp.)	1	3
Eastern Pygmy Possum (*Cercartetus nanus*)	1	3
White-throated Nightjar (*Eurostopodus mystacalis*)	1	3
Tawny Frogmouth (*Podargus strigoides*)	1	3

Assessment 2—sites with pre-fire Greater Glider VBA records (March – May 2021)

During Assessment 2, spotlighting occurred at all 30 sites, covering over 14.4 km of transects, and owl call playback occurred at 29 sites. Eleven nocturnal mammal and bird species were detected (Table 10), including three of the target species—the Greater Glider (at 57% of sites), Yellow-bellied Glider (at 53% of sites) and Powerful Owl (at 7% of sites). The sites where Powerful Owls were detected were in close proximity to one another (within 2.6 km), so it is conceivable that the same individual was detected at these 2 sites. One individual *Tyto* was detected making short screeches, but no definitive identification could be obtained and it could have been a Masked Owl or a Sooty Owl.

Greater Gliders were detected at 14 (56%) of the 25 sites occupied prior to the bushfire, and at another 3 sites where there have been no previous Greater Glider records within 500 m of the transect. Yellow-bellied Gliders were detected at 10 (53%) of the 19 sites where they were present prior to the bushfire. The other 6 sites where they were detected are new locations for this species. One Powerful Owl was recorded from 1

(17%) of the 6 sites occupied prior to the bushfire, and this species was detected at 1 additional location. Forty-nine individual Greater Gliders were observed on the 30 transects surveyed during Assessment 2. Greater Glider relative abundance varied from 1 to 6 individuals per transect (Table 11). Five or more gliders were detected on three transects (10%). The mean number of Greater Gliders seen on the transects surveyed was 1.6 individuals per transect.

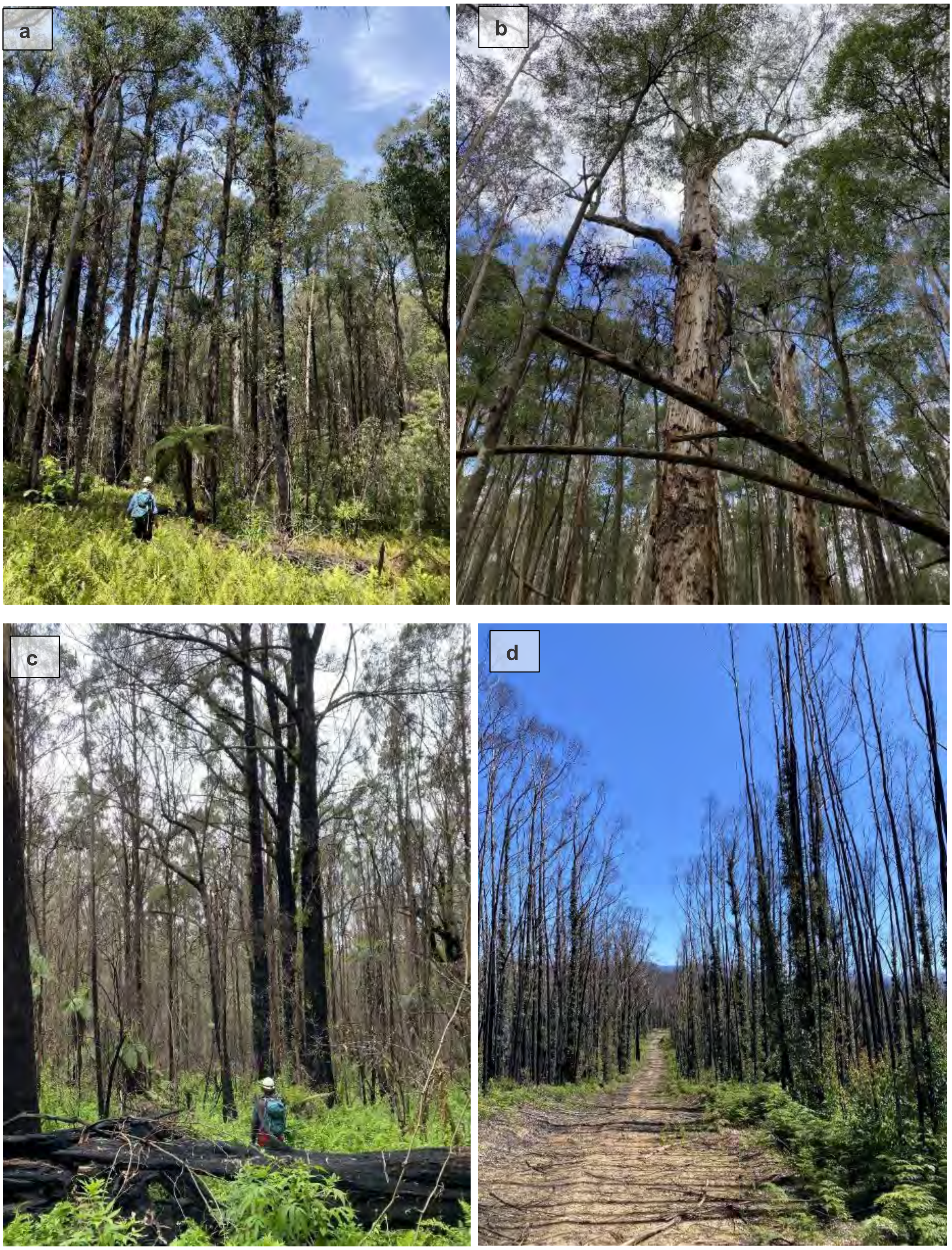

Figure 21. Example images showing the various fire-severity types in East Gippsland burnt forest, as mapped by the DELWP fire-severity spatial layer. (a, b): low-severity burn (<20% of canopy scorched); (c): medium-severity burn (20–80% of canopy scorched); and (d): high-severity burn (>80% of canopy scorched) and/or canopy burnt (>20% of canopy consumed) (photos: Louise Durkin)

Table 10. Nocturnal species detected during Assessment 2 spotlighting (*n* = 30) and owl call playback (*n* = 29) surveys in East Gippsland, March–May 2021. Target species are shown in bold.

Species	No. of sites with detections	Percentage of sites with detections
Greater Glider (*Petauroides volans*)	**17**	**57**
Yellow-bellied Glider (*Petaurus australis*)	**16**	**53**
Sooty Owl (*Tyto tenebricosa*)	**0**	**0**
Powerful Owl (*Ninox strenua*)	**2**	**7**
Masked Owl (*Tyto novaehollandiae*)	**0**	**0**
***Tyto* spp. (could not confirm identification)**	**1**	**3**
Mountain Brush-tailed Possum (*Trichosurus cunninghami*)	26	87
Sugar Glider (*Petaurus breviceps*)	18	60
Southern Boobook (*Ninox boobook*)	17	57
Australian Owlet-nightjar (*Aegotheles cristatus*)	7	23
Eastern Ring-tailed Possum (*Pseudocheirus peregrinus*)	3	10
Common Brush-tailed Possum (*Trichosurus vulpecula*)	2	7
Feather-tailed Glider species (*Acrobates* spp.)	2	7

Table 11. The number of Greater Gliders detected through spotlighting line transects at 17 occupied sites in East Gippsland, during Assessment 2 surveys in March–May 2021. Fire-severity categories are based on the classifications defined in the DELWP fire-severity spatial layer: unburnt (canopy and understorey foliage are largely >90% unburnt); low-severity burn (<20% of canopy scorched); medium-severity burn (20–80% of canopy scorched); canopy burnt (>20% of canopy consumed).

Site	Transect length (m)	Fire-severity category	Greater Glider relative abundance
BBRR-26	250	Unburnt	1
BBRR-34	500	Low	1
BBRR-40	500	Low	1
BBRR-12	400	Canopy burnt	2
BBRR-19	500	Unburnt	2
BBRR-20	500	Low	2
BBRR-24	500	Medium	2
BBRR-36	500	Low	2
BBRR-4	500	Low	2
BBRR-6	500	Low	3
BBRR-43	500	High	3
BBRR-14	500	Low	4
BBRR-22	500	Unburnt	4
BBRR-3	400	Unburnt	4
BBRR-8	500	Low	5
BBRR-45	500	Medium	5
BBRR-42	500	Low	6

Fire severity varied across the landscape, and in Assessment 2 sites were sampled across a range of fire severities (Table 8). However, fire severity also varied along each transect due to the patchiness of the fire at some locations. Habitat assessments on transects, when pooled, scored 50% of sampled points as having experienced a low-severity burn (<20% of canopy scorched; understorey burnt), 18% of sampled points as unburnt (not affected by fire at all; often the site was just outside the fire boundary), 15% of sampled points as having the canopy burnt (>20% of canopy consumed), 11% of sampled points as having experienced a high-severity burn (>80% of canopy scorched) and 6% of sampled points as having experienced a medium-intensity burn (20–80% of canopy scorched). Hollow-bearing trees were observed at all of the 30 sites surveyed (100%).

Spotlighting sites were assessed on ground in the field, and an average burn severity for each site was then used to assign each site to a fire category. Habitat assessments were not conducted at owl-call playback sites, so the DELWP fire-severity mapping was used to assign a fire-severity category (in some cases these differed from the spotlight transect categories). It was difficult to examine the relationship between fire severity and the occupancy of sites, due to the small sample sizes. However, the Greater Glider was detected least frequently at high-severity burn sites, compared with those that were burnt at low to medium severity, or were not affected by the fire (Table 12). The Yellow-bellied Glider showed the same pattern of detection in relation to fire severity (Table 12). The Powerful Owl detections occurred at sites burnt at high severity, but as owls are largely detected via hearing their calls, it is possible they were calling from nearby habitat burnt at a different severity or were just outside the bushfire extent. (Both detection sites were close to the edge of the fire footprint.)

Table 12. Target species detected during Assessment 2 spotlighting and owl-call playback surveys in East Gippsland, summarised according to fire severity (classifications based on the DELWP fire-severity layer). Unburnt sites were not affected by fire. Low-severity burn is defined as understorey burnt and <20% of the canopy scorched, and medium severity burn is defined as medium canopy scorch (20–80% scorched). For the purposes of this table, high-severity burn sites incorporated sites classified under two categories: canopy burnt (>20% of canopy consumed) and high-severity burn (>80% of canopy scorched).

Species	Unburnt sites surveyed	Unburnt sites with detections	Low- to medium-severity burn sites surveyed	Low- to medium-severity burn sites with detections	High-severity burn sites surveyed	High-severity burn sites with detections
Greater Glider	5	4 (80%)	18	11 (61%)	7	2 (29%)
Yellow-bellied Glider	5	3 (60%)	18	11 (61%)	7	2 (29%)
Sooty Owl	7	0 (0%)	16	0 (0%)	6	0 (0%)
Powerful Owl	7	0 (0%)	16	0 (0%)	6	2 (33%)
Masked Owl	7	0 (0%)	16	0 (0%)	6	0 (0%)

Conclusions

In total, 61 sites were surveyed for gliders and owls over both assessments. Two areas stood out as having the highest occupancy for the Greater Glider—the forest around Bendoc and the forest around Swifts Creek (Figure 22). These sites were located at higher elevations (680–1220 m a.s.l.) than many of the sites surveyed in the lowland forests of East Gippsland and are considered likely future climate refugia for this species (Wagner et al. 2020). Many of the occupied sites were located on the edge of the fire footprint, rather than well within the fire footprint. The results of these surveys suggest that the Greater Glider may have declined in abundance and distribution; it was not detected at 44% of the sites it occupied prior to the bushfires and was more likely to occupy unburnt forest, or forest burnt at low or medium severity, than forest burnt at high severity. However, it is difficult to assess changes in Greater Glider abundance without undertaking repeated visits to sites or monitoring sites through time. Some sites had large numbers of the Greater Glider before the fire. For example, at site BBRR-24 there were 13 individuals found pre-fire, but only 2 individuals found post-fire. However, the pre-fire records were collected during several visits (generally 2–3 individuals per site per visit being recorded), but multiple visits were not possible in this time-limited post-fire survey assessment. Detectability of gliders could also change quite substantially pre- and post-fire, as the structure of the forest has changed. This makes it very difficult to directly compare changes in abundance due to the bushfires.

In recent surveys for Greater Gliders, following the 2019–2020 bushfires, Rutter and Blake (2020) found large declines—they detected Greater Gliders at 7 (29%) of 24 sites and found a higher likelihood of Greater Gliders occupying sites with low-severity burn. Burns and Atkins (2021) detected Greater Gliders at only 1 (8%) of 12 previously occupied sites, and it was a low-severity-burn site. The impact of the fire may extend beyond the burnt area—Lindenmayer et al. (2013) showed that the Greater Glider was less abundant at sites where the surrounding landscape had been burnt, even if the site itself remained unburnt.

The Yellow-bellied Glider had a similar frequency of detection at sites in both assessments (48% and 53% of sites, respectively). Detections occurred throughout the fire footprint, both in the lowland and highland forests of East Gippsland (Figure 23). Like the Greater Glider, the Yellow-bellied Glider was more likely to be detected in unburnt forest, or in forest with low- or medium-severity burn, than in forest burnt at high severity. Burns and Atkins (2021) also found that the likelihood of Yellow-bellied Gliders occupying a site decreased with increasing fire severity. In their surveys, Yellow-bellied Gliders were detected at 14 (47%) of 30 sites (which is similar to the findings of the current survey). Rutter and Blake (2020) detected Yellow-bellied Gliders at 10 (42%) of 24 of their sites.

While approximately 50% of sites surveyed in this reconnaissance program had a Yellow-bellied Glider record prior to the bushfire, the survey effort in Assessment 2 was prioritised towards the Greater Glider and did not focus on returning to locations where Yellow-bellied Gliders had been recorded. As a result, it is difficult to comment on the impacts of the fire on the abundance of this species. From the subset of the data that did incorporate previously occupied sites, it appears that the species has declined, with detections occurring at only about half of the previously occupied sites [i.e. Yellow-bellied Gliders were detected at 55% (Assessment 1) and 53% (Assessment 2) of the sites occupied prior to the bushfires]. Burns and Atkins (2021) found Yellow-bellied Gliders at 11 (58%) of 19 previously occupied sites. Additional post-fire sampling designed for this species would assist in evaluating this decline more accurately, as would establishing long-term monitoring sites within the fire footprint.

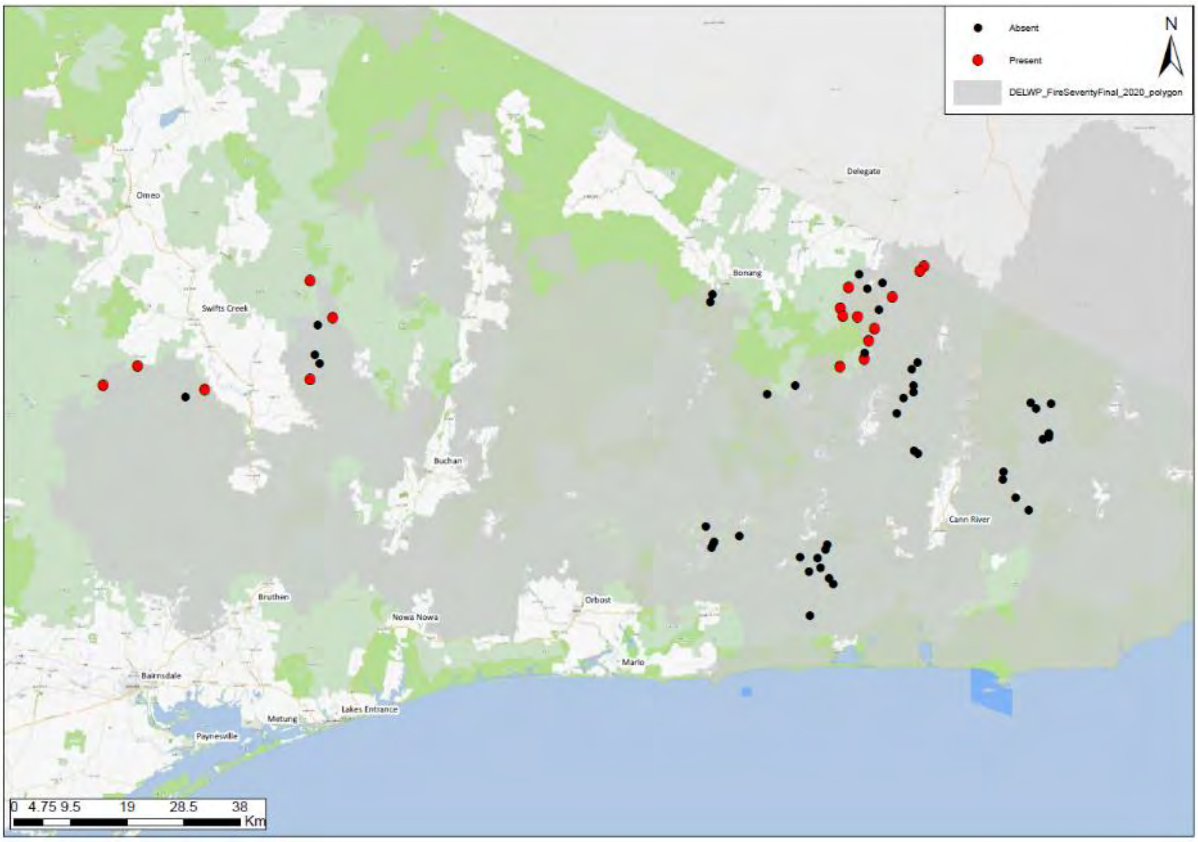

Figure 22. The distribution of occupied sites post-fire for the Greater Glider (red circles) and survey sites where it was not detected (black circles) in East Gippsland. The bushfire extent is shown in grey. Note that sites shown include those where Greater Gliders were known to occur prior to the bushfires (Assessment 2), as well as sites with no contemporary records, but potentially suitable habitat (Assessment 1).

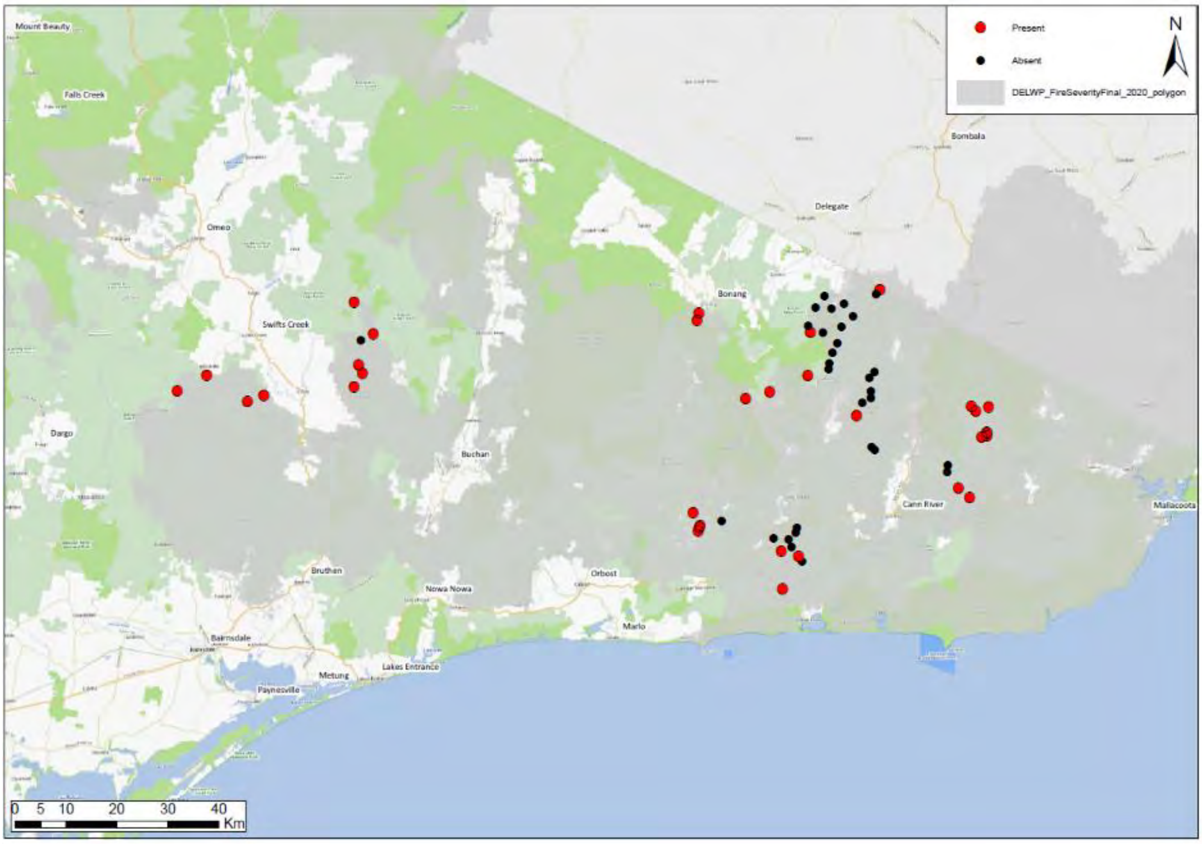

Figure 23. The distribution of occupied sites post-fire for the Yellow-bellied Glider (red circles) and survey locations where it was not detected (black circles) in eastern Victoria. The bushfire extent is shown in grey.

Very few detections of large forest owls were made. This is potentially unsurprising given that they naturally occur at low densities, are flexible in their use of forest types, and have large home ranges (Debus 1993; Soderquist and Gibbons 2007; Bilney et al. 2011), all of which make them difficult to survey. The Sooty Owl was recorded at 3 sites (Figure 24) and the Powerful Owl was recorded at 2 sites (Figure 25). It is difficult to comment on the impacts of the bushfires on these two species, although due to reductions in key resources (prey abundance and hollow-bearing trees) it is possible that all three owl species have undergone declines. However, targeted surveys at known pre-fire sites, repeated in key seasons (e.g. spring, Loyn et al. 2011) would allow this possibility to be more accurately evaluated. In both assessments, low numbers of the Eastern Ring-tailed Possum (*Pseudocheirus peregrinus*) were observed—this species is dependent on midstorey and understorey vegetation and is likely to have been significantly impacted by the bushfires, in addition to land management activities such as planned burning and timber harvesting. A study in East Gippsland found that the Greater Glider, the Eastern Ring-tailed Possum and the Sugar Glider (*Petaurus breviceps*) represented over 81% of prey items detected in both Powerful Owl and Sooty Owl diets (Bilney et al. 2006); a reduction in any of these glider or possum species may impact owl survival and breeding success.

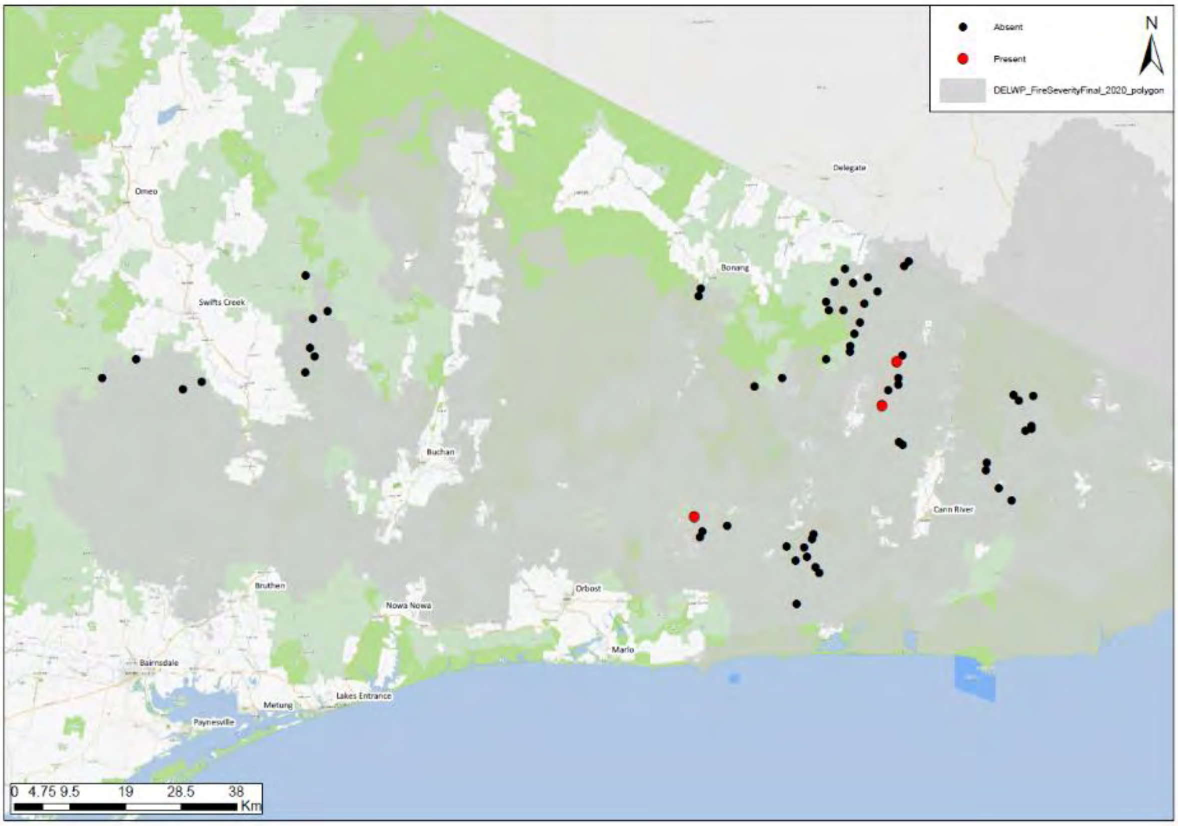

Figure 24. The distribution of occupied sites post-fire for the Sooty Owl (red circles) and survey locations where it was not detected (black circles) in eastern Victoria. The bushfire extent is shown in grey.

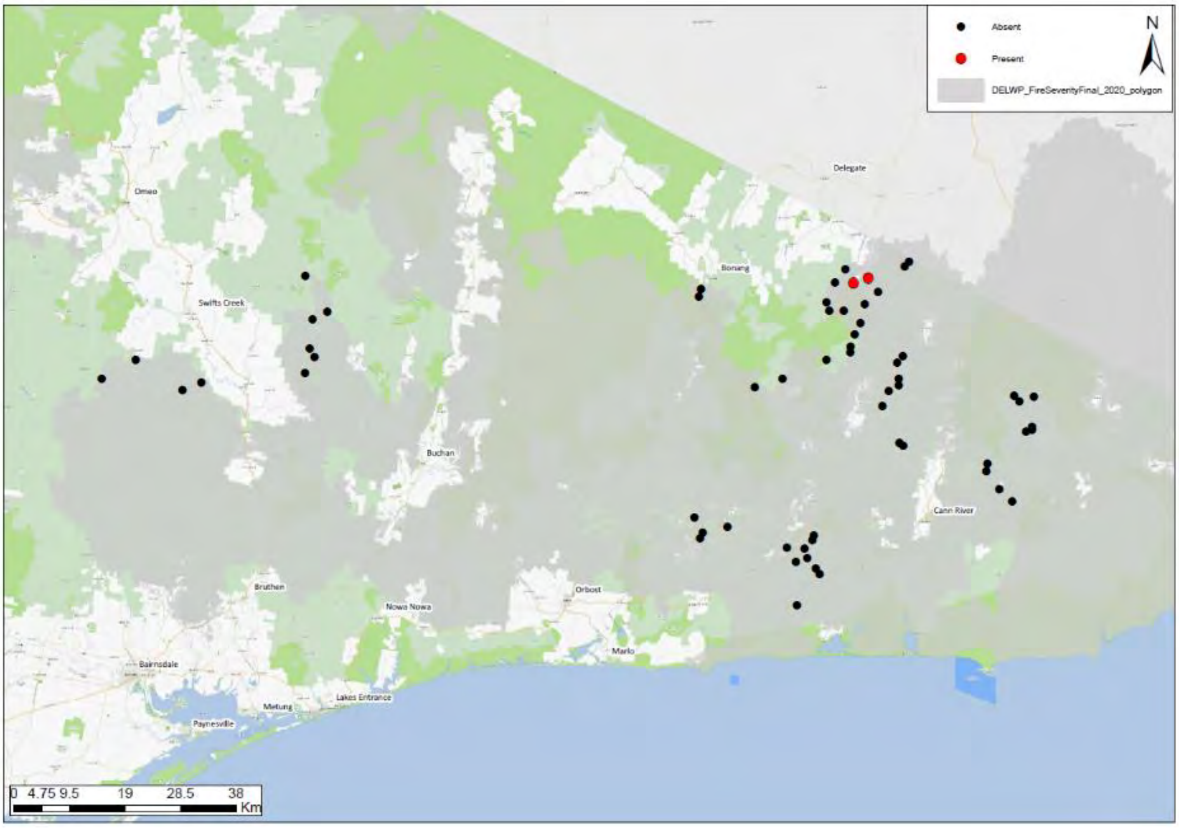

Figure 25. The distribution of occupied sites post-fire for the Powerful Owl (red circles) and survey locations where it was not detected (black circles) in eastern Victoria. The bushfire extent is shown in grey.

Risks

Pre-existing risks (i.e. before the bushfires)

Prior to the bushfires, the main risks and causes of declines in arboreal gliders and owls were:

Loss of hollow-bearing trees from the landscape (required for denning or nesting), due to landscape-scale bushfires, timber harvesting, and planned burning

Loss of prey species for forest owls: resources that are key determinants of survival and breeding success

Climate change (in the form of e.g. drought and hotter weather) has been implicated as a threat to the Greater Glider (Wagner et al. 2020).

Habitat fragmentation and the impacts of small populations being in isolated pockets may also be a threat for the Greater Glider.

Additional risks driven by the 2019–2020 bushfires

Reductions in the population size for both glider species due to the direct impacts of the bushfires, especially at high-severity burn sites

Reduction in arboreal prey species for owls, and the potential negative impacts of reduced prey availability on owl populations

Fragmentation of occupied glider habitat due to high-severity burns, which might prolong natural recolonisation into burnt habitat due to isolation by distance

Potential increased pressure on genetic diversity, due to reduced connectivity of Greater Glider populations

Limited availability of habitat with intact canopy at sites where gliders occur in East Gippsland

The absence of understanding of tolerable fire intervals for gliders and owls, and how regular prescribed burning may affect these species.

Future directions

Specific Needs analysis was carried out for the Greater Glider and the Masked Owl in 2020, prior to these two post-fire reconnaissance assessments. The four actions considered for the Greater Glider were: protecting hollow-bearing trees during fire management; installation of artificial hollows; installation of artificial hollows, with the addition of supplementary water; and gene mixing. The three actions considered for the Masked Owl were: installation of artificial hollows; protecting hollow-bearing trees during fire management; and installing tree guards to prevent lace monitor predation. The analysis showed that, for the Greater Glider, experts considered the action of installation of artificial hollows, with the addition of supplementary water, as being of most benefit to the species. For the Masked Owl, experts considered the installation of artificial hollows and the protection of hollow-bearing trees during fire management as being of most benefit to the species.

The post-fire reconnaissance surveys have now identified sites that could benefit from actions for these species, especially for the Greater Glider. Furthermore, many potential conservation actions were not considered in the Specific Needs analysis that was carried out prior to these surveys. Additional Specific Needs analysis should be undertaken to assess the following conservation actions for the protection and recovery of the glider and owl species:

Gliders

Short-term

Protection of key unburnt and low-severity burn areas, critical glider populations, and habitat within the fire extent. These areas could be identified using these reconnaissance data, post-fire VBA data and the SMP tool.

Protect and manage key glider populations outside the current fire extent, especially in ecologically important habitat (e.g. climate refugia, as identified via SMP)

Assess the need to review existing timber harvesting and planned burning prescriptions to determine their adequacy post-fire

Trial provision of artificial hollows for gliders (already in progress, through work undertaken by WWF and the Australian National University, and post-fire work funded by the Federal Government).

Long-term

Increase understanding of the impacts of high-severity fire and the value of refugia for both glider species.

Protect hollow-bearing trees from fire and land management activities.

Ensure adequate recruitment of hollow-bearing trees across the landscape, within various forest age-classes.

Explore the feasibility of translocations of the Greater Glider to mitigate the risk of population fragmentation and the impact of future fires.

Improve understanding of tolerable fire intervals for the Greater Glider and the Yellow-bellied Glider, and how regular prescribed burning may affect these species.

Owls

Short-term

Protection of key unburnt areas and owl habitat within the fire extent. These areas could be identified using this reconnaissance data, post-fire VBA data, Important Populations modelling and SMP.

Audit the Owl Management Areas (OMAs) in East Gippsland to assess their status and efficacy post-fire.

Assess the need to review existing timber harvesting and planned burning prescriptions to determine their adequacy post-fire.

Long-term

Retain high numbers of prey species in the landscape. Ensure midstory vegetation is promoted for arboreal mammal prey, and undertake predator control within and adjacent to the fire footprint, to increase the numbers of terrestrial mammalian prey.

Protect hollow-bearing trees from fire and land management activities.

Ensure adequate recruitment of hollow-bearing trees across the landscape, within different forest age classes.

Improve understanding of tolerable fire intervals for owls (and their prey) and how the impacts of regular prescribed burning may affect these species.

Acknowledgements

This project was funded by the Victorian Government’s Bushfire Biodiversity Response and Recovery program.

Field surveys and data collection were undertaken by ARI–DELWP staff Jemma Cripps, Louise Durkin, Phoebe Macak, Daniel Purdey and Judy Downe, and were completed with the assistance of staff from Wildlife Unlimited. We are very grateful to DELWP East Gippsland regional staff and Parks Victoria for their assistance with logistics and survey planning, especially Lucas Bluff, Marc Perri, James Pardew, Bradley Fisher, Jo Andrews, Russ Cutlack, Trent Tonissen, Shaun Cottrell, Glenn Ennis, Gareth Story, Sarah Gill, Glen Digby, Zoe McLellan, John Wood, David Butterworth, Gary Bellesini, Mark Mickelburough, Elaine Thomas and Dave Burton. We thank Zak Atkins, Phoebe Burns and Brad Blake for their conversations around survey effort and for making their survey data accessible.

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Birds

Female Glossy Black-Cockatoo feeding on seeds of Green She-oak (*Allocasuarina paradoxa*), The Pines Flora Reserve, Frankston North, June 2020 (photo: Peter Menkhorst).

The following bird species were targeted for assessment and are reported on below:

3.1 Glossy Black-Cockatoo

3.2 Eastern Ground Parrot

Large forest owl assessments were completed and have been reported within the *Arboreal mammals and large forest owls* section of this report.

3.1 Glossy Black-Cockatoo

Prepared by Peter Menkhorst (ARI), Martin Schulz (consultant) and Kasey Stamation (ARI)

Summary of bushfire impacts

In Victoria, the Glossy Black-Cockatoo (*Calyptorhynchus lathami*) occurs only in East Gippsland[1], mostly on the foothills and coastal plains east of Lake Tyers and Nowa Nowa, at a variety of altitudes. Of the species' modelled habitat in Victoria, 64% was within the 2019–2020 bushfire extent, with 26% of their habitat being affected by high-severity fire. In East Gippsland, Glossy Black-Cockatoos are almost entirely dependent on the seeds of a single tree species for food—the Black She-oak (*Allocasuarina littoralis*). *A. littoralis* is often killed by hot fires, which means that the 2019–2020 bushfires had a potentially severe impact on this cockatoo species.

Summary of key findings

During surveys undertaken before the fires (in May and November 2019, as part of a different project), two areas stood out as having higher occupancy of Glossy Black-Cockatoo: (1) the valley of the Genoa River and its tributaries between Wroxham and Top Lake, Mallacoota Inlet, and (2) forest east of Lake Tyers and Nowa Nowa, including Ewing Morass State Game Reserve.

Before the fires, 35.7% of randomly selected *A. littoralis* stands showed feeding sign of Glossy Black-Cockatoo. After the fires, the occurrence of feeding sign presence in burnt areas had declined to 6.4% of stands, less than one-fifth of the pre-fire frequency.

In the extensive area of unburnt forest west of Marlo, there was no difference between the frequency of feeding sign before and after the fires (38.5% and 38.1%, respectively).

Assuming that the frequency of fresh feeding sign presence across *A. littoralis* stands is an index of Glossy Black-Cockatoo abundance, our findings reveal that:

The carrying capacity of burnt stands is roughly one-fifth that of unburnt stands (6.4% and 35.7%, respectively), but probably much less, as remaining birds are likely to be roaming over a larger area to find living *A. littoralis* with unopened cones still containing seed, and may soon deplete the available food resource.

Five to six weeks after the fires, the population in an extensive area of unburnt habitat had not noticeably changed, suggesting that few birds had relocated from burnt habitat to this area, the nearest extensive area of unburnt habitat (the coastal plain between Marlo and Lake Tyers).

Background

The Glossy Black-Cockatoo has an extremely restricted diet—seeds extracted from the closed woody cones of small trees from a single genus, *Allocasuarina* (Family Casuarinaceae), with only very occasional reports of feeding on the closely related genus *Casuarina* (Chapman 2007; North et al. 2020). In the south of its distribution, the Glossy Black-Cockatoo (nominate subspecies) overwhelmingly prefers the seeds of *A. littoralis* (Clout 1989; Forshaw and Cooper 2016).

In Victoria, records of both *A. littoralis* and the Glossy Black-Cockatoo are concentrated along the coast and in the foothills and valleys of East Gippsland, mostly east of Lake Tyers. Generally, *A. littoralis* grows on sites with low soil-nutrient status, including on near-coastal sands or heavy clay soils, or among rocks (Walsh and Entwisle 1996). It occurs in scattered small stands as a subcanopy tree up to 10 m tall, among mixed eucalypt forest.

Glossy Black-Cockatoos extract seeds from *Allocasuarina* cones using their massive bill, which is highly adapted for this task, with the distal end of the lower mandible forming a broad, curved blade (Forshaw and

[1] Three individuals were present in the south-eastern suburbs of Melbourne from mid-May 2020 to late July 2020, and two birds were still being reported at the time of writing (mid-October 2021) (see photo on page 56). These are the first records of the species outside East Gippsland or north-east Victoria for about a century. These individuals are likely to have been displaced by the 2019–2020 bushfires.

Cooper 2002) (Figure 26). This process results in the woody remnants of the cone ('orts') being discarded, so that trees in which Glossy Black-Cockatoos have been feeding are obvious by the presence of cone fragments on the ground beneath (Figure 27). No other animal species is known to leave this feeding sign in south-eastern Australia (Clout 1989; North et al. 2020; authors' pers. obs.).

Reliance on the tiny seeds (Figure 28) of a single, patchily distributed and small tree species represents an unparalleled level of dietary specialisation among Australian birds (Chapman 2007; North et al. 2020). Glossy Black-Cockatoos are selective in their choice of individual feed trees, with tree selection being driven by nutritional profitability and tree size (North et al. 2020). Further, because *A. littoralis* is dioecious (Walsh and Entwisle 1996), only female specimens produce seed cones; this means that roughly half the population of *A. littoralis* trees produce no food for the cockatoo.

Observations indicating that Glossy Black-Cockatoos will switch to other *Allocasuarina* species if cones of the locally preferred species are in short supply or of lower quality have been reported, but rarely (Chapman 2007). In drier forest in the upper Snowy River valley, there are reports of Glossy Black-Cockatoos eating the seeds of *Allocasuarina verticillata* (N. Walsh, Victorian Herbarium, pers. comm.), but extensive stands of that species elsewhere seem not to be used (P. Menkhorst pers. obs.). In East Gippsland, the only other widespread *Allocasuarina* species is *A. paludosa*, a shrub that grows in heathlands (Walsh and Entwisle 1996). There are no records of Glossy Black-Cockatoos eating seeds of that species, but there are recent records of three displaced birds near Melbourne feeding on the closely related species *A. paradoxa* during June and July 2020 (Figure 26) (P. Menkhorst, pers. obs.).

Figure 26. Glossy Black-Cockatoo extracting seeds from a cone of *Allocasuarina paradoxa*, Frankston North, 23 June 2020 (photo: Peter Menkhorst)

Allocasuarina littoralis flowers mostly in the winter months, although some flowers can be found year-round. The woody cones mature over a period of 6–9 months, and remain on the tree for up to several years after maturing without shedding their seeds. Thus, food is potentially available for the cockatoos year-round, although large home ranges may be needed to provide a guaranteed supply.

Seed-shed in *A. littoralis* is induced by hot, dry conditions and by fire, and seed-shed renders the seed inaccessible to the cockatoo, which has never been reported to feed from the ground (Higgins 1999; Forshaw and Cooper 2016). Some seed is shed in late summer, but many cones remain closed throughout the summer, unless there is a fire (Clout 1989). Thus, fire removes the food of the Glossy Black-Cockatoo by two processes: hot fires burn the cones and seeds, and cooler fires cause the cones to open and shed seed.

Figure 27. Litter beneath an *Allocasuarina littoralis* tree in which a Glossy Black-Cockatoo has recently fed. Naturally fallen old cones (grey) that have shed their seed are intermixed with the chewed remains ('orts') of unopened cones (honey-coloured) discarded by the cockatoo (photo: Peter Menkhorst).

Hot fire frequently kills *A. littoralis* (Clout 1989; Morrison and Renwick 2000; N. Walsh, pers. comm.) (Figure 29), although some basal resprouting was observed in June 2020 (Figure 30). Even mild burns turn the foliage brown, with uncertain long-term consequences for the individual tree (Figure 31). The time required for a resprouting or a seedling tree to begin producing viable seeds is an estimated 5–20 years (Morrison and Renwick 2000), although the lower bound seems highly optimistic to the authors. In combination, this information suggests that the status of the Glossy Black-Cockatoo will decline under predicted climate change scenarios.

Figure 28. Seeds of *Allocasuarina littoralis*. The kernel (the nutritious part) is contained within the black section, the pale section is a membrane to promote wind dispersal (photo: Peter Menkhorst).

Figure 29. A stand of *Allocasuarina littoralis* burnt and presumably killed by bushfire in January 2020 (photo taken June 2020). The green epicormic growth is on eucalyptus trees intermixed with the *Allocasuarina* (photo: Martin Schulz).

Figure 30. Basal resprouting by *Allocasuarina littoralis* ~6 months after the January 2020 bushfires (photo: Martin Schulz)

Figure 31. *Allocasuarina littoralis* in a less intensively burnt site with scorched foliage. The impact of this on the future production of seed cones is unknown (photo: Martin Schulz, June 2020).

During 2019 (i.e. before the 2019–2020 bushfires), ARI had commenced a study of the distribution and feeding preferences of the Glossy Black-Cockatoo in East Gippsland. The aims of this initial study were to:

Investigate the occupancy rate of feeding Glossy Black-Cockatoos in *A. littoralis* stands in the survey area, as indicated by the presence of chewed seed cones.

Investigate the preferences of Glossy Black-Cockatoos for *A. littoralis* stem density, tree size classes, and landscape position of stands.

Assess the accuracy of the Glossy Black-Cockatoo habitat suitability model.

Following the intense bushfires in December 2019 and January 2020, which burnt a large proportion of the survey area after the initial data collection, the opportunity was taken to investigate the impacts of the fires on the cockatoo. All sites were revisited and data collection was repeated. Two extra aims were added:

Assess survivorship of the *A. littoralis* stands, and the availability of cones, following the 2019–2020 bushfires.

Compare site occupancy rates before and after the fires in both burnt and unburnt forest.

This preliminary report considers Aims 1, 4 and 5, directly pertaining to the impacts of the 2019–2020 bushfires on the Glossy Black-Cockatoo and on *A. littoralis* in East Gippsland, Victoria.

Methods

Selection of sample sites

The habitat distribution model for the Glossy Black-Cockatoo was prepared by ARI–DELWP (see Lui et al. 2011 for details of the modelling procedure) and then overlain with a model of *A. littoralis* distribution to provide a more refined map of likelihood of occurrence of the Glossy Black-Cockatoo. Within this area, 175 survey sites were allocated using a stratified random sampling procedure based on (i) probability of occurrence and (ii) selection of sites within practical walking distance (~500 m) of a vehicle track, with at least 300 m between sites.

Data collection at sample sites

During May and November 2019, a hand-held GPS unit was used to navigate to as many of the survey sites as possible. Altogether, 174 stratified random sites were sampled, and an extra 186 incidental sites (i.e. chosen non-randomly while in the field) were also sampled. Incidental sites included stands where Glossy Black-Cockatoos were observed feeding, and stands located while navigating to the randomised sites. These incidental non-randomised sites will not be used in analyses associated with Aims 1 and 2, but are suitable for Aims 3, 4 and 5. Incidental sites were usually over 1 km from any other data collection site.

At all sites, the following data were recorded:

Using the nearest *A. littoralis* tree to the GPS point (up to a maximum of 50 m from the GPS point) as the centre of a 30 × 30 m quadrat, the size class of each *A. littoralis* stem, based on diameter at breast height (dbh). Size classes were 2–5 cm, 6–15 cm, 16–50 cm and >50 cm.

The number of russet-brown cones [as distinct from grey (old) cones] on each tree that carried fully formed cones, scored using three categories: 0, 1–200, >200

The abundance of chewed cone ends on the ground beneath each tree that had fully formed cones, scored using four categories: 0, 1–20, 21–100, >100

The number, sex and age class (adult, juvenile) of any Glossy Black-Cockatoos present, along with any other natural history observations.

The extensive 2019–2020 bushfires in East Gippsland provided an opportunity to revisit burnt and unburnt sample sites to collect comparable data on the presence of fresh feeding sign, and thus to assess the impacts of the bushfires on the presence of Glossy Black-Cockatoos and on *A. littoralis* seed availability. Sample sites in unburnt forest to the west of Orbost were visited in March 2020, and sites in burnt forest were revisited in June 2020 if access was possible. Many tracks were closed or impassable due to fallen trees or burnt bridges, necessitating walking on tracks and cross-country.

Results

Pairs or threesomes (a pair plus their young of the previous year) of Glossy Black-Cockatoos seek out the scattered stands of *A. littoralis* and will utilise even small, isolated stands. Larger groupings of up to 10 individuals were observed drinking from puddles along forest roads in the evening.

A preliminary analysis of the data on occurrence of chewed cones at the 174 stratified randomised sites is presented in Table 13. After the fires, 84 (48.3%) of the randomised sites were revisited, comprising all sites that supported a stand of *A. littoralis* in the pre-fire surveys. The remaining 90 sites were excluded from the post-fire field program. At the time of writing, data from the 186 incidental sites (non-randomised site selection) had not been analysed, nor had the data on abundance of *A. littoralis* at survey sites, size classes of *A. littoralis*, or abundance of ripe cones.

The locations of survey sites at which *A. littoralis* was present are shown Figure 32 (pre-fires) and Figure 33 (post-fires).

Table 13. Summary of Glossy Black-Cockatoo field trips and feeding sign frequency relative to the 2019–2020 East Gippsland bushfires

Relationship to 2019–2020 bushfires	Area covered	Dates	Number of sites visited that had *A. littoralis*	Number of sites with chewed cones	Percentage of sites with *A. littoralis* and chewed cones
Pre-fire	East of Orbost	11–19 May 2019	58 of 74 visited	20	34.5
Pre-fire	West of Orbost	11–18 Nov 2019	26 of 100 visited	10	38.5
Post-fire unburnt sites that previously had *A. littoralis*	West of Orbost (in part)	10–14 Mar 2020	21 of 21 visited	8	38.1
Post-fire burnt sites that previously had *A. littoralis*	Entire burnt footprint	18–28 Jun 2020	63 of 63 visited	4	6.4

The initial analysis of the occurrence of chewed cones at the randomised sites (Table 13. Summary of Glossy Black-Cockatoo field trips and feeding sign frequency relative to the 2019–2020 East Gippsland bushfires Figures 32 and 33) revealed that:

During 2019, before the fires, feeding sign of Glossy Black-Cockatoos at sites with *A. littoralis* was equally likely to be found in the area east of Orbost [north to the New South Wales (NSW) border] and in the area west of Orbost (west to the shores of Lake Tyers). However, the frequency of occurrence of *A. littoralis* was much lower in the west (26% west of Orbost, 78% east of Orbost).

Pre-fires, two areas stood out as having higher occupancy of Glossy Black-Cockatoo:

The valley of the Genoa River and tributaries between Wroxham and Top Lake, Mallacoota Inlet

Forest east of Lake Tyers and Nowa Nowa, including Ewing Morass State Game Reserve.

Before the 2019–2020 fires, feeding sign was apparent at 35.7% of 84 randomised survey sites where *A. littoralis* was present.

After the fires, the rate of feeding sign presence in burnt areas (6.4%) was reduced to 18% of the pre-fire rate.

There was no change in the rate of feeding sign before and after the fires (38.5% and 38.1%, respectively) in the extensive area of unburnt forest west of Marlo.

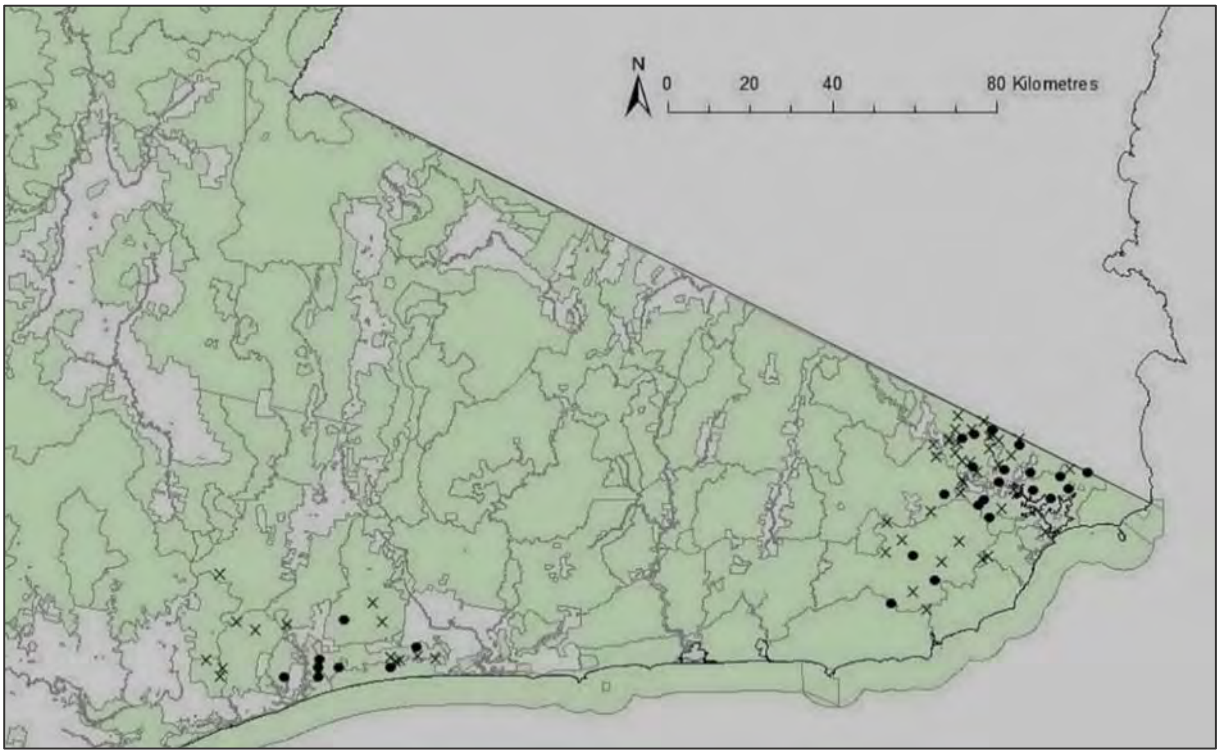

Figure 32. Location of survey sites pre-fires (visited in May and November 2019). Dots represent chewed cones present beneath at least one *A. littoralis* tree; crosses represent *A. littoralis* present, but no feeding sign found; green represents crown land.

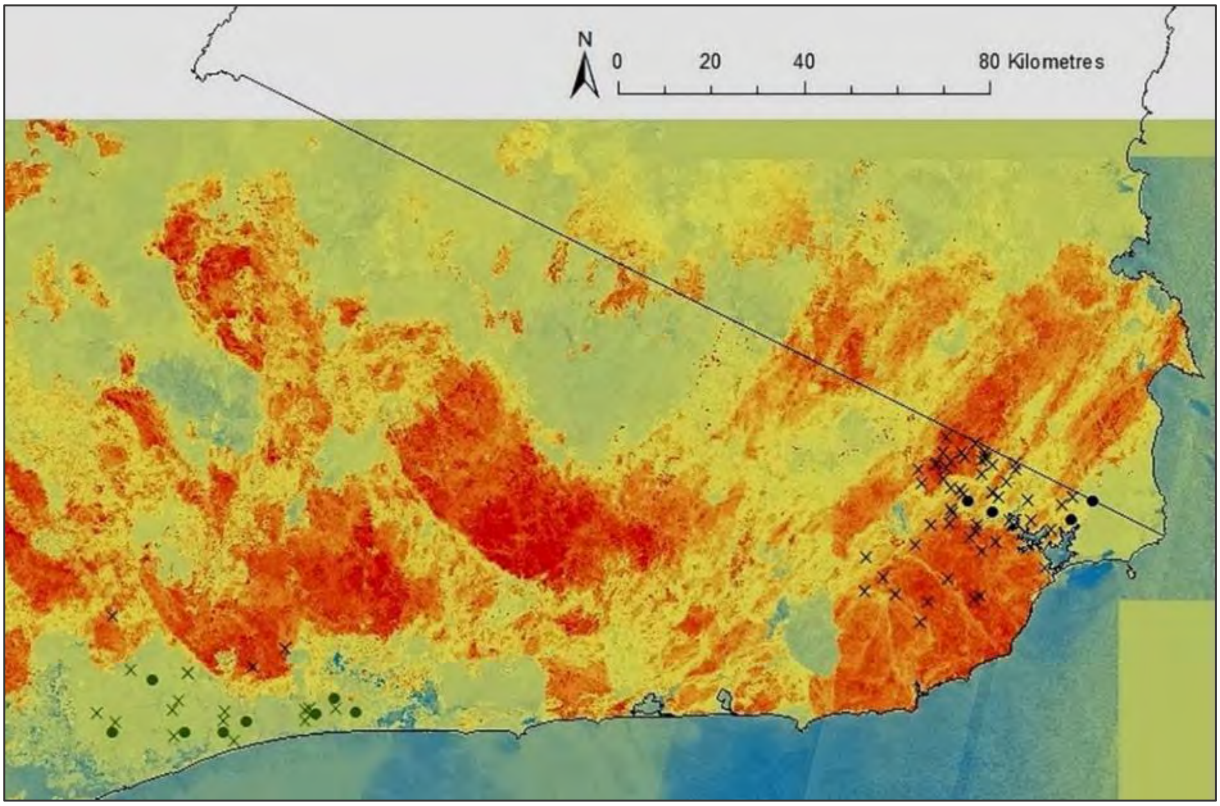

Figure 33. Location of survey sites visited post-fires overlain with modelled fire severity (pale green = unburnt; yellow to red = burnt at increasing severity). The dark-green dots and crosses represent unburnt sites west of Orbost visited in March 2020; black dots and crosses represent burnt sites visited in June 2020. Dots represent chewed cones present beneath at least one *A. littoralis* tree; crosses represent *A. littoralis* present, but no feeding sign found.

If the frequency of fresh feeding sign across *A. littoralis* stands is an index of Glossy Black-Cockatoo abundance, the findings reveal that:

The carrying capacity of burnt stands is roughly one-fifth that of unburnt stands (6.4% and 35.7%, respectively), and probably much less, as the remaining birds are likely to be roaming over a larger area to find living *A. littoralis* with unopened cones still containing seed, and may soon deplete the available food resource.

Five to six weeks after the fires, the population in an extensive patch of unburnt habitat had not noticeably changed, suggesting that few birds had relocated from burnt habitat to areas of unburnt habitat (the coastal plain between Marlo and Lake Tyers).

Risks

Pre-existing risks (i.e. before the bushfires)

The species' extreme dietary specialisation means that it will always be at risk from a reduction in the abundance of fruiting *A. littoralis*. Climate change and associated increased fire risk is likely to be a key driver of *A. littoralis* abundance and the Glossy Black-Cockatoo population number in the future.

Decreasing availability of mature, hollow-bearing eucalypts is also a continuing threat to the reproductive capacity of the species. Major causes of loss of hollow-bearing trees include fire (planned and unplanned), management aimed at enhancing fire suppression capacity, and timber harvesting.

Additional risks driven by the 2019–2020 bushfires

The surveys indicated that the 2019–2020 bushfires are likely to have reduced the Victorian population significantly. The Glossy Black-Cockatoo has low breeding capacity—only a single egg is laid per breeding attempt (Forshaw and Cooper 2016). It may therefore take many years for the population to recover. Further widespread fires during this population recovery period will result in further population decline.

Future directions

Priority actions identified for consideration within DELWP's decision-support tools are as follows:

Revisiting of sites in the unburnt forest between Lake Tyers and Orbost to determine whether the rate of feeding sign is being maintained, and thus whether the population of Glossy Black-Cockatoos can be maintained in the longer term

Revisiting (e.g. at 5-yearly intervals) of a sample of survey points (randomised and incidental) that supported *A. littoralis* before the fires to monitor post-fire recovery of *A. littoralis* stands and the occurrence of Glossy Black-Cockatoo feeding sign

Monitoring of future breeding productivity during late spring and summer to record the proportion of feeding pairs that are accompanied by a juvenile [as in the approach taken for the South-eastern Red-tailed Black-Cockatoo (*Calyptorhynchus banksii graptogyne*)].

Further, all surviving stands of *A. littoralis* are of great significance for this highly specialised bird species, regardless of the size of the stands or the sizes of the constituent trees. A range of age-classes is required to ensure continuity in the availability of mature trees, which provide the most efficient foraging sites (North et al. 2020). This will necessitate great care being taken to avoid crown scorch of *A. littoralis* during future management burns throughout East Gippsland.

The existing timber harvesting prescriptions should also be reviewed to assess their appropriateness for the post-fire environment, with particular emphasis on the retention of mature eucalypts with large hollow spouts for nest sites.

Acknowledgements

This project was funded by the Victorian Government's Bushfire Biodiversity Response and Recovery program.

Matt White (ARI) provided the Habitat Distribution Models for both the Glossy Black-Cockatoo and *A. littoralis*. Edward Tsen and Matt White assisted with the design of the stratified random sampling process to identify sites to be scored for the presence of these two species. Martin Schulz singlehandedly carried out the field work with incredible efficiency and stamina. Tim O'Brien and Jenny Nelson (ARI) arranged funding and provided much-needed administrative support, and Danny Rogers reviewed a draft.

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3.2 Eastern Ground Parrot

Prepared by Peter Menkhorst (ARI)

Summary of bushfire impacts

In Victoria, the stronghold of the Eastern Ground Parrot (*Pezoporus wallicus*) is the extensive mosaic of treeless heaths along the coast and foothills of East Gippsland, east of Lakes Entrance. Smaller populations are known from heaths at Wilsons Promontory, from the north-western foothills of the Otway Ranges (though this population may have died out) and from sedgelands around Long Swamp near Nelson (Emison et al. 1987; R. Hill, DELWP, pers. comm.). The 2019–2020 bushfires in eastern Victoria are estimated to have burnt 33% of the species' modelled habitat in Victoria, including 21% that was burnt at high intensity (Table 1). This level of habitat removal, though temporary, places greater importance (in the short to medium term) on populations that were not subjected to bushfire. Thus, it was deemed important to gain a better understanding of the status of the Eastern Ground Parrot at Wilsons Promontory, the area with by far the largest extent of potential habitat outside East Gippsland.

Summary of key findings

The survey has provided evidence of the persistence of the Eastern Ground Parrot at Wilsons Promontory.

Much more needs to be learned about the size of the Wilsons Promontory population and its habitat preferences.

Deployment of automated recording units (ARUs) in unsurveyed areas of heath in northern Wilsons Promontory and away from access tracks should now be a priority.

Background

The cryptic Eastern Ground Parrot inhabits wet, sedge-rich, treeless coastal heaths in south-eastern Australia, from south-western Victoria to south-eastern Queensland (Forshaw and Cooper 2016). It is classified as Endangered in Victoria [*Flora and Fauna Guarantee Act 1988* (FFG Act) listing, July 2021], but the species is not considered threatened nationally due to the strong Tasmanian population (Oliver et al. 2021). Fire plays an important role in determining Eastern Ground Parrot habitat suitability, due to the influence of fire on floristic diversity and vegetation structure in coastal heaths (Meredith and Jaremovik 1990; Bluff 2016). Consequently, its habitat is patchy in space and time; however, the fire regimes required to produce optimal habitat are not well understood and vary across the broad latitudinal range (Oliver et al 2021).

In Victoria, the stronghold of the Eastern Ground Parrot is the extensive mosaic of treeless heaths along the coast and foothills of East Gippsland, east of Lakes Entrance. Smaller populations are known from heaths at Wilsons Promontory, the north-western foothills of the Otway Ranges (though this population may have died out) and from sedgelands around Long Swamp near Nelson (Emison et al. 1987; R. Hill, DELWP, pers. comm.). Irregular sightings of individual birds at other locations such as Cape Liptrap and the Gippsland Lakes are likely to be dispersing juveniles, rather than signs of a resident population.

The 2019–2020 bushfires in eastern Victoria are estimated to have burnt 33% of the species' modelled habitat in Victoria, including 21% that was burnt at high intensity (Table 1). This level of habitat removal, though temporary, places greater importance (in the short to medium term) on populations that were not subjected to bushfire. Thus, it was deemed important to gain a better understanding of the status of the Eastern Ground Parrot at Wilsons Promontory, the area with by far the largest extent of potential habitat outside east Gippsland.

Despite extensive tracts of heathland that appear to be suitable for the species, there are surprisingly few records of the Eastern Ground Parrot at Wilsons Promontory National Park (NP). It was first reported in an unpublished bird species list prepared in 1909 by the park's first ranger, Charles McLennan (in Cooper 1975). There were only sporadic reports thereafter, until focused surveys undertaken by a team of amateur ornithologists led by Roy Cooper recorded up to 11 birds at an unspecified heathland site in the early 1970s (Cooper 1975). As part of a statewide survey, Meredith and Isles (1980) partially surveyed heathlands in Wilsons Promontory in 1980 and estimated that "population levels were relatively low (<100 birds) due to the old age of the heaths". However, further work undertaken in 1981 led to a revised population estimate of

200–250 birds (Meredith and Jaremovic 1990), but they emphasised that the lack of detailed floristic mapping of heathland and sedgeland at Wilsons Promontory precluded a confident estimate.

Methods

The cryptic behaviour of the Eastern Ground Parrot, and its dense, swampy habitat, mean that standard bird monitoring techniques based on frequency of observation are not appropriate. However, the recent development of ARUs has provided the potential to undertake more efficient surveys by taking advantage of the Eastern Ground Parrot's distinctive song and predictable calling behaviour—birds reliably sing around dawn and dusk (Bluff 2016; Thomas et al. 2020). This approach allows much greater coverage to be achieved per unit time.

Habitat and site selection

A map of broad vegetation classes (Figure 34) was used to identify areas within Wilsons Promontory NP likely to support Eastern Ground Parrot habitat. Within these areas, sites for each ARU were selected visually in the field, based on published descriptions of Eastern Ground Parrot habitat in Victoria (Isles and Menkhorst 1975; Meredith and Isles 1980; Meredith and Jaremovic 1990; Bluff 2016) and on the author's field experience with the species, including at Wilsons Promontory in the 1970s. Recent (post 2010) records in the ebird bird sightings database (https://ebird.org/australia/explore) were also scrutinised to help determine broad areas to survey within Wilsons Promontory NP. Elevated sites that overlooked an expanse of heath (Figure 35) were selected, because elevation of the recorder relative to the source of the sound has been shown to have a significant bearing on detection probability—elevation reduces sound attenuation for ground-frequenting birds by reducing the distance the sound must travel through dense vegetation (Thomas et al. 2020).

Twenty ARUs (Song Meter Mini, Wildlife Acoustics Inc., Maynard MA) were deployed in potential habitat in the north of Wilsons Promontory NP on 15 and 16 December 2020, and data from these units were retrieved on 11 and 12 January 2021. Each ARU was attached via zip-lock ties to a metal garden stake that had been driven into the substrate such that the height of the ARU was 1.5–1.8 m, enough for it to protrude above the surrounding vegetation (Figure 35). The Song Meters were set to record for the 45 minutes before official sunrise and the 45 minutes after official sunset in each 24-hour period. The sampling rate was set at 16,000 Hz (following advice from Sarah Comer, Department of Biodiversity, Conservation and Attractions, Western Australia), and a gain level of x dB (the default setting) was used.

Data analysis

A preliminary analysis of the recorded data was undertaken using Kaleidoscope Lite Analysis software (Wildlife Acoustics). A more complete analysis is planned that will use call recogniser software incorporating artificial intelligence being developed at ARI (P. Griffioen, pers. comm.).

Results

Each of the 20 ARUs provided recordings of birdsong at dawn and dusk over 27 days—a total of 1100 files of data, each of 45 minutes' duration. Aural and visual checking of the sonographs produced by the Kaleidoscope software has revealed Eastern Ground Parrot calls on at least seven of the recorders, four along Vereker Break Track and three towards the eastern end of 5 Mile Road (Figure 34). It is possible that the calls detected by the two southernmost recorders on Vereker Break Track were of the same individual bird because those two recorders were about 80 m apart.

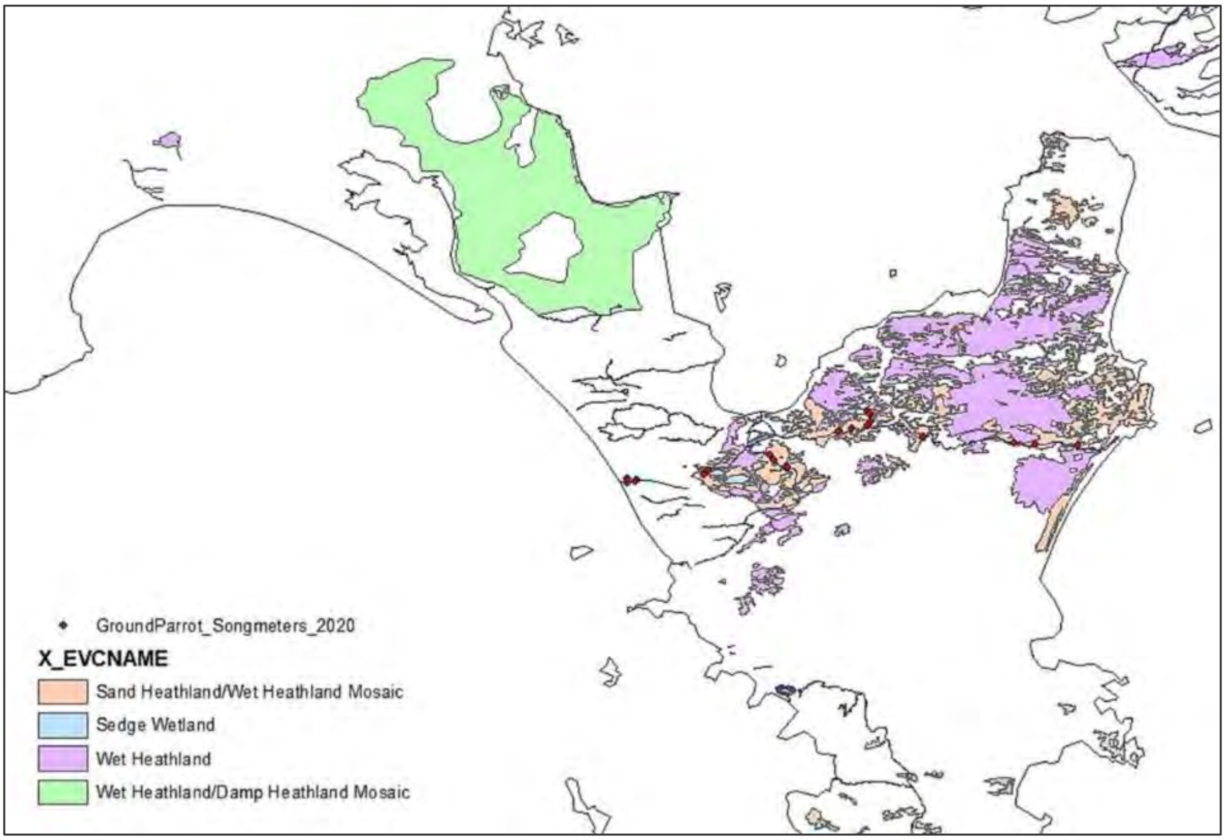

Figure 34. Map of heath vegetation communities in Wilsons Promontory National Park, showing the location of the automatic recording units (red diamonds)

Figure 35. An automatic recording device set along 5 Mile Road, Wilsons Promontory National Park (photo: Peter Menkhorst)

Risks

Pre-existing risks (i.e. before the bushfires)

The species has a very patchy distribution in Victoria, made worse by the extensive clearance of coastal heathland and sedgeland along our coast over the past two centuries. Populations are now highly fragmented, and there is little likelihood of genetic exchange between the populations in the east and west of Victoria. For this reason, the Eastern Ground Parrot has been given a genetic risk score of 'very high'.

Additional risks driven by the 2019–2020 bushfires

The 2019–2020 fires are likely to have reduced the Victorian population by reducing the area of habitat by at least 20%, and probably by 30%. While most of the burnt habitat is likely to become optimal again within a decade or so, the species must survive the intervening period and breed successfully in unburnt refugia.

Future directions

Priority actions identified for consideration within DELWP's decision-support tools are as follows:

Increase the monitoring effort for the Eastern Ground Parrot in East Gippsland and at other Victorian localities that may support the species.

Increase the intensity of control measures for introduced predators within unburnt heathland in East Gippsland and at Wilsons Promontory NP.

Acknowledgements

This project was funded by the Victorian Government's Bushfire Biodiversity Response and Recovery program.

Kasey Stamation and Tim O'Brien assisted with deployment and retrieval of the ARUs, and David Bryant carried out most of the Kaleidoscope analysis of recordings.

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Reptiles and frogs

Spotted Tree Frog (photo: G. Johnson)

The following frog and reptile species or groups were targeted for assessment and are reported on below:

4.1 Spotted Tree Frog and Booroolong Frog

Prepared by Matt West (the University of Melbourne) and Glen Johnson (FFR—Hume Region, DELWP)

Summary of bushfire impacts

The Spotted Tree Frog (*Litoria spenceri*) and the Booroolong Frog (*L. booroolongensis*) are considered Critically Endangered in Victoria (DSE 2013). Disease caused by Chytrid fungus (*Batrachochytrium dendrobatidis*), predation by non-native fish, and habitat loss and degradation have all contributed to population declines of both species. Climate change is also a threat to these species, especially if it increases the duration or frequency of drought conditions, or the frequency, timing and intensity of bushfires. Drought conditions can reduce breeding opportunities for Booroolong Frogs. Bushfire events can kill the frogs, either directly (due to heat) or indirectly (due to loss of cover, loss of food availability, and blackwater events following fire).

Of the Spotted Tree Frog's modelled habitat in Victoria, 22% was within the 2019–2020 bushfire extent; 13% of its modelled habitat in Victoria was affected by high-severity fire. Of the Booroolong Frog's modelled habitat, 39% was within the fire extent; again, 13% was affected by high-severity fire.

Summary of key findings

Three separate post-fire assessments of Spotted Tree Frog populations and two assessments of Booroolong Frog populations were conducted in north-eastern Victoria, to better understand the impacts of the 2019–2020 Victorian bushfires and to identify targeted recovery actions.

Booroolong Frog—February–March 2020 results (first post-fire assessment)

Only two Booroolong Frog populations are known in Victoria, as the species mostly occurs in New South Wales (NSW). The 2019–2020 fires affected one Victorian population that is distributed over two contiguous streams: Burrowye Creek and Guys Forest Creek. Fire intensity was most severe at Guys Forest Creek. Both streams also experienced post-fire flooding events that buried the best breeding habitat in ash, mud, and other debris. Three Booroolong Frogs were found during post-fire surveys, but only at Guys Forest Creek. All three frogs were swabbed for Chytrid, but all were negative. The survey occurred during a period of low frog activity, and additional surveys are required to verify the fire and flood impacts on this species.

Booroolong Frog—November 2020 updated results (second post-fire assessment)

The two fire-affected sites were resurveyed in November 2020, and this time a total of 39 Booroolong Frogs were observed (37 males and 2 females). A similar number of frogs were found at each site, even though there was more than double the amount of available rocky habitat at Guys Forest Creek (186 m of rocky habitat; n = 18 frogs observed) compared with Burrowye Creek (80 m of rocky habitat; n = 21 frogs). Exotic trees (willows and poplars) and grasses are a key problem at both sites, particularly along sections of the Burrowye Creek and in areas that are fenced to exclude livestock. The root systems of these trees and exotic grasses act to reduce the available rocky habitat for the frogs. Tree canopy cover may increase the sites' thermal suitability for Chytrid by shading and therefore lowering solar radiation, thus lowering the ambient temperatures of the streams. Weed control may be crucial to ensure the persistence of the frog population at each site.

Spotted Tree Frog—February–March 2020 results (first post-fire assessment)

The Spotted Tree Frog is predominantly found in north-eastern Victoria, with one historic population in south-eastern NSW. The 2019–2020 bushfires affected approximately half of the known Spotted Tree Frog populations. In Victoria, the fire intensity for two populations was low, for three populations it was moderate, and for two populations it was severe. Post-fire flooding, the associated ash and debris flows, and subsequent sedimentation also affected the populations at locations at which moderate and severe fires occurred. The February–March 2020 post-fire surveys found Spotted Tree Frogs at the locations of three populations, but not at Bundarra River, Buckland River, Buffalo Creek or Dargo River. Chytrid was detected at all surveyed sites. A low-intensity fire at Big River was extinguished before burning the Spotted Tree Frog habitat, and a small population of adults and new metamorphlings were discovered after the fire; 14.2% of the adults found were Chytrid positive. Following a medium- to high-intensity fire, few adults were found on the Wongungarra River, and 70% were Chytrid positive; however, 56 metamorphling frogs were found (over a 4.5-km transect). The Wongungarra population is the only known representation of the Spotted Tree Frog

Wonnangatta Evolutionary Significant Unit (ESU) and likely requires special management intervention to reduce the risk of extirpation. Following the severe-intensity fire at the Wheelers Creek population location, only four frogs were found; there was no evidence of breeding, and three out of the four frogs were Chytrid positive, two dying only minutes after their discovery. The Wheelers Creek population may now be at a high risk of extirpation. Additional surveys are required to verify the findings for all populations and to prepare for management intervention.

Spotted Tree Frog—November 2020 – March 2021 results (second and third post-fire assessments)

Spotted Tree Frogs were found at three of four sites surveyed that were affected by the 2019–2020 bushfires during the second and third post-fire assessments. The most abundant Spotted Tree Frog populations were observed at Big River and Wongungarra River, where the 2019–2020 fire intensity was low and moderate, respectively, but only a small number of adults were detected at each site. The smallest number of frogs (n = 3) were detected at Wheelers Creek, which was one of the most severely fire-impacted sites. Spotted Tree Frogs were not detected at a site on the Dargo River where they had been detected pre-fire (in 2019), but three frogs were detected further upstream during the third survey; the combined survey results suggest that the species is very rare on this stream. Chytrid fungus was detected at all sites, and dead and sick Spotted Tree Frogs at Big River and Wongungarra River tested positive for Chytrid infection. Recruitment appears to have been very low across all known Spotted Tree Frog populations during the 2020–2021 season, and only a low number of metamorphlings were found at the two fire-affected population locations (Big River and Wongungarra River). The poor recruitment seems to be a stochastic event associated with a La Niña year and the accompanying higher rainfall and cooler conditions at sites, which can exacerbate Chytrid impacts on frog populations. This decline in recruitment is likely to further exacerbate the extinction risk of fire-affected populations and further reduce their resilience to future fire and flood events and disease caused by Chytrid. The only individual detected at Wheelers Creek during the third survey was translocated to Zoos Victoria (Healesville Sanctuary) to help establish a captive conservation and insurance population. Twenty-six other frogs were collected from three other populations (Big River, Snowy Creek and Wongungarra River) for the captive program.

Background

Spotted Tree Frog

The Spotted Tree Frog is an obligate stream breeder that is found in north-eastern Victoria and southern NSW (Watson et al. 1991; Gillespie and Hollis 1996; West 2015a). The species prefers swift-flowing streams at between 280 and 1110 m a.s.l. (Gillespie and Hollis 1996). Most populations have been recorded on the north-western fall of the Great Dividing Range, although two populations in Victoria are historically known from the southern fall (Gillespie and Hollis 1996). All records of the Spotted Tree Frog have been from forested mountainous areas within the South Eastern Highlands and Australian Alps bioregions [Interim Biogeographic Regionalisation for Australia (IBRA); https://www.environment.gov.au/land/nrs/science/ibra] bioregions. Fourteen historic Spotted Tree Frog populations are known (13 in Victoria and 1 in NSW) at 50 sites across 21 streams. The populations have been grouped into three genetic clusters or ESUs: the Goulburn River ESU, the Upper Murray River ESU and the Wonnangatta River ESU, which broadly correspond to three river catchments of the same names, except for the Wonnangatta ESU, which is within the Mitchell River Catchment (M. West, S. Donnellan, A. Weeks and G. Gillespie, unpubl. data).

The Spotted Tree Frog is listed as Critically Endangered in Victoria under the Victorian *Flora and Fauna Guarantee Act 1988* (FFG Act). The Spotted Tree Frog is also listed as Critically Endangered in NSW under the NSW *Threatened Species Conservation Act 1995* (TSC Act). The Spotted Tree Frog has disappeared from 50% of known sites and is rare at all remaining sites (West 2015a). Prior to the 2019–2020 bushfires, eight of the Victorian Spotted Tree Frog populations were extant, and the Spotted Tree Frog had been reintroduced in NSW to re-establish the one population at a site from which the species had disappeared and translocated to a separate new site (M. West and D. Hunter, unpubl. data). All extant populations are highly fragmented, with no gene flow between populations, and the distribution within sites on streams is also patchy (M. West, unpubl. data).

Habitat disturbances, including eductor dredging and forestry activities, are likely to have contributed to some population declines (Watson et al. 1991; Gillespie 2001a). However, non-native fish predation of Spotted Tree Frogs and disease caused by Chytrid fungus are considered the primary contemporary threats (Gillespie 2001a; Gillespie 2001b; West et al. 2020). Experimental work has demonstrated that non-native Brown and Rainbow Trout (*Salmo trutta* and *Oncorhynchus mykiss*, respectively) readily eat Spotted Tree Frog tadpoles, whereas native fish species do not (Gillespie 2001b). Chytrid is known to have caused the rapid decline and extirpation of the species at the only known site in NSW (Gillespie et al. 2015). Population modelling indicates that, under some conditions, Spotted Tree Frogs may be able to cope with low levels of non-native fish predation or a low incidence of disease. However, populations cannot cope if conditions are optimal for either or both threats (West et al. 2020).

Bushfire can influence Spotted Tree Frog populations (Gillespie and West 2012). All terrestrial life stages of the Spotted Tree Frog can perish if they are in flammable or shallow shelter sites during bushfires. Frogs at all life stages can suffer from reduced food availability and be more vulnerable to predation with reduced vegetation cover and fewer shelter opportunities. The timing of bushfires and subsequent heavy rainfall events can influence the survival of eggs, tadpoles and metamorphlings.

Half of the remaining Spotted Tree Frog populations were affected by the bushfires in 2019–2020. This included the translocated Spotted Tree Frog populations in NSW which experienced high-intensity fire events. Eight Victorian Spotted Tree Frog sites were directly affected by fire, and other sites were affected by ash and debris flows related to the bushfires.

Spotted Tree Frogs use a wide range of microhabitats in streams and within the surrounding riparian zone. Eggs are deposited under rocks or bedrock crevices within fast-flowing stream sections. After hatching, tadpole development occurs in slower-flowing sections of streams, including connected side pools. Metamorphosing frogs then climb out of the water onto exposed rocks, loose rocky cobble banks, debris, and low vegetation (such as sedges and ferns). The juvenile frogs (metamorphlings) remain near the stream edge as they develop. Adults utilise the same microhabitats as juveniles, but also use larger ferns, shrubs, log jams, and fallen or live trees and overhanging tree branches. Adult frogs have been found in shrubs up to 6 m above the stream (Gillespie 1997) and trees up to 10 m above the stream (M. West, unpubl. data). Individuals have been found up to 30 m from the stream bank (Gillespie 1997). At times, all terrestrial life stages seek shelter under loose rocks, in rock crevices, in soil within banks, under loose tree bark, within trees and log hollows, and under loose fallen vegetation.

Spotted Tree Frog activity is restricted to spring, summer, and early autumn between October and April (Watson et al. 1991; Gillespie and Hollis 1996). Males call from rocks and vegetation within and near to the fast-flowing sections of streams in late October to early January. Breeding and egg deposition predominantly occur in November to early January. Tadpole development and metamorphosis predominantly occur from late December to early March. Adult and juvenile frogs remain active and continue to feed until late March or April. Peak activity occurs at night, but all terrestrial life stages will bask and feed during the day.

The life history of the Spotted Tree Frog varies with elevation and climatic conditions, both of which can influence growth and development (Gillespie 2011; West et al. 2020). Development within eggs to the tadpole stage takes 3–6 weeks. The tadpole stage may last for several weeks to months. Juvenile frog development through to adulthood is influenced by the climatic conditions at particular sites, and maturation is reached earlier (maturation at 3–4 years) at lower warmer elevations compared with cooler higher elevations (maturation at 4–5 years) (Gillespie 2010, 2011). The frogs also tend to live longer at higher-elevation sites, where the cooler conditions restrict their activity more than at lower warmer sites (Gillespie 2010, 2011).

All catchments associated with Spotted Tree Frog populations have been burnt by bushfire over the last two decades, including during the Eastern Victorian Alpine Fires in 2003, the Eastern Victorian Great Divide Fires in 2006–2007, and the Black Saturday Bushfires in 2009. Fire impacts on populations were difficult to evaluate prior to the Black Saturday Bushfires, as the population monitoring program had not been running long enough to disentangle the fire effects from impacts resulting from other factors that can influence populations. In 2009, fires burnt two sites with extant Spotted Tree Frog populations that were being monitored using mark–recapture methods. An investigation following the 2009 fires found that adult Spotted Tree Frogs tended to survive the fire event (Gillespie and West 2012). However, the fire event and subsequent flooding and associated ash and sediment events had a more substantial impact on the survival of the juvenile life stages; only a low level of recruitment occurred in the following year (Gillespie and West 2012). The investigation acknowledged that interpretation of the results was limited due to insufficient replication and the lack of unburnt controls.

The Spotted Tree Frog is a useful case study species for evaluating the impacts of major disturbances like fire and flood on frog populations. A long-term monitoring and research program (established in the early to mid-1990s) now allows a relatively thorough understanding of Spotted Tree Frog population dynamics and the processes that influence both the survival of individual frogs and population persistence (Hero 1990; Watson et al. 1991; Gillespie 1992, 2010; Gillespie and Hollis 1996; West 2015a; West et al. 2020). The previous monitoring permits an opportunity to evaluate the fire impacts on these populations. The current report details the results of surveys undertaken at seven sites in Victoria between 28 February and 28 March 2020, immediately following the 2019–2020 fires.

Booroolong Frog

The Booroolong Frog is known from a broad distribution, primarily in NSW but with two populations in central north-eastern Victoria. Like the Spotted Tree Frog, the species is an obligate stream breeder. However, the two species' distributions do not overlap, as the Booroolong Frog has a more northern distribution than the Spotted Tree Frog. Booroolong Frogs predominantly utilise western-flowing streams of the Great Dividing Range from 200 to 1300 m a.s.l. The Booroolong Frog has been recorded across multiple IBRA bioregions, including the NSW South Western Slopes, the South Eastern Highlands, the Sydney Basin, the Brigalow Belt South, Nandewar, the New England Tablelands and the NSW North Coast.

The Booroolong Frog prefers slow-flowing sections of permanent streams associated with low canopy cover and loose rocky cobble banks or bedrock structures within stream margins (Hunter 2007; Hunter and Smith 2013). The species is predominantly active in the spring and summer months, with the core breeding season occurring between October and January (Anstis et al. 1998; Hunter 2007). At night, males use the rocky substrates, often forming small to large congregations, to call and attract females. Females deposit eggs under submerged rock and attached to rock crevices within shallow slow-flowing stream sections and connected side pools (Anstis et al. 1998; Anstis 2013), where tadpole development also occurs (Anstis et al. 1998). Metamorphosing frogs climb out onto the rocky substrate and use the stream margins as they develop (Anstis et al. 1998). Frogs at all life stages can be found basking during the day (Anstis et al. 1998). At all times of the year, individuals utilise loose rock, rock crevices, and loose vegetation and debris for shelter, particularly during the day. Although frogs may disperse away from the stream following the breeding season, juveniles and adults may remain near the stream and have been observed under rocks within the riparian zone during winter (Anstis et al. 1998; D. Hunter, pers. obs.).

The species is currently listed as Endangered under the NSW TSC Act, Critically Endangered in Victoria under the FFG Act. Key threats include habitat loss and degradation (Hunter 2012; Hunter and Smith 2013), disease caused by Chytrid infection (Hunter 2012; Cashins et al. 2013), and non-native fish predation (Hunter 2007; Hunter et al. 2011; Hunter and Smith 2013). Booroolong Frogs are also sensitive to stream drying during drought, which is predicted to increase under climate change (Hunter 2012).

Bushfire has the potential to influence Booroolong Frog populations. All terrestrial life stages of the Booroolong Frog can perish if they are in flammable or shallow shelter sites during bushfires. Frogs at all life stages can also have reduced food availability and be more vulnerable to predation with reduced vegetation cover and fewer shelter opportunities. The timing of bushfires and subsequent heavy rainfall events can influence the survival of eggs, tadpoles and metamorphlings, particularly if ash, debris and sediment bury egg deposition sites, or juvenile refuge sites.

In Victoria, the Booroolong Frog is known from only two populations. One population was affected by the 2019–2020 bushfires at two sites. NSW Booroolong Frog populations have been severely affected by drought in recent years, and some sites were affected by the 2019–2020 fires (D. Hunter, pers. comm.). The demographic impacts of the bushfires on the NSW Booroolong Frog populations will be assessed separately. The current report details the results of surveys undertaken in March 2020 at the two main fire-affected sites in Victoria.

Methods

First post-fire assessment

Reconnaissance assessments of fire-affected sites were undertaken by teams of two or more, led by personnel experienced in Spotted Tree Frog and Booroolong Frog research, management, and survey methods.

Day and night surveys of (sometimes multiple) 1-km transects within Spotted Tree Frog Special Protection Zones were undertaken at each location between 28 February and 28 March 2020 (the first post-fire assessment). Australia's COVID-19 pandemic restrictions came into place at the end of March 2020 and caused a cessation of field work. All key locations were assessed at least once by 28 March 2020; however, planned repeat assessments at sites were not able to be undertaken after this date. In most situations, existing transects were used so that historical pre-fire data could be used as a benchmark against which to compare the post-fire population status.

The post-fire surveys were designed to detect the maximum number of frogs as well as confirm the relative level of post-breeding recruitment on each stream. Metamorphlings generally emerge from the stream from mid-February (depending on the seasonal climate), and surveys are generally viable until early to mid-April. To further maximise frog detection, day surveys were undertaken to coincide with favourable sunny warm weather during the late morning to mid-afternoon period. Night surveys were conducted under headlamp if dusk temperatures were above 10°C.

All frogs of all species detected were recorded by logging individual GPS waypoints. All targeted Spotted Tree Frogs and Booroolong Frogs and a proportion of other frog species were temporarily hand-captured and swabbed. Each swab was allocated a unique number, which was also used as the GPS waypoint number to cross-reference the location of each captured frog, together with its related metadata (species, age, sex, tissue sample and other general observations) and Chytrid infection status. Swabs were refrigerated at the earliest opportunity post–field collection and held in this state until polymer chain reaction (PCR) analysis (for detecting the DNA of Chytrid fungus) could be undertaken to determine each individuals Chytrid infection status, following methods adapted by West (2015a) [from Boyle et al. (2004)].

Protocols to preclude potential disease transmission between frogs were adopted in all instances. Each frog was processed (handled and swabbed) using a new pair of surgical nitrile gloves, and equipment was cleaned by flaming or with 95% ethanol if it contacted a frog during processing (Figure 36). Frog snout–vent measurements were undertaken using callipers and a process that avoided calliper contact with the frog.

A toe-tip tissue sample was collected from a representative number of the captured Spotted Tree Frog individuals at each site. A maximum of 10 Spotted Tree Frog tissue samples were collected per kilometre from each site. Tissue samples were stored in 95% ethanol for future genetic analysis (genotyping).

Second and third post-fire assessments

The two Booroolong Frog sites were resurveyed in November 2020 to count frogs and quantify the available rocky habitat. These surveys were conducted with Dr David Hunter (NSW Department of Planning, Industry and Environment), during the species' peak activity period. Booroolong Frogs were recorded but not captured and swabbed during these second post-fire assessments. Instead, the amount of available rocky habitat was evaluated, because this is a key habitat requirement for the species' persistence.

Four Spotted Tree Frog sites were resurveyed between November and December 2020 (the second post-fire assessments) and between February and March 2021 (the third post-fire assessments) to verify the status of key populations during the frog's first post-fire breeding and active season (10–14 months after the fire event). Surveys were conducted at the Big River, Dargo River, Wheelers Creek and Wongungarra River sites. During these surveys, all observed frogs were counted and, where possible, captured and swabbed to evaluate the proportion of Chytrid-infected frogs. During the third post-fire assessments, founders were also captured to help establish a new captive conservation breeding and insurance population at Zoos Victoria. Tissue samples were only taken from frogs that were found dead during surveys. All other survey methods were the same as those described for the first post-fire assessments.

Figure 36. Swab sampling a Spotted Tree Frog for Chytrid fungus (photo: Adam Lee)

Results

First post-fire assessment

A total of seven Spotted Tree Frog and two Booroolong Frog fire-affected locations were assessed within the boundary of the 2020 north-eastern Victoria fire (Table 14, Figure 37, Figure 38). Fire intensity varied at a landscape scale (Jarrod Bowd, Parks Victoria, pers. comm.), and the extent to which the bushfires affected frog sites varied. Of the assessed sites, low-intensity burns occurred at two Spotted Tree Frog sites (e.g. Figure 39, Figure 40) and one Booroolong Frog site, medium-intensity burns occurred at three Spotted Tree Frog sites (e.g. Figure 41), high-intensity burns occurred at one Spotted Tree Frog site (Figure 42) and one Booroolong Frog site, and a very high-intensity burn occurred at one Spotted Tree Frog site (Figure 43). Fire was stopped before reaching the stream sections used by frogs at one Spotted Tree Frog site (Big River) and one Booroolong Frog site (Burrowye Creek). At other sites, approximately 70–95% of the vegetation was burnt.

Based on pre-bushfire surveys, and observations from post-fire reconnaissance flights and field inspections, the most serious threats to frog populations in the immediate post-fire period are disease caused by Chytrid, predation by non-native fish [and potentially Red Foxes (*Vulpes vulpes*) and Cats (*Felis catus*)], and injury, suffocation and death associated with post-fire flood ash and debris flows. However, these threats did not operate equally across the fire area. Post-fire ash and debris flows impacts varied depending on the proximity of the burn to the stream edge and the intensity of the burn at the catchment scale (Figure 44, Figure 45, Figure 46). Occasionally, some threats may temporarily subside after fire, such as predation by non-native fish [e.g. Brown Trout, Rainbow Trout, Carp (*Cyprinus carpio*) and Redfin (*Perca fluviatilis*)] that may also have been negatively affected by the fires and post-fire flooding.

Critically, the 2019–2020 bushfire and flood events occurred towards the end of the Spotted Tree Frog breeding season and during the egg and tadpole development life stages. Spotted Tree Frogs were detected at three of the seven surveyed sites (Big River, Wheelers Creek and Wongungarra River; Table 15, Figure 47). Numerous metamorphling and adult Spotted Tree Frogs were detected at two sites (Big River and Wongungarra River; Table 15). At the most severely burnt known extant population, on Wheelers Creek, only one juvenile and three adult Spotted Tree Frogs were detected during surveys, despite searching over 3 km of stream.

The 2019–2020 bushfire and flood events occurred after the peak breeding season but during the tadpole developmental and metamorphling emergence periods for the Booroolong Frog populations. Extensive diurnal surveys were undertaken at the two assessed Booroolong Frog sites. Only three Booroolong Frogs were detected at Guys Forest Creek, and none were detected at Burrowye Creek (Table 16).

Table 14. Spotted Tree Frog reconnaissance survey sites and DELWP 2019–2020 fire information

Survey site	Reported catchment burn intensity	Fire district and fire number—fire name name
Wheelers Creek	Very high	Upper Murray 26—Upper Murray – Walwa
Big River	Low	Upper Murray 12—Glen Valley – Frog Track
Bundara River	High	Tambo 60—Shannonvale – McNamara Hut
Buckland River	Medium	Ovens 41—Abbeyard
Wongungarra River	Medium	Macalister 43—Hotham Heights – Blue Rag Range
Dargo River	Medium	Tambo 60—Shannonvale – McNamara Hut
Buffalo Creek	Low	Ovens 41—Abbeyard
Burrowye Creek	Low	Upper Murray 26—Upper Murray – Walwa
Guys Forest Creek	High	Upper Murray 26—Upper Murray – Walwa

Four other frog species were detected at the Spotted Tree Frog sites (Table 15, Figure 48). Lesueur's Frogs (*Litoria lesueurii*) were present at all seven Spotted Tree Frog sites, with low numbers detected at most sites except for Wheelers Creek, where 84 frogs were found (50 adults, 5 subadults, 10 juveniles, 19 metamorphlings). Leaf Green Tree Frogs (*Litoria nudidigita*) were found at Dargo River (*n* = 6), Plains Brown Tree Frogs (*L. paraewingi*) were found at Buckland River (*n* = 2) and Buffalo Creek (*n* = 14), and Dendy's Toadlets (*Pseudophryne dendyi*) were found at Wheelers Creek (1 observed and ~4 others heard calling). The presence of Dendy's Toadlet at Wheelers Creek was notable, as previously known calling sites (M. West, unpubl. data) were buried in large amounts of ash and sediment, but obviously some toadlets were able to dig their way out or were not completely buried. The only other frog species detected at a Booroolong Frog site was the Common Eastern Froglet (*Crinia signifera*), which was calling in a marshy area adjacent to Burrowye Creek.

Dead and sick frogs were also encountered at three Spotted Tree Frog sites during surveys immediately following the 2019–2020 bushfires (Figure 50). The sick frogs displayed symptoms consistent with moderate to late stages of chytridiomycosis, including lethargy, sticky and sloughing skin, and a reluctance or inability to right themselves when turned onto their backs. At Wongungarra River, one dead adult Spotted Tree Frog was found in the water (Figure 50) near metamorphlings on a cobble bank, two sick adult Spotted Tree Frogs were found on a log perching near one another, and one recently deceased metamorphling Leaf Green Tree Frog was found floating in the water on the stream edge (Figure 51). All three adult Spotted Tree Frogs found at Wheelers Creek were sick, and two died within minutes after capture (Figure 50). Lesueur's Frogs were also found with mild signs of chytridiomycosis at Wheelers Creek, but the symptoms were considered less severe as the frogs were able to right themselves and had enough strength to leap away and find shelter upon release. One Spotted Tree Frog was also encountered with mild to moderate signs of chytridiomycosis at Big River. The bodies of frogs that were found dead or that died soon after capture were retained for post-mortem analysis, so that if there was an infection the pathogen could be isolated for future experimental use. No sick or dead frogs were detected at the Booroolong Frog sites. Swabs of sick and dead frogs were taken, and PCR testing revealed that the sick and dead frogs at all Spotted Tree Frog sites were all infected with Chytrid; there was no incidence found at Booroolong Frog sites (Table 17).

The incidence of Chytrid infection was highest at Wheelers Creek, where all three (100%) detected adult Spotted Tree Frogs were Chytrid positive; one 1-year-old Spotted Tree Frog was Chytrid negative, and just under half (46%) of the individuals of other frog species tested were Chytrid positive. Infections were also high in adult Spotted Tree Frogs at Wongungarra River, with 7 of 10 (70%) adult frogs testing positive, although infections were lower in the younger life stages, with 8 of 46 (17%) of metamorphlings testing Chytrid positive. Chytrid infections were less at Big River, with two of 14 (14.3%) adults and two of 26 (7.7%) metamorphlings testing positive; overall, at Big River, 10% of Spotted Tree Frogs were Chytrid positive. Positive Chytrid results were also confirmed in Leaf Green Tree Frogs at Wongungarra River (39.4%, *n* = 66 tested), Plains Brown Tree Frogs at Buffalo Creek (11.1%, *n* = 9 tested), and Lesueur's Frogs at Buckland River (36%, *n* = 11 tested), Buffalo River (25%, *n* = 4 tested), Bundara River (100%, *n* = 1 tested), Dargo River (30%, *n* = 20 tested), Wheelers Creek (46%, *n* = 34 tested) and Wongungarra River (50%, *n* = 8 tested).

Non-native fish (i.e. trout) species were observed at Big River, Buckland River, Buffalo River, Dargo River and Wongungarra River during the survey period. The water quality was too poor to verify fish presence at other sites. Blackberry (*Rubus fruticosus*) was present at all sites with intact vegetation, except at Wongungarra River. Willow (*Salix cinerea*) was observed at Buffalo Creek, Wongungarra River, Burrowye Creek and Guys Forest Creek. Poplar (*Populus nigra*) was observed at Burrowye Creek and Guys Forest Creek.

Second post-fire assessment results for Booroolong Frogs

A total of 39 Booroolong Frogs were detected at the two sites during the second post-fire assessments (Table 16, Figure 49). This included 17 adult males and 1 adult female at Guys Forest Creek, and 20 adult males and 1 adult female at Burrowye Creek. A greater length of the rocky habitat was found and mapped at Guys Forest Creek (186 m), compared with Burrowye Creek (80 m) (Table 16). Willow and poplar trees occur at both sites, and have been promoted to grow particularly along Burrowye Creek.

Second and third post-fire assessment results for Spotted Tree Frogs

Spotted Tree Frogs were detected at three of the burnt sites during the second and third post-fire assessment periods (Big River, Wheelers Creek and Wongungarra River). Figure 52, which shows the average number of Spotted Tree Frogs per kilometre in each age class, reveals that low numbers of frogs were encountered at all sites and that the species was particularly uncommon at Wheelers Creek. Spotted Tree Frogs were not detected at the previous known site on the Dargo River, but four individuals were detected further upstream, including three (all males) during the third post-fire assessment period and one adult female during the December 2020 willow control works undertaken by a contractor engaged by the East Gippsland Catchment Management Authority.

Metamorphling Spotted Tree Frogs were only detected at two of the assessed sites (Big River and Wongungarra River) in the third post-fire assessment period. Furthermore, fewer metamorphling frogs were detected at the two sites in the third post-fire assessment compared with the first post-fire assessment (Figure 52). Several other frog species were detected during surveys of streams occupied by Spotted Tree Frogs; their detection rates varied, as shown in Figure 53.

Dead and sick frogs were encountered at Wheelers Creek, Big River and Wongungarra River. These included one Chytrid-negative metamorphling Spotted Tree Frog found at Big River during the third assessment, and two Spotted Tree Frogs found at Wongungarra River in each reporting period, all of which were Chytrid positive. Three dead Lesueur’s frogs were also found at Wheelers Creek during the third assessment, of which two were Chytrid positive. Other individuals displaying mild symptoms of chytridiomycosis were found among the tested Spotted Tree Frogs, Lesueur’s Frogs and Leaf Green Tree Frogs that were captured at Big River, Dargo River, Wheelers Creek and Wongungarra River. Testing of these frogs confirmed Chytrid infection in most cases.

Chytrid-infected frogs were confirmed via PCR analysis of swabs at Big River, Dargo River, Wheelers Creek and Wongungarra River (Figure 54). Chytrid-positive Spotted Tree Frogs were detected at Big River and Wongungarra River during the second and third survey periods. However, none of the Spotted Tree Frogs found at Dargo River and Wheelers Creek were chytrid positive during the same period. The average percentage of Chytrid-positive Spotted Tree Frogs across all assessment periods was 12.5% at Big River and 29.8% at Wongungarra River. During the second and third assessments, positive Chytrid results were also confirmed in Leaf Green Tree Frogs at Dargo River and Wongungarra River; in Lesueur’s Frogs at Dargo River, Wheelers Creek and Wongungarra River; and in a Common Eastern Froglet at Dargo River (Figure 54).

With DELWP Translocation Evaluation Panel approval, Spotted Tree Frogs were collected from four sites to establish a captive conservation breeding and insurance program at Zoos Victoria for bushfire-affected populations. Assessment of the need for the collection of frogs from each site was based on extinction risk, population importance and genetic representation criteria, and the availability of an alternative secure translocation site (in this case captivity) (see Table 20). During the third post-fire assessment, 12 individuals were collected from the Upper Murray ESU and 14 individuals from the Wonnangatta ESU (listed in Table 19). Where possible, metamorphling frogs were collected, to minimise the impact on the remaining wild population (as only a very small proportion of frogs at this stage survive to maturity in the wild). However, 13 frogs were collected at later life stages (4 subadult females, 2 subadult males, 2 adult females and 5 adult males).

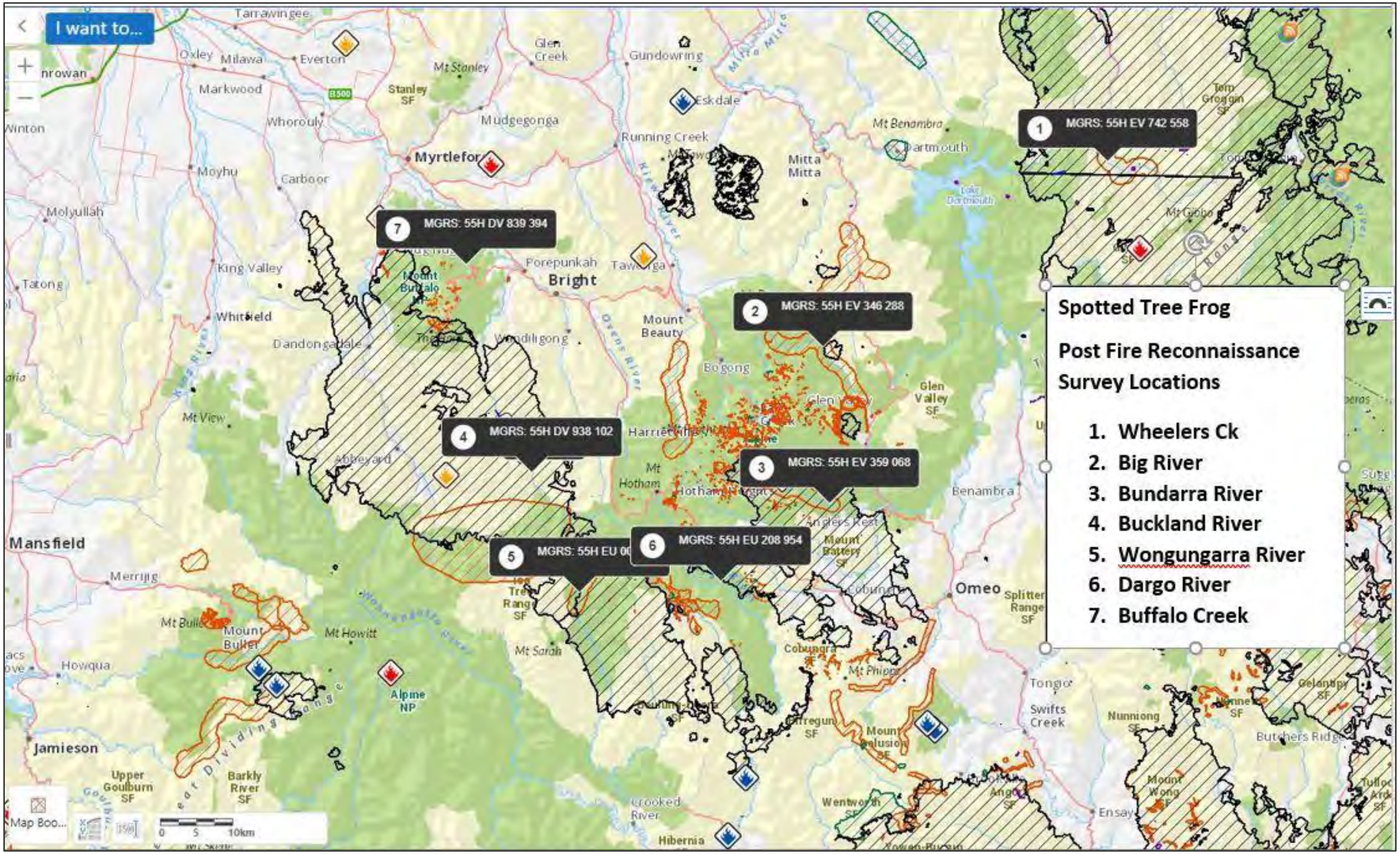

Figure 37. Spotted Tree Frog survey locations within the boundary of the 2020 bushfires (hatched black area)

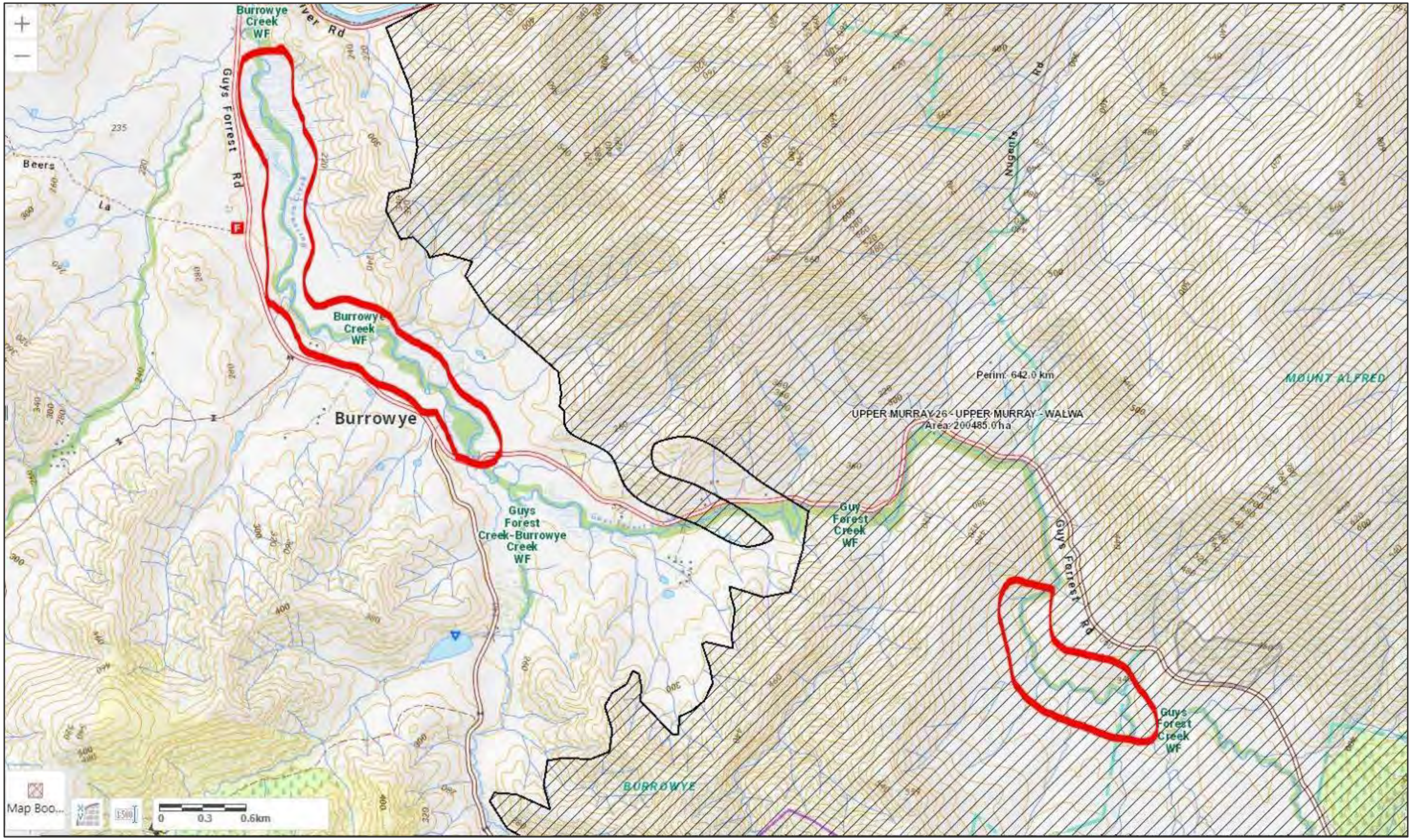

Figure 38. Booroolong Frog survey sites (outlined in red) and Upper Murray #26 Walwa fire boundary (black diagonal hatch zone) on Burrowye and Guys Forest Creeks, Burrowye

Figure 39. Big River: a low-impact fire was extinguished before reaching the stream edge. Burnt understorey vegetation can be seen at the far end of the stream (photo: Matt West).

Figure 40. Buckland River: a site that experienced low-impact fire damage, evidence of the fire is difficult to see from the stream (photo: Matt West)

Figure 41. Wongungarra River post-fire surveys. Upper: a section burnt by a moderate- to high-intensity fire (photo: Adam Lee). Middle left: Wongungarra River helipad and survey team drop-off (photo: Glen Johnson). Middle right: helipad camp site (photo: Glen Johnson). Lower left: survey personnel (photo: Adam Lee). Lower right: Wongungarra River survey, showing section burnt by low- to moderate-intensity fire (photo: Glen Johnson)

Figure 42. Two areas of the Bundara River, showing the severe fire impact 1 month after the 2020 fires. Minimal signs of vegetation regrowth can be seen. (photos: Matt West)

Figure 43. Wheelers Creek surveys. Upper: severe fire impact with signs of regrowth 1 month after the bushfires; lower: showing survey team processing a Spotted Tree Frog in the hand [photos: Matt West (upper + lower right) and Gabrielle Vening (lower left)]

Figure 44. Bundara River—post-fire and flood ash and sediment in stream (photo: Matt West)

Figure 45. Dargo River—post-fire and flood ash and sediment in stream (photo: Matt West)

Figure 46. Wheeler's Creek—post-fire and flood ash and sediment in stream (photo: Matt West)

Figure 47. Spotted Tree Frogs encountered during surveys. Upper left: Spotted Tree Frog undergoing metamorphosis (metamorphling with tail), Big River; upper right: Spotted Tree Frog metamorphling, Wongungarra River; lower: adult female Spotted Tree Frog, Big River (photos: Matt West)

Figure 48. Other frog species encountered during the post-fire Spotted Tree Frog surveys. Upper left: Leaf Green Tree Frog (*Litoria phyllochroa*), Dargo River; upper right: Plains Brown Tree Frog (*Litoria paraewingi*), Buffalo Creek; middle left: Dendy's Toadlet (*Pseudophryne dendyi*), Wheelers Creek; middle right: Lesueur's Frog (*Litoria lesueuri*), Wheelers Creek; lower: the only frog found at Bundara River: Lesueur's Frog (photos: Matt West)

Figure 49. Post-fire and -flood surveys for Booroolong Frogs. Upper and middle left: Guys Forest Creek, showing cobble banks covered in sediment; middle right: Burrowye Creek stream section that was relatively unburnt, although the site experienced severe flooding; lower: Booroolong Frog on Guys Forest Creek (photos: Matt West)

Figure 50. Recently deceased adult Spotted Tree Frogs at Wheelers Creek (upper photo) and Wongungarra River (lower photo). Swabbing and PCR tests confirmed that both individuals were infected with Chytrid fungus. The dead Wongungarra River Spotted Tree Frog was found in the water near to a recently metamorphosed Spotted Tree Frog (photos: Matt West).

Figure 51. A recently deceased metamorphling Leaf Green Tree Frog on the Wongungarra River found during the post-fire surveys. A swab and PCR test confirmed that this individual was infected with Chytrid fungus (photo: Matt West).

Table 15. Number of frogs detected at each of the Spotted Tree Frog sites assessed immediately following the 2019–2020 bushfires, during the first post-fire assessment period. The number of individuals observed in each age class is shown. No tadpoles were encountered. For frogs other than Spotted Tree Frogs, the species name is given, and the number of individuals is in parentheses.

Site	Survey season	Surveyed distance (km)	Numbers and health status of Spotted Tree Frogs detected						Numbers and health status of other frog species detected		
			Total	Adults	Sub-adults	1-year-old	Meta-morphlings	Injured, sick or dead	Species	Injured, sick or dead	Total individuals
Big River	1	1.5	**48**	14	2	0	32	3	None	0	**0**
Bundara River	1	1	**0**	0	0	0	0	0	*Litoria lesueurii* (1)	0	**1**
Buckland River	1	2.5	**0**	0	0	0	0	0	*Litoria lesueurii* (11)	1	**11**
Buffalo River	1	2	**0**	0	0	0	0	0	*Litoria lesueurii* (1)	0	**9**
									Litoria paraewingi (8)	0	
Dargo River	1	3	**0**	0	0	0	0	0	*Litoria lesueurii* (20)	1	**26**
									Litoria nudidigita (6)	0	
Wheelers Creek	1	3	**4**	3	0	1	0	3	*Litoria lesueurii* (34)	1	**35**
									Pseudophryne dendyi (1)	0	
Wongungarra River	1	4.5	**67**	10	1	0	56	4	*Litoria lesueurii* (6)	4	**59**
									Litoria nudidigita (53)	1	

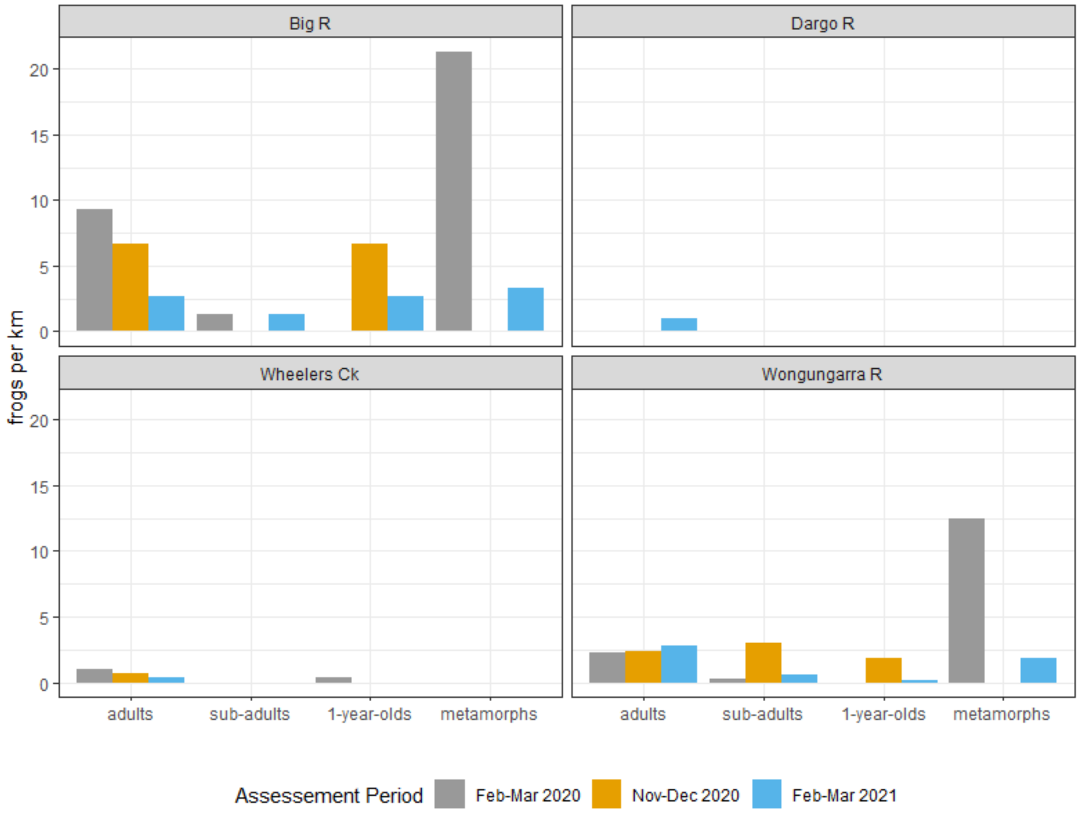

Figure 52. The average numbers of each age class of Spotted Tree Frogs that were observed per kilometre at the four streams during the three post-fire assessment periods—February–March 2020, November–December 2020 and February–March 2021

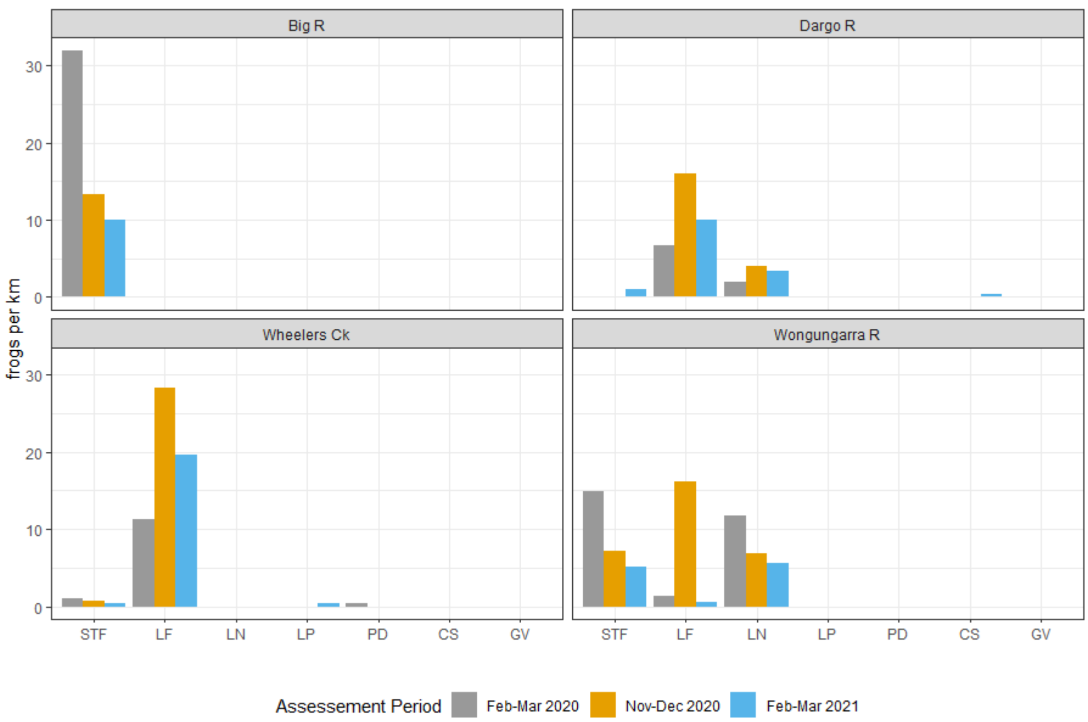

Figure 53. The average numbers of each frog species that were observed per kilometre at the four streams occupied by Spotted Tree Frogs during the three post-fire assessment periods—February–March 2020, November–December 2020 and February–March 2021. STF = Spotted Tree Frog, LF = Lesueur's Frog, LN = Leaf Green Tree Frog, LP = Plains Brown Tree Frog, PD = Dendy's Toadlet, CS = Common Eastern Froglet and GV = Eastern Smooth Froglet.

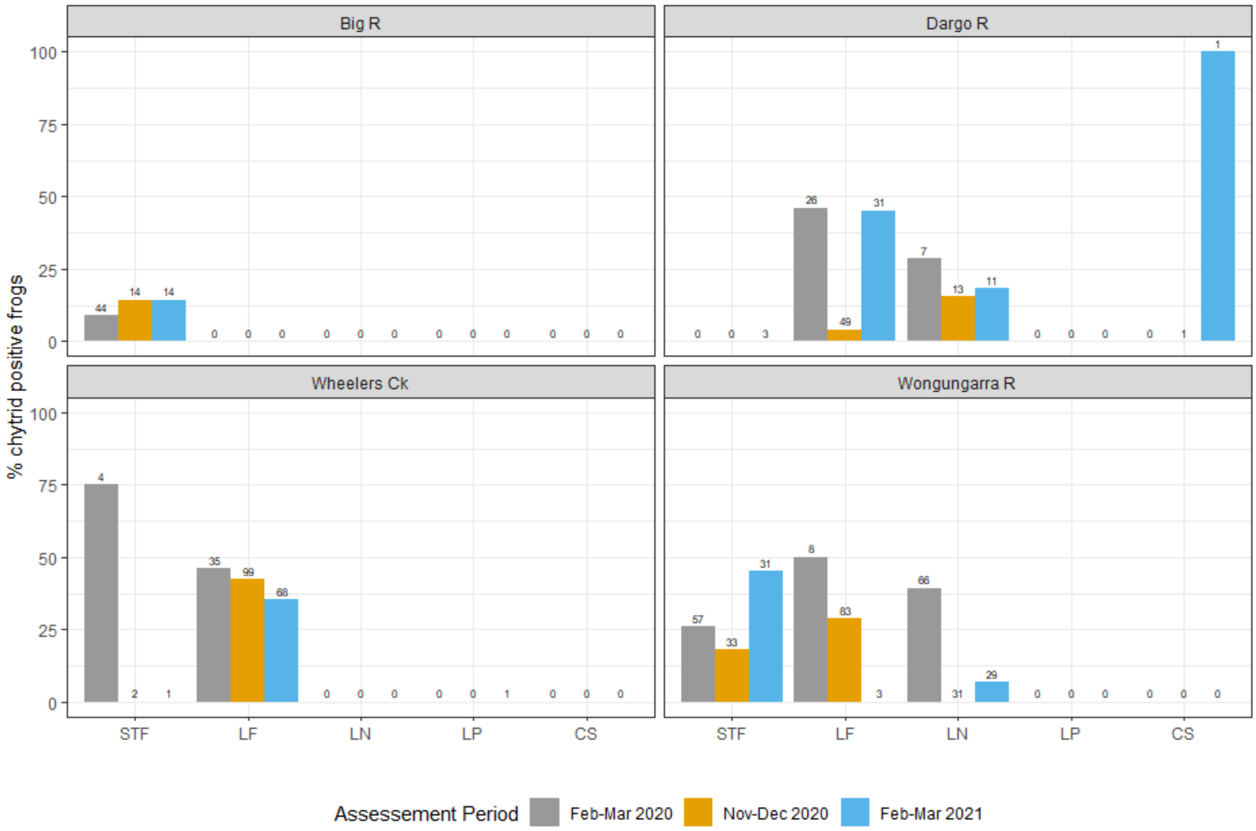

Figure 54. The percentage of frogs that tested positive for Chytrid at four streams occupied by Spotted Tree Frogs during the three post-fire assessment periods—February–March 2020, November–December 2020 and February–March 2021. Results are provided for all tested frog species. STF = Spotted Tree Frog, LF = Lesueur's Frog, LN = Leaf Green Tree Frog, LP = Plains Brown Tree Frog and CS = Common Eastern Froglet.

Table 16. Number of frogs detected at each of the Booroolong Frog sites assessed following the 2019–2020 bushfires. The number of individuals observed in each age class is shown. No tadpoles were encountered. No other frog species were detected on the stream, but one species, Common Eastern Froglet, was heard calling in marshy areas neighbouring Burrowye Creek.

Site	Surveyed distance (km)	Available rocky habitat (m)	Booroolong Frog detections							Other frog species detected		
			Total	Adults	Sub-adults	1-year-olds	Meta-morphlings	Meta-morphling with tail	Injured, sick or dead	Species	Injured, sick or dead	Total individuals
First post-fire assessments												
Guys Forest Creek	1	Not assessed	3	2	1	0	0	0	0	None	–	–
Burrowye Creek	1	Not assessed	0	0	0	0	0	0	0	*Crinia signifera*	–	Chorus heard, none seen
Second post-fire assessment												
Guys Forest Creek	1	186	18	18	0	0	0	0	0	*Limnodynastes dumerilii*	–	3
Burrowye Creek	2	80	21	21	0	0	0	0	0	*Limnodynastes dumerilii*	–	1
										Litoria peronii	–	3

Table 17. Swabbing effort and Chytrid testing results for frogs at each of the Spotted Tree Frog and Booroolong Frog sites during the first season (February–March 2020) surveys after the 2019–2020 bushfires. Chytrid (*Bd*) results indicate the percentage of swabbed frogs that tested positive (+ve).

Site	Surveyed distance (km)	Spotted Tree Frog		Booroolong Frog		Other frog species		Comment
		Total frogs swabbed	% Chytrid positive	Total frogs swabbed	% Chytrid positive	Total frogs swabbed	% Chytrid positive	
Spotted Tree Frog sites								
Big River	1.5	44	9	–	–	0	–	14.2% of (2 of 14) adult STFs *Bd* +ve 7.6% of meta (2 of 26) STFs *Bd* +ve
Bundara River	1	0	–	–	–	1	100	Only *L. lesueurii* frog found *Bd* +ve
Buckland River	2.5	0	–	–	–	11	36	
Buffalo River	2	0	–	–	–	16	12.5	
Dargo River	3	0	–	–	–	26	23	
Wheelers Creek	3	4	75	–	–	35	46	100% of (all 3) adult STFs *Bd* +ve
Wongungarra River	4.5	57	26	–	–	74	40.5	70% of (7 of 10) adult STFs *Bd* +ve 0% of (0 of 4) juv STFs *Bd* +ve 17.4% of (8 of 46) meta STFs *Bd* +ve
Booroolong Frog sites								
Guys Forest Creek	1.5	–	–	3	0	0	–	No *Bd* detected at site
Burrowye Creek	1	–	–	0	–	0	–	No *Bd* detected at site

Bd = Chytrid fungus (*Batrachochytrium dendrobatidis*); juv. = juvenile; *L. lesueurii* = *Litoria lesueurii*; meta = metamorphling; STF = Spotted Tree Frog.

Table 18. Summary comparing reported catchment fire burn intensity, and observed assessed fire impacts, post-fire sedimentation and other threats for each site during the first, second and third post-fire assessment periods (dash indicates threat not assessed)

Survey site	Reported catchment burn intensity	Riparian frog habitat burnt (Y or N)	Surrounding catchment burnt (Y or N)	Observed bushfire impacts on frog habitat	Post-fire sedimentation and debris flows? (1st period)	Post-fire Chytrid detected? (1st period)	Post-fire non-native fish detected? (1st period)	Post-fire Chytrid detected? (2nd + 3rd periods)	Post-fire non-native fish detected? (2nd + 3rd periods)
Spotted Tree Frog sites									
Wheelers Creek	Very High	Y	Y	Severe	Severe	Y	N	Y	N
Big River	Low	N	Y	Negligible	Negligible	Y	Brown + Rainbow Trout	Y	Brown Trout + Rainbow Trout
Bundara River	High	Y	Y	Severe	Severe	Y	Brown + Rainbow Trout	–	–
Buckland River	Medium	Y	Y	Low to medium in patches	Medium	Y	Brown + Rainbow Trout	–	–
Wongungarra River	Medium	Y	Y	Medium to very high in patches	Low to medium	Y	Brown + Rainbow Trout	Y	Brown Trout + Rainbow Trout
Dargo River	Medium	N	Y	Medium to very high in patches	Medium to severe	Y	Brown + Rainbow Trout	Y	Brown Trout + Rainbow Trout
Buffalo Creek	Low	N	Y	Negligible	Negligible	Y	Brown + Rainbow Trout	–	–
Booroolong Frog sites									
Burrowye Creek	Low	N	Y	Low	Medium	N	N	–	N
Guys Forest Creek	High	Y	Y	Severe	Very high	N	N	–	N

Table 19. Number of Spotted Tree Frogs collected at four sites to help establish a captive conservation breeding and insurance program at Zoos Victoria during the third post-fire assessment

Site	ESU	Metamorphlings	Juvenile or subadult males/females	Adult males/females	Total
Big River	Upper Murray	3	2 M / 2 F	2 M	9
Snowy Creek	Upper Murray	2	–	–	2
Wheelers Creek	Upper Murray	–	–	1 F	1
Wongungarra River	Wonnangatta	8	2 F	3 M / 1 F	14

Spotted Tree Frog

During the first post-fire assessment, Spotted Tree Frogs were present at three of the seven sites surveyed and affected by the 2019–2020 bushfires. Effective fire suppression activities that prevented fires reaching the stream are likely to have ensured the immediate survival of the Big River Spotted Tree Frog population. During post-fire surveys at Big River, a small number (n = 14) of adults were detected, and modest juvenile recruitment was observed. While similar numbers of Spotted Tree Frogs were detected at Wongungarra River, this was over a much larger distance (1.5 km at Big River vs 4.5 km at Wongungarra River). The initial Spotted Tree Frog survival and recruitment success at Wongungarra River may have been because the fire activity along the surveyed area was patchy, even though in some patches fire intensity was high. The effects of post-fire flooding may also have been relatively low at the Wongungarra River, as during the surveys the stream was running clear, and most unburnt vegetation and the rocky cobble areas were free of ash and sediment. The survey results suggest that Spotted Tree Frogs are at a particularly low abundance on the Wheelers Creek, with only three adults, one 1-year-old frog and no evidence of recent (2019–2020) breeding (tadpoles or metamorphlings) found during the post-fire and flood surveys. The high- to severe-intensity fire activity (which dramatically reduced the streamside vegetation) and subsequent extensive ash, debris and sedimentation flows are likely to have contributed to the findings at Wheelers Creek.

Statistical modelling suggests that Spotted Tree Frogs may have already disappeared from three surveyed sites (Bundara River, Buckland River and Buffalo Creek) prior to the recent fire and flood events (West 2015a; West et al., in prep). Spotted Tree Frogs were not found at these sites during surveys, providing further evidence of the species' likely extirpation. At Buffalo Creek, an earlier attempt had been made to reintroduce Spotted Tree Frogs (West and Marantelli 2014; West 2015b). The poor survival of the reintroduced Spotted Tree Frogs at Buffalo Creek was primarily attributed to disease caused by Chytrid infection (West 2015b). Fire did not directly affect the Buffalo Creek survey site, and so is not likely to be contributing to the Spotted Tree Frog survey results for the 2019-2020 season. Fire intensity along the Buckland River was moderate and patchy, and the impact on other frog populations in the survey zone appears to have been low, with mostly intact streamside vegetation and reasonable numbers of Lesueur's Frogs found. Fire effects on frog populations may have been high at Bundara River, with only one frog (a Lesueur's Frog) found following the high- to severe-intensity burn that almost eliminated streamside vegetation. The stream bed and bank were also heavily affected by post-fire flooding and the associated ash, debris and sedimentation flows.

Spotted Tree Frogs had been discovered for the first time at one site (Dargo River) in the months immediately prior to the 2019–2020 fires (M. West, unpubl. data), yet no individuals were found following the recent bushfire and flood events. The site has now been burnt twice in the last 2 years, although fire activity was at a low to moderate severity in 2019–2020. Only one individual frog was known at the site prior to the 2019–2020 bushfires. The vegetation at the specific location on the stream at which the Spotted Tree Frog had been found was not directly burnt; however, large amounts of ash and sediment covered the streamside vegetation and the rocky cobble bank areas immediately downstream of the capture location. If breeding occurred at the site, then survivorship of the early Spotted Tree Frog life stages is likely to have been reduced by the extensive ash and debris flows. Brown trout and rainbow trout were observed at the site, both before and after the bushfire and flood events, and PCR testing reveals that other frog species (Lesueur's Frogs and Leaf Green Tree Frogs) were infected with Chytrid. The male Spotted Tree Frog detected prior to the fires was swabbed twice during the single capture occasion, and both swabs returned negative results. Other frog species were found at the site following the bushfire and flood event upstream of the areas affected by sedimentation. There was one observation of a dead (and decomposing) Platypus (*Ornithorhynchus anatinus*) at the site near to where the Spotted Tree Frog had been found (Figure 55). The reasons for the failure to find Spotted Tree Frogs at the site during this report's survey period are not clear, but it may indicate Spotted Tree Frogs are at a very low abundance at the site.

Figure 55. Left: a deceased and decomposing Platypus encountered during the first post-fire surveys at Dargo River; right: a second encountered during the second post-fire surveys, also at Dargo River

Chytrid presence was confirmed at all Spotted Tree Frog sites surveyed. The results of the surveys now confirm that Chytrid is present at all known historic Spotted Tree Frog sites, with the first confirmed cases of Chytrid infection at Wongungarra River and Dargo River confirmed in 2019-2020. Worryingly, recently deceased and dying adult Spotted Tree Frogs were detected on two streams. Additionally, a high incidence of Chytrid infection was documented in the adult Spotted Tree Frogs at two sites, with 100% (n = 3) adults infected at Wheelers Creek and 70% (n = 10) at Wongungarra River. A high incidence of chytridiomycosis at sites is concerning at any time, and even more so when additional processes are also reducing the rates of survival and recruitment (West et al. 2020). At Wheelers Creek and Wongungarra River, the combined impacts of fire, flood and Chytrid infection are cause for alarm at the Spotted Tree Frog sites, and further investigation and potential urgent management intervention may be required.

Additional survey effort is required at all fire-affected sites during future frog-active periods. The Wongungarra River population requires additional assessment and may require collection of frogs, particularly as the population is genetically distinct from all other known extant populations (it is the only known population in the Wonnangatta River ESU; M. West, unpubl. data). The Wheelers Creek population also requires additional assessment and may require collection of frogs, as the survey results indicate that few adults have survived the combined impacts of fire, flood and disease. Only one metamorphling was found, indicating that recruitment was very low. Recent survey efforts pre- and post-fire indicate that the Big River population is the largest remaining population of known extant populations clustered within the Upper Murray River ESU (M. West, unpubl. data), despite ongoing Chytrid infection and the recent low- to moderate-severity burns. At the Big River site, strong protections and frequent monitoring is required to ensure persistence of the species. Triggers for further intervention should be identified. A more extensive survey is required at Dargo River, to assess the population status there. At other sites, surveys are required to further verify suspected extirpations.

The Wongungarra River is unique for its extremely low incidence of high-threat weeds. Remarkably, it appears to still be Blackberry free—it is perhaps the only stream or catchment of considerable size in north-eastern Victoria or Gippsland to be Blackberry free. Willows are present, but with limited distribution and low abundance. Generally, the few plants present are small, reflecting ongoing recruitment from seed sources potentially tens of kilometres away. Willow control to preclude specimens developing to maturity is an important proposed action.

The Spotted Tree Frog has a low capacity for natural recovery from major disturbances and other processes that drive major population declines. This is because: (i) the remaining populations are already in a state of decline; (ii) the remaining populations are isolated and highly fragmented, and there is no mixing between populations; (iii) egg clutch sizes are relatively small compared with other stream-breeding species; (iv) non-native fish are known to predate on the tadpoles, and survival of the tadpoles to the juvenile life stage is very low; and (v) the frogs take a relatively long time (2–4 years) to mature.

All extant Spotted Tree Frog populations in Victoria are affected by both Chytrid fungus and the presence of non-native fish. There are currently no feasible options for mitigating the Chytrid impacts at sites, and few opportunities to reduce non-native fish impacts (West 2015a; West et al. 2020). A Specific Needs analysis for the Spotted Tree Frog should be considered for the following management options for fire-affected Spotted Tree Frog populations that continue to be impacted by the pervasive threats:

Wild salvage or emergency collections to establish captive insurance colonies

Supplementation or genetic rescue using captive-bred stock or via wild-to-wild translocations

Experimental introductions of frogs to sites without threats or to sites at which the impact of the threats on Spotted Tree Frogs is expected to be low.

Supplementation and genetic rescue of Spotted Tree Frog populations is a reasonable approach when one or both threats have a relatively low impact on a population, or the existing genetic variability is low. Experimental introductions of frogs are a potentially viable option if sites without threats can be identified, or if captive-bred stock has been produced to test the suitability of a site at which the threat impacts are expected to be low. Wild salvage or emergency collection may be an important management strategy for some populations, especially when various combinations of the following criteria are met:

The population has a high probability of extinction, with evidence of:

a major reduction in survival or abundance of the adult population, and/ or

a major reduction in the recruitment of the juvenile population.

The population is an important (or the only remaining) wild example of a recognised and distinct genetic unit.

The threats to the wild population cannot be alleviated within a time frame to permit natural recovery.

The population is not sufficiently represented in captivity, either in terms of numbers of individuals or genetic variability.

There is an alternative wild site to which animals can be moved, without known threats or with threats that can be effectively managed. For wild-to-wild translocation, it must be ensured that there are no negative impacts upon any existing important recipient populations at the new site. (If not, is criterion 6 met?)

Captive resources are available to protect the short- and long-term security (survival) of the translocated individuals. A captive management plan is in place or can be developed with clear goals, including for any captive-produced frogs. (If not, is criterion 5 met?).

Of the populations assessed during the post-2019–2020 bushfire surveys, the Wongungarra River and Wheelers Creek populations may both warrant emergency salvage in 2021–2020.

Updated implications for Spotted Tree Frogs following the second and third post-fire assessments

During the second and third assessments, Spotted Tree Frogs were found at all three of the sites at which they had been detected during the first post-fire assessment (i.e. Big River, Wheelers Creek and Wongungarra River). Spotted Tree Frogs were not detected at the previous (2019) known site on the Dargo River, but were discovered at a new site further upstream.

The Big River and Wongungarra River populations are two of the three most abundant remaining Spotted Tree Frog populations, and the largest populations in the Upper Murray and Wonnangatta ESUs, respectively. Despite this, adult Spotted Tree Frogs appear to occur at a low observed population density along both streams (averages of 6.6 adult Spotted Tree Frogs/km at Big River and 2.4 Spotted Tree Frogs/km at the Wongungarra River were detected during the second post-fire assessment period). In contrast to the first post-fire assessments, very few metamorphling Spotted Tree Frogs were detected during the third post-fire assessment (which was undertaken at the same time of year and 1 year on). Low recruitment was observed across all remaining Spotted Tree Frog populations in February to April 2021, including at unburnt sites, even though at some sites several pairs of Spotted Tree Frogs were seen in amplexus (M. West, unpubl. data). This suggests a landscape-level factor, such as climate, could have influenced egg or tadpole survival rates. Notably, high rainfall, increased stream flows and relatively cool conditions were experienced across all sites. This was associated with a La Niña event during the 2020–2021 Spotted Tree Frog breeding and active season. The cool conditions may have increased the thermal suitability of the sites for non-native trout, leading to higher rates of tadpole predation, and increased the sites' thermal suitability for Chytrid fungus, leading to higher rates of chytridiomycosis among frogs. Furthermore, increased rainfall and periods of high stream flows could also increase stream sedimentation turbidity and influence egg and tadpole survival. Regardless of the cause, the poor recruitment this year is expected to increase the species' risk of extinction and further reduce Spotted Tree Frog populations' resilience to threats, including bushfire, in future years. This is because Spotted Tree Frog population decline can be accelerated by any process that reduces population recruitment (West et al. 2020).

The population at Wheelers Creek appears to be very small, with only three adult individuals found (two during the second assessment and a different individual during the third assessment). There was no evidence of breeding or recruitment at Wheelers Creek, and other frog species detected at the site (Lesueur's Frogs) continue to harbour Chytrid infections. However, the riparian habitat is showing signs of recovery and regrowth, the amount of sediment within and adjacent to the stream appears to have reduced since the post-fire floods, and non-native trout were not detected during frog surveys.

Based on the results of all three post-fire assessments, the Wheelers Creek population met all but two of the above criteria for emergency collection (Table 20). The adult female detected during the third post-fire assessment at Wheelers Creek was therefore translocated to Healesville Sanctuary. Additional surveys will be required to determine whether the combined impacts of the 2019–2020 bushfires, the subsequent flood, the ongoing disease risk, and the recent translocation of the frog from the site, have resulted in the extirpation of the Wheelers Creek population.

All three post-fire assessments suggest that Spotted Tree Frogs occur at a very low density on the upper Dargo River. The stream has been affected by fire twice during the last 3 years, and both Chytrid fungus and non-native trout species are present at the sites. Genetic samples have been collected from three of the five individuals that have been detected at the site, and single nucleotide polymorphism (SNP) analysis (a type of DNA sequencing) is currently being conducted to determine their relationship to other known Spotted Tree Frog populations. Additional surveys are required to assess the medium- and long-term impacts of these threats.

Despite extensive surveys, Spotted Tree Frogs have not been since seen at the site at which the Dargo Spotted Tree Frog was first discovered in 2019 (M. West, unpubl. data). The discovery of a small number of Spotted Tree Frogs further upstream on the Dargo River suggests that this is a very small population. The population has been impacted by fire twice (in consecutive years 2018–2019 and 2019–2020). Chytrid is also present.

Two dead Platypus were found during the Dargo River surveys (one during the first season and the other during the second season), immediately above the 2019–2020 burnt habitat (Figure 55). The reasons for the Platypus deaths are unknown, but the discoveries warrant further investigation. Live Platypus are regularly encountered during surveys of all sites, including the Dargo River.

The 27 frogs collected from the two separate ESUs were collected during the March 2021 follow-up surveys (separate to the surveys discussed in this report) (Figure 56). Collections were timed to maximise the potential to collect metamorphling frogs (juveniles recruited from the 2020–2021 breeding season) in order to minimise the impact on remaining populations, as few metamorphlings typically reach maturity under the current conditions (Gillespie 2001b, 2002, 2010, 2011). However, because breeding and metamorphling recruitment at each site was low, Spotted Tree Frogs at other life stages also had to be collected (Table 19). Additional collections will be required to ensure the establishment of a robust conservation breeding and insurance population at Zoos Victoria.

The combined survey results across all three assessment periods have:

Demonstrated that the combined impacts of a severe fire event and the post-fire ash and sediment events associated with the post-fire flooding, coupled with disease (caused by the deadly amphibian Chytrid fungus, which was recorded at all sites) have exacerbated the risk of extinction for the Spotted Tree Frog in north-eastern Victoria

Confirmed the dire conservation status of most extant Spotted Tree Frog populations, especially on the severely fire-impacted Wheelers Creek and Dargo River sites

Shown the status of Spotted Tree Frogs at the remaining two sites that experienced less-severe fire impact to be better (than Wheelers Creek and Dargo River); however, Chytrid fungus infections to be active, and the frog numbers recorded were still significantly down on the pre-fire transect count results

Confirmed the need for urgent management intervention, including additional collection of frogs from the wild to act as founders for the establishment of a new Zoos Victoria Captive Breeding Program (CBP).

Figure 56. Emergency salvage and translocation of Spotted Tree Frogs in March 2021 from sites affected by the 2019–2020 bushfires (photo: Matt West)

Table 20. A simple evaluation of the need for wild salvage or emergency collection of Spotted Tree Frogs from each of the assessed extant Victorian populations that were affected by the 2019–2020 fires

Criteria for Spotted Tree Frog wild salvage or emergency collection	Big River	Dargo River	Wheelers Creek	Wongungarra River
1. The population has a high probability of extinction with evidence of:	Moderate	Yes	Yes	Moderate
a) a major reduction in survival or abundance of the adult population, and/or	–	Yes	Yes	–
b) a major reduction in the recruitment of the juvenile population.	Yes (very low recruits in 2020–2021)	Yes (no recruits found in 2020–2021)	Yes (no recruits found in 2020–2021)	Yes (very low recruits in 2020–2021)
The population is an important (or the only remaining) wild example of a recognised and distinct genetic unit.	Yes—most abundant population in Upper Murray ESU	Relationship to other populations currently unknown	Considered a population within the Upper Murray ESU	Yes—only known population in Wonnangatta ESU
The threats to the wild population cannot be alleviated within a time frame to permit natural recovery.	Yes	Yes	Yes	Yes
The population is not sufficiently represented in captivity, either in terms of numbers of individuals or genetic variability.	Yes	Yes	Low level represented at Amphibian Research Centre	Yes
There is an alternative wild site to which animals can be moved, without known threats or with threats that can be effectively managed. For wild-to-wild translocation, it must be ensured that there are no negative impacts upon any existing important recipient populations at the new site. (If not, is criteria 6 met?)	No	No	No	No
Captive resources are available to protect the short- and long-term security (survival) of the translocated individuals. A captive management plan is in place (or can be developed) with clear goals, including for any captive-produced frogs. (If not, is criteria 5 met?)	Yes	Yes	Yes	Yes
Comments:	Surveys suggest small adult population	Surveys suggest very small population	Surveys suggest very small population	Surveys suggest small population

Booroolong Frog

During the first post-fire assessment, only three Booroolong Frogs were found; they were present at only at one of the two sites surveyed (Guys Forest Creek). The low counts of Booroolong Frogs at Guys Forest Creek and the failure to detect the frogs at Burrowye Creek may not reflect the actual status of the population, or the impact of the fires, as the surveys were conducted during a period of low Booroolong Frog activity. Similarly, the non-detection of Chytrid at the sites is likely to be due to the low number of frogs sampled. Despite this, the surveys provided an opportunity to evaluate the fire impacts on habitat and thus to provide a context for future survey efforts.

The fire was most intense at Guys Forest Creek: it destroyed fencing on the surrounding agricultural properties and much of the streamside vegetation. The grass on the banks and adjoining paddocks was already growing, and fence rebuilding was underway. The fire was stopped prior to reaching the Booroolong Frog transect sites on the Burrowye Creek. However, the post-fire flooding affected both sites, and there was clear evidence of extensive ash and debris flows, particularly in the Guys Forest Creek, with much of the species-preferred microhabitats (loose rocky substrate and vegetation on the banks) being buried in ash, burnt vegetation and sediment. The three Booroolong Frogs on Guys Forest Creek were found among some of the remaining free loose rock in the cobble bank areas. Booroolong Frogs using vegetation near the stream or in the adjoining paddocks and forest may have been affected by the fire activity and, similarly, Booroolong Frogs remaining near the stream during the post-flood fire event may have been buried under sediment. Additional surveys are required in order to further understand the population’s response.

The Booroolong Frog is generally considered to have a reasonable capacity to recover from major disturbances or other processes that drive major population declines (Hunter 2013). This is because adult females can produce large numbers of eggs (mean 1257; range 688–1700), and individuals can rapidly reach reproductive maturity (males in 1–2 years and females in ~2–3 years) (Hunter 2001; Gillespie 2011). In addition, Victorian populations are genetically like those in NSW, and restocking from neighbouring populations in NSW is possible if Victorian populations are reduced or become locally extinct (Hunter 2013). For these reasons, emergency salvage of the Victorian Booroolong Frog populations is not recommended (Hunter 2013), despite the potential impacts of the bushfire and the post-fire flooding events. Management requirements of the Victorian populations may need to be reassessed if the state of the NSW populations deteriorates.

Implications for Booroolong Frogs following the second post-fire assessments

Results from the second post-fire assessments indicate that Booroolong Frogs are persisting at the two sites, despite exposure to multiple stressors and threats: the pre-fire drought conditions, the immediate fire impacts (heat and the short-term reduction of streamside vegetation), a significant subsequent post-fire flood and sedimentation event (ash, soil and debris flows), and habitat loss and degradation, particularly associated with increasing proliferation of exotic trees [Willows and Poplars (*Populus tremula*)] and grasses. A total of 39 Booroolong Frogs were counted at the two sites and, while this is a relatively small number of frogs, the results are consistent with the pre-fire survey results, especially as large population fluctuations are known to occur following extreme drought and flooding events (Hunter 2013). Booroolong Frogs require rocky habitat during the breeding season as calling, feeding, shelter and egg-deposition sites. But rocky habitat is depleted in areas that have been fenced to exclude stock, because the exotic grass and weedy tree root systems grow over the top of the rocky habitat and trap sediment, which provides a substrate for further weed and grass growth. Unfenced areas permit livestock to graze exotic grasses and woody weeds and can help to maintain rocky habitat. The loss of rocky habitat caused by exotic tree and grass proliferation, particularly in fenced areas, is the main ongoing threat to Booroolong Frogs at the sites (particularly along Burrowye Creek).

Additional risks driven by the 2019–2020 bushfires

Seven Spotted Tree Frog populations and one Booroolong Frog population that had been affected by the 2019–2020 bushfires in north-eastern Victoria were assessed during the post-fire reconnaissance projects. Several key threats to these species were identified or confirmed during these assessments. These include:

Over half the locations assessed experienced high or extreme fire severity. Post-fire rain events compounded the fire impacts by adding high ash and sediment loads during Spotted Tree Frog egg and tadpole development phases; these life stages are critically sensitive to the resultant reduced oxygen levels and associated poor water quality.

Notably, some Spotted Tree Frog catchments have now been burnt twice or more in recent decades, which is likely to have compounded the impacts of the 2019–2020 bushfires on these populations.

Small population size, disease caused by Chytrid infection, and a lack of recruitment are presenting the greatest threats to the bushfire-affected Spotted Tree Frog populations.

Booroolong Frogs were confirmed at both surveyed sites, and their populations were comparable to pre-fire surveys, suggesting the 2019-2020 fires had a minimal impact.

Habitat loss and degradation particularly associated with exotic tree and weed encroachment are presenting as the greatest threats to Booroolong Frogs.

Future directions

Potential management interventions for these species may include collection of frogs from critical populations to establish captive insurance populations. Once established, Chytrid-resistance breeding and research could be undertaken, and captive-bred frogs could later be used to re-establish and augment populations in experimental translocations. Programs to improve understanding of the combined impacts of fire, flood, and other threats (such as chytridiomycosis) are important, particularly given that the frequency of intense bushfires is predicted to increase under climate change.

Priority actions identified for consideration within DELWP's decision-support tools are as follows:

Spotted Tree Frog

Reassess outcomes of the Spotted Tree Frog taxon-specific management needs workshop, to confirm future management actions.

Regularly monitor all populations to:

determine the adult numbers, breeding status and level of recruitment of each population

determine the prevalence of Chytrid infection and verify the presence of non-native fish

inform numbers to be collected per location, as per findings of Point 1 and as proposed in Point 3.

Collect additional Spotted Tree Frogs from populations that are at a high risk of extirpation due to the combined impacts of fire, flood and chytridiomycosis, to maximise the genetic integrity and numbers of the CBP at Zoos Victoria. Zoos Victoria currently has the capacity to hold animals in quarantine and is committed to constructing new facilities at Melbourne Zoo and Healesville Sanctuary, which are expected to be completed in late 2021.

Undertake genetic analysis of stored Spotted Tree Frog samples, including:

genotyping of stored tissue samples to evaluate the genetic variation, which will inform which wild populations should be targeted for collection to establish captive populations and which need augmentation via genetic rescue

screening of frog samples for Major Histocompatibility Complex genes that have been linked to Chytrid resistance. If these genes can be identified, individuals with Chytrid-resistant traits may be selectively bred for release.

Implement proposed Phase 2 of the Willow eradication program on the Wongungarra River, to protect its weed-free status and enhance its habitat values.

Booroolong Frog

Manage weeds and remove exotic trees in key locations, to protect and increase the amount of available rocky habitat for Booroolong Frog populations.

Monitor changes in the available habitat and the adult frog numbers at each site.

Acknowledgements

This project was funded by the Australian Government Bushfire Recovery Package for Wildlife and Their Habitat (Spotted Tree Frog) and the Victorian Government's Bushfire Biodiversity Response and Recovery program (Spotted Tree Frog and Booroolong Frog), Zoos Victoria, and the National Environmental Science Program Threatened Species Recovery Hub.

Field assessments were able to proceed due to tremendous support from Forest Fire Management (FFM) staff in the Ovens, Upper Murray, Macalister and Tambo Fire Districts. The Spotted Tree Frog occupies rocky riparian habitats in steep mountainous environments. Many sites experienced high fire severity. Respective Incident Management Teams facilitated priority tree hazard removal to open key fire-affected tracks required to access Spotted Tree Frog sites. We thank Edan Brennan and James Cleven (Upper Murray District FFM) for facilitating provision of access into the Wheelers Creek site. We also thank Simon Gough, Jarrod Hayse, Matthew Koers and the Ovens Rappel crew (Ovens District FFM) for facilitating a specially constructed helipad and helicopter transit into the most remote site, the Wongungarra River.

Jarrod Bowd, Mark Mickleburough and Connor Wilson (Parks Victoria) provided valuable reconnaissance observations on access into the Bundara River and Dargo River sites.

Thanks to Adam Lee, Matt Clancy, Karina Sorrell, Rebecca Spence, Elizabeth Wemyss, Adam Schwebel, Gabrielle Vening, Mark Mickleburough, Wendy Sherlock, Amanda Smith, Tim Willersdorf, Blair Yates, Harry McKimmie, Gavin Melgaard, Daniel Littlewood, Lydia Wilson, and David Hunter, who all assisted with field assessments. Thanks to Glen Weisner for OH&S and data entry support.

Cesar Pty Ltd conducted the Chytrid PCR analysis.

Jane Roots (DELWP FFR Hume Region), Tim O'Brien and Nick Clemann (both ARI), and Mark Whyte and Anne Buchan (both DELWP Biodiversity Division) provided additional oversight of the project.

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4.2 Threatened and non-threatened frogs in East Gippsland

Prepared by Jeremy Tscharke (Parks Victoria) and Geoffrey Heard (Australian National University).

Summary of fire impacts

East Gippsland supports Victoria's highest diversity of frogs, with 23 species known from the region. Of these, seven species are listed as threatened in Victoria under the FFG Act 1988 and five are listed as threatened under the Commonwealth EPBC Act 1999. East Gippsland therefore represents a significant region of Victoria for frog conservation. The 2019-20 bushfires burnt around 230,000 ha of East Gippsland, including large swathes of Victoria's threatened frog habitat as well as key habitat for several non-threatened species.

Summary of key findings

Martin's Toadlet was detected at four of 11 sites with previous records (36%), with those sites that were inundated supporting breeding populations. Several occupied sites were burnt at high intensity, indicating these populations have been resilient to the immediate fire impacts.

The Green and Golden Bell Frog was detected at 63% of sites with previous records, including severely burnt sites. Abundances were low however, with a maximum count of 8 individuals. Relatively intact sites at Dock Inlet and Bemm River supported the highest abundance of this species.

Keferstein's Tree Frog was not detected at the three wetlands with previous records. However, surveys were restricted to listening for calls from the nearby public road. These sites were not burned, and calling has been subsequently detected, indicating persistence of the only known population of this species in Victoria.

The stream-dwelling Blue Mountains Tree Frog and Leaf-green Tree Frog were detected at most sites with previous records (57% and 73% respectively), including severely burnt sites. Counts were low and appear lower than those pre-fire (author pers. obs.)

Surveys were conducted too early in the season for reliable detection of Dendy's Toadlet. Near complete absence of detections of this frog should not be interpreted as absence in the landscape.

Background

Gippsland supports Victoria's highest diversity of frogs, with 23 species known from the region (Victorian Biodiversity Atlas). Of these, seven species are listed as threatened in Victoria under the FFG Act 1988 and five are listed as threatened under the Commonwealth EPBC Act 1999 (Table 21). East Gippsland therefore represents a significant region of Victoria for frog conservation.

This study sought to assess the post-fire status of selected frog species in East Gippsland following the Black Summer fires, namely:

Green and Golden Bell Frog (*Litoria aurea*)

Blue Mountains Tree Frog (*Litoria citropa*)

Keferstein's Tree Frog (*Litoria dentata*)

Leaf-green Tree Frog (*Litoria nudidigita*)

Dendy's Toadlet (*Pseudophryne dendyi*)

Martin's Toadlet (*Uperoleia martini*)

These species were selected because of their conservation status at the time of the fires or as a result of a significant portion of their Victorian range being affected by the 2019-20 fires (Table 22; Figure 57).

Four additional threatened species were excluded from this assessment for reasons listed below:

1. Watson's Tree Frog (formerly Large Brown Tree Frog) (*Litoria watsoni*) – the focus of a dedicated assessment.
2. Growling Grass Frog (*Litoria raniformis*) – East Gippsland populations were not affected by fires.
3. Stuttering Frog (Mixophyes balbus) – likely extinct in Victoria.
4. Giant Burrowing Frog (Heleioporus australiacus) – the focus of a dedicated assessment.

Table 21. Threatened frogs of Gippsland, including conservation status at State (Flora and Fauna Guarantee Act 1988) and Federal (Environment Protection and Biodiversity Conservation Act 1999) levels.
Abbreviated statuses are: VU, Vulnerable; EN, Endangered; CE, Critically Endangered.

Common Name	Scientific Name	Victorian status 2013	Victorian status 2021	Federal status
Green and Golden Bell Frog	*Litoria aurea*	VU	Not listed	VU
Keferstein's Tree Frog	*Litoria dentata*	VU	CE	Not listed
Watson's Tree Frog	*Litoria watsoni*	EN	CE	VU
Growling Grass Frog	*Litoria raniformis*	EN	VU	VU
Giant Burrowing Frog	*Heleioporus australiacus*	CE	CE	VU
Southern Barred Frog	*Mixophyes balbus*	CE	CE	VU
Southern Toadlet	*Pseudophryne semimarmorata*	VU	EN	Not listed
Martin's Toadlet	*Uperoleia martini*	CE	CE	Not listed

Table 22. Percentage of sites in the Victorian Biodiversity Atlas (VBA) for each target species that were burnt in the 2019-20 fire season.

Common Name	Scientific Name	Total VBA records for species	Percentage of records in burnt area
Green and Golden Bell Frog	*Litoria aurea*	121	6.6%
Blue Mountains Tree Frog	*Litoria citropa*	21	95.2%
Keferstein's Tree Frog	*Litoria dentata*	3	0%
Leaf-green Tree Frog	*Litoria nudidigita*	126	77.8%
Dendy's Toadlet	*Pseudophryne dendyi*	221	71.5%
Martin's Toadlet	*Uperoleia martini*	52	38.4%

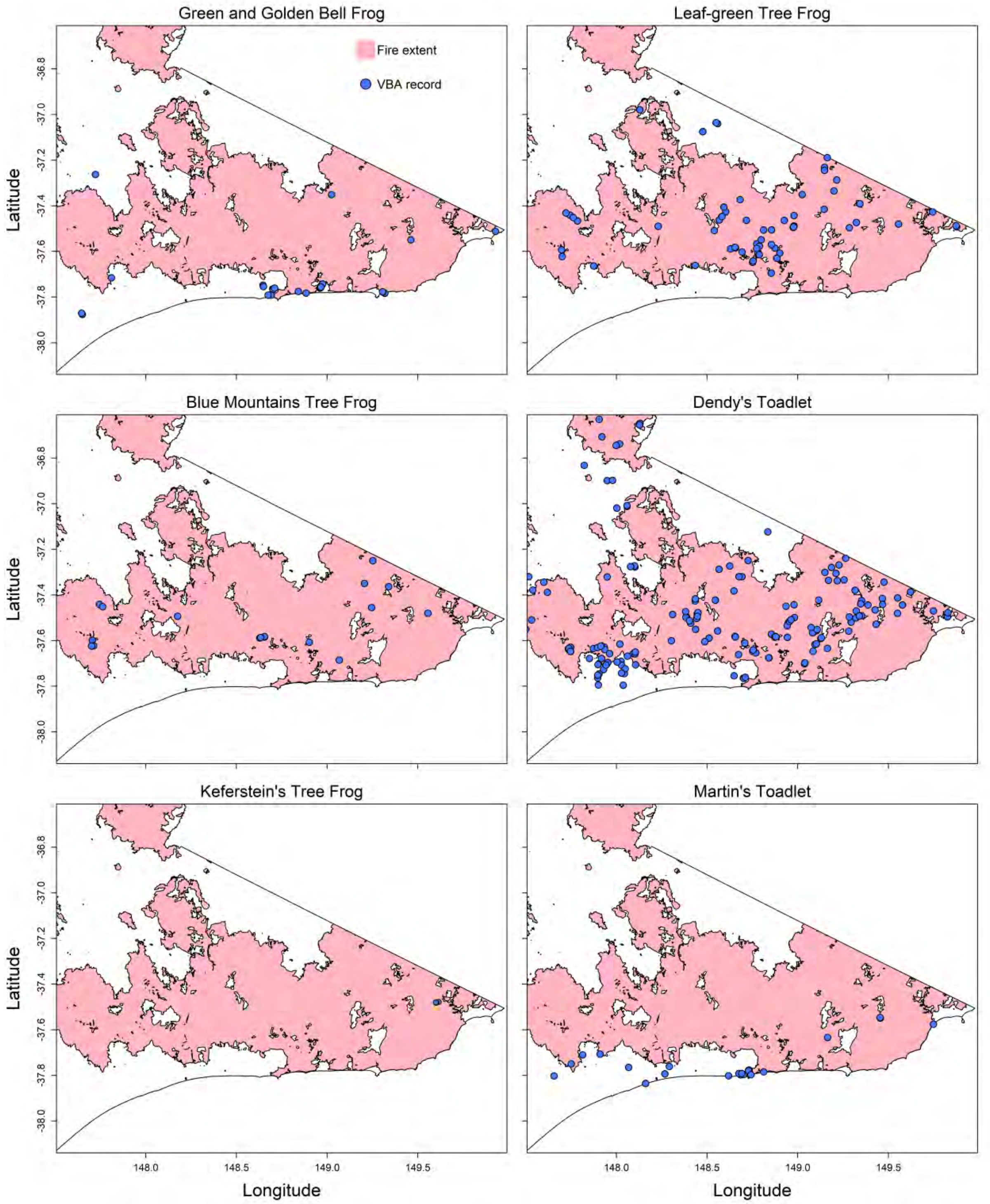

Figure 57. Mapped fire extent in East Gippsland, with records of each of the focal frog species from the Victorian Biodiversity Atlas (VBA) overlaid.

The Green and Golden Bell Frog is a large hylid (to 85mm snout-vent length) with a geographic range that extends from Yuragir National Park in northern New South Wales to Sale in Victoria, with a primarily coastal distribution (Anstis 2013). The species' distribution is now significantly fragmented, following significant declines in the 1980s and 1990s because of the spread of the amphibian chytrid fungus (*Batrachochytrium dendrobatidis*) and habitat loss, degradation, and fragmentation (Mahony *et al.* 2013). The species is usually associated with permanent freshwater bodies, radiating to satellite waterbodies in wetter conditions (Mahony *et al.* 2013). Breeding occurs in spring and summer, with tadpole development taking 2-3 months (Anstis 2013).

In East Gippsland, the Green and Golden Bell Frog extends from the Avon River catchment near Sale in the west to the NSW border (Figure 57), being almost exclusively associated today with coastal wetlands, particularly large morasses. In Victoria, the species is no longer listed as threatened (DELWP 2021), although impacts from chytridiomycosis, habitat loss and exotic fish remain of concern. Around 7% of known sites in Victoria were burnt by the 2019-20 fires (Table 22).

The Blue Mountains Tree Frog is a medium sized hylid (to 65 mm SVL) that occurs from the ranges west of Newcastle, New South Wales, to eastern Victoria (Anstis 2013). It is a stream-breeding frog usually associated with rocky environments in the foothills and slopes of the Great Dividing Range. The species breeds in slowly flowing sections of these streams, including pools, rock pools and inundated verges of rocky riffles (Anstis 2013). Breeding takes place from late winter to early summer. In Victoria, the species occurs in rocky streams and rivers of the eastern fall of the Great Dividing Range in Gippsland (Figure 57). The species occurs primarily in forested landscapes and 95% of known Victorian sites were burnt by the 2019-20 fires (Table 22). While the species is not listed as threatened in Victoria, it is possible the 2019-20 fires could have led to reductions in range and population size sufficient to warrant revision of conservation status.

Keferstein's Tree Frog (also known as the Bleating Tree Frog) is a small hylid (to 44mm SVL) that inhabits the coast and ranges of Victoria, New South Wales, and southern Queensland. This species was only relatively recently discovered in Victoria (December 2010) at three locations on the Genoa River floodplain in far-eastern Gippsland (Gillespie and Chang Kum 2011; Figure 57). Each of these sites in grazing land are shallow pools with extensive emergent and fringing vegetation (Gillespie and Chang Hum 2011). The species has also been recorded calling in over-hanging Eucalypts adjacent to these sites along the Genoa-Mallacoota Rd (M. Clancy pers. comm). None of these sites burned in the 2019-2020 fires.

The Leaf-green Tree Frog is the southern-most member of the *Litoria phyllochroa* species complex; a group of small hylid frogs ranging up to ~42 mm SVL. The species occurs from along the coast and ranges from Sydney to eastern Victoria (Anstis 2013). Populations are mostly associated with flowing streams, in or near a forest or coastal heathland (Anstis 2013). Breeding occurs from spring to summer in still or slowly flowing sections of streams, including pools, rock pools and inundated areas adjacent to riffles (Anstis 2013).

The Leaf-green Tree Frog is widespread in streams of eastern Victoria, including those on both the eastern and northern fall of the Great Dividing Range (Figure 57). The species is not currently listed as threatened, but like the Blue Mountains Tree Frog, could be eligible for listing if the 2019-20 caused significant range and population size reductions (some 78% of sites in the VBA were in areas mapped as burnt; Table 22).

Dendy's Toadlet is a small myobatrachid frog (to 32 mm SVL) that occurs in south-eastern New South Wales and eastern Victoria. The species breeds in ephemeral drainages, swamps, bogs and seeps in late summer and autumn, and occurs through forest, woodland and heathland environments (Anstis 2013).

Dendy's Toadlet is not listed as threatened in Victoria (DELWP 2021). Although widespread (Figure 57) and common in some locations, the distribution of the species is difficult to define given morphological similarities with Bibron's Toadlet (*P. bibroni)* and known hybridisation with this taxon. A large percentage of known sites of this species were within the mapped burnt area of the 2019-20 fires (72%; Table 22). Impacts on this species could therefore have been significant during the recent bushfires.

Martin's Toadlet is a small myobatrachid frog (to ~35mm SVL) known only from the east coast of Victoria and far south-eastern corner of New South Wales (Anstis 2013). The species is a poorly known burrowing frog, occupying forest, woodland, and heathland environments across its range. Sandy and peaty soils appear to be favoured by the species (J. Tscharke pers. obs.). The species breeds in ephemeral or small permanent wetlands after heavy rain in spring, summer, and autumn (Anstis 2013).

Martin's Toadlet is listed as Critically Endangered in Victoria (DELWP 2021), having a restricted range (Figure 57) and very small area of occupancy. Just over 1/3 of known sites were burnt in the 2019-20 fires, with sites at the far-western end of the range burnt in the 2018-19 fire season (notably at Holey Plains

National Park). Combined, the 2018-19 and 2019-20 fires have had the potential to drive significant range and population reductions of Martin's Toadlet.

Methods

Locations surveyed

Victorian Biodiversity Atlas records were collated for each of the target species (Figure 57) and potential sites were identified for survey across East Gippsland, from Bairnsdale in the west to the New South Wales border in the east, restricted to the eastern fall of the Great Dividing Range. Sites were primarily identified from the VBA, although these were supplemented by additional sites known to the authors.

For logistical and safety reasons sites further than 500 m from a mapped road or vehicle track were excluded. To maximise efficiency of survey effort by minimising travel distances, clusters of sites within 4 km of each other were identified, prioritising those clusters with at least three sites. A total of 55 site clusters for survey were identified from the previous pool, covering 84 potential sites.

Selection of sites from within this set was *ad hoc* due to uncertainty about access due to track closures (resulting from the ongoing process of clearing dangerous trees post fire) and risk assessments for nocturnal fieldwork. Thirty six sites were ultimately surveyed during this study, giving priority to sites that maximised the coverage of the focal species as well as variation in site burn severity. Survey sites are shown in Figure 58.

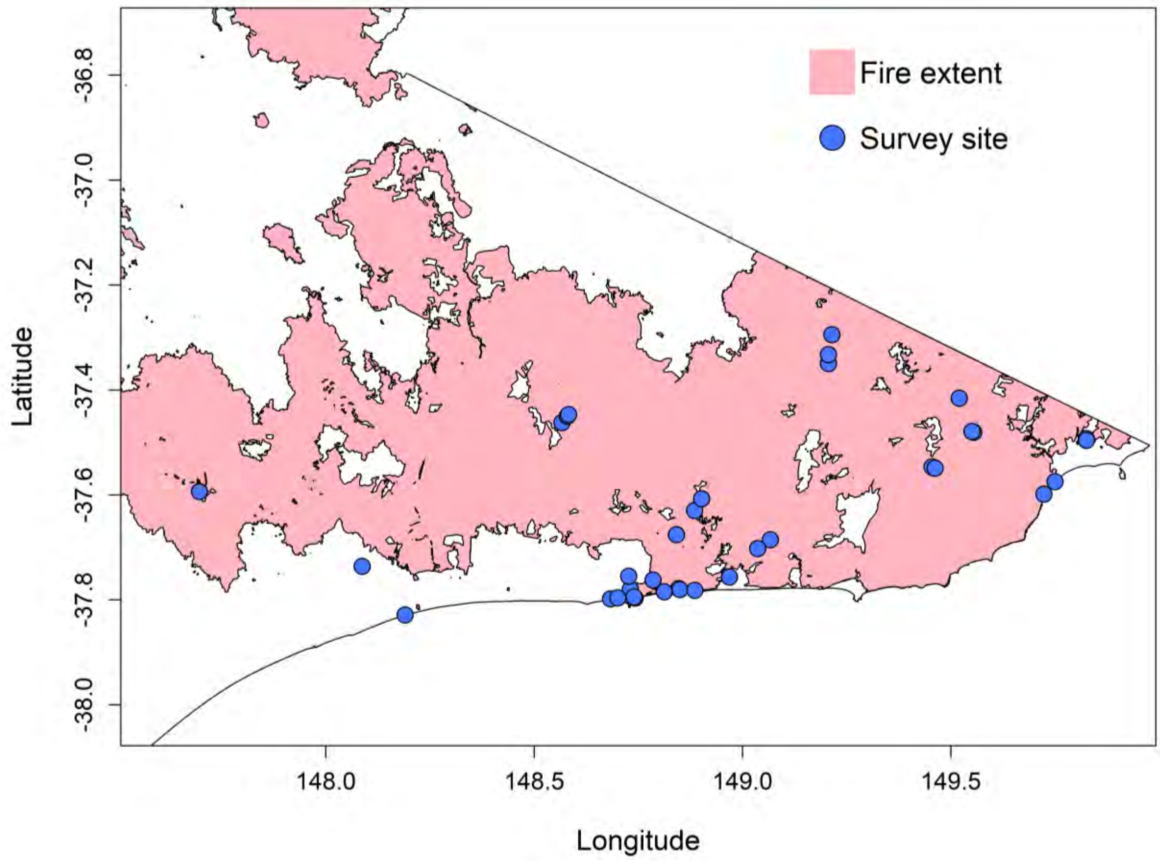

Figure 58. Distribution of survey sites across East Gippsland, showing relationship to mapped fire extent (36 sites in total, with some overlapping at his scale).

Survey methods

Surveys were completed between October and early December 2020, the peak calling period for all but one of the target species. Planned autumn surveys for Dendy's Toadlet could not be completed due to travel and fieldwork restrictions resulting from the Coronavirus pandemic. Although this species was recorded incidentally, this project provides no information on the response of this species to the 2019-20 fires. Private land where records of Keferstein's Tree Frog originate could not be accessed, and so surveys of these sites were not conducted. Assessments for this species were therefore restricted to listening for calls from the nearby sections of the Genoa-Mallacoota Rd.

Standard encounter survey methods for amphibians were employed throughout (Crump and Scott 1994). Surveys of each site commenced no sooner than 30 minutes after dark and consisted of recording calls and visual searches of the sites with the aid of spotlights. The survey procedure at each site was as follows:

On arrival at the site, the first five minutes was spent quietly standing at the water's edge listening for calls and recording weather conditions (air and water temperature [°C], relative humidity, wind strength, cloud cover, rain intensity and moon phase).

A further five minutes was spent listening for frog calls from the water's edge. Call imitation or playback was conducted during the last minute of this period, to stimulate a response from any male that may be present but not calling.

Following completion of the initial call listening period, the entire waterline of the site (circumference of standing water bodies < 200 m, and both banks of pools along streams) was slowly examined using spotlights to detect active frogs. This entailed systematically searching all surfaces of the water body for active frogs. Observers inspected the bank 10-15 m from the waterline to detect frogs that were terrestrially active.

Counts of all frog species were recorded (with estimates made when very large choruses were encountered), with detections recorded either as calls, visual encounter, or both.

Detections of tadpoles were recorded, to species level where possible.

Detections of fish and other wildlife of note were also recorded.

Surveys continued for up to 40 minutes, including the initial 10-minute listening and recording period followed by 30 minutes of active search. Most sites were completed within these time periods.

Habitat assessments were completed at all sites, focusing on fire intensity and impacts on structural habitat elements important to frogs. Briefly, these assessments included:

1. Site type (stream, marsh/bog, standing water body, forest) and description.
2. Structural characteristics of stream sites, estimated as percentage of site that was a cascade, pool, log jam, rocky riffle, waterfall or silt deposit.
3. Burn status (burnt / unburnt) and fire severity measured on an ordinal scale between 0 (0% of overstorey or understorey burnt) to 5 (>50% of canopy consumed). [Note: these fire severity classes only broadly align with the Victorian Government fire severity mapping accessible publicly at data.vic.gov.au].
4. Extent of recovery at burnt sites, on a four-point ordinal scale between none and high.
5. Disturbance and threats, measured on a four-point ordinal scale (none to high) covering erosion, feral deer impacts, and weed invasion.
6. Vegetation type and cover estimates for trees, shrubs, emergent aquatic vegetation, submergent aquatic vegetation, algae, bare ground within 5 m of the waterline and cover of any vegetation within 5 m of the waterline.
7. Water quality, including extent of sedimentation (none to high), turbidity (none to high), water temperature (°C) and conductivity (in ppm, measured with the aid of a Tracer Pocket meter #1749).
8. Detection of predators, particularly exotic and native fish.

Standard chytrid fungus hygiene protocols were followed throughout (Murray *et al.* 2011).

Results

Detections for each of the focal species are summarised in Table 23, with the distribution of detections for the Green and Golden Bell Frog, Blue Mountains Tree Frog, Leaf-green Tree Frog and Martin's Toadlet shown in Figure 59 (Keferstein's Tree Frog and Dendy's Toadlet are excluded due to the limited nature of surveys for these species; see below). Histograms of counts for Green and Golden Bell Frog, Blue Mountains Tree Frog, Leaf-green Tree Frog and Martin's Toadlet at sites at which they were known from previous records are shown in Figure 60.

The Green and Golden Bell Frog was detected at five of the eight sites with previous records (62.5%) and at eight sites in total (Table 23). This included Ewing's Morass Wildlife Reserve, Dock Inlet area east of Cape Conran and a pond adjacent to the Mallacoota Airport (Figure 57). A maximum of eight individuals were counted at any site (Figure 60). Calling males were recorded at six sites.

The Blue Mountains Tree Frog was detected at four of the seven sites with previous records (57%) and at 10 sites in total. This included Martin's Creek, Nicholson River and Chandlers Creek, Cann River gorge and

Genoa Falls (Figure 59). A maximum count of 10 was recorded (Figure 60), with calling at all 10 sites at which the species was detected.

Surveys for Keferstein's Tree Frog were restricted to listening from the Genoa-Mallacoota Rd adjacent to known breeding sites. The species was not detected at any of these sites; however, this species calls for limited periods after large rain events, in which case our failure to detect this species may be due to inappropriate survey conditions. The presence of this species has been confirmed at one of these sites subsequently (M. Clancy pers. comm.).

The Leaf-green Tree Frog was detected at eight of the 11 with previous records (73%) and at 11 sites in total. As for Blue Mountains Tree Frog, this included Martin's Creek, Nicholson River and Chandlers Creek, Cann River gorge and Genoa Falls (Figure 59). A maximum count of 10 was recorded (Figure 60), with calling recorded at nine of the 11 sites.

Dendy's Toadlet was detected calling at a single site south-east of Bellbird Creek; however, surveys were completed outside the primary calling season of late summer and autumn, in which case the lack of detections elsewhere is the result of inappropriate survey timing.

Martin's Toadlet was detected at four of the eleven sites with previous records (36%). Detections occurred at the Ewing's Morass Wildlife Reserve, wetlands adjacent to the East Wingan Road and in the vicinity of Dock Inlet. A maximum of 10 individuals was recorded, with calling activity recorded at all four sites with detections.

Table 23. Detections of each of the target species, including the percentage of sites where species were detected during this study and where they have been previously recorded (from the Victorian Biodiversity Atlas or the author's personal observations).

Species	No. of sites at which species was detected	Sites with previous records	Percentage of sites with previous records at which detected [1]
Green and Golden Bell Frog	8	8	62.5%
Blue Mountains Tree Frog	10	7	57.1%
Keferstein's Tree Frog [2]	0	3	0%
Leaf-green Tree Frog	9	11	72.7%
Dendy's Toadlet [3]	1	4	25%
Martin's Toadlet	4	11	36.4%

[1] Note: species may have been detected at sites without previous records, in which case the proportion of sites with previous records at which the species was detected is not the first column divided by the second.

[2] Note: surveys for this species were restricted to listening for calls from the adjacent road.

[3] Note: surveys were conducted outside the primary calling season for Dendy's Toadlet and are not reliable.

Relationship with burn status and severity

Examining relationships between burn status and severity and either the prevalence or abundance of the focal species is constrained by small samples sizes, and a lack of repeat visits to survey sites. The Green and Golden Bell Frog, Blue Mountains Tree Frog, Leaf-green Tree Frog and Martin's Toadlet were all detected at burnt sites and there was no clear difference between detection rates at burnt and unburnt sites (Table 24). Count data suggest higher abundance at unburnt sites for each of these species (Figure 61); however, the relatively high counts for Blue Mountains Tree Frog, Leaf Green Tree Frog and Martin's Toadlet at unburnt sites are from single locations. Plotting counts against burn severity scored onsite shows no clear trends, with maximum counts for Blue Mountains Tree Frog, Leaf-green Tree Frog and Martin's Toadlet (10 in each case) occurring both at unburnt sites and those burnt at the highest severity (Figure 61).

Detections of other frogs

Thirteen frog species were detected during this study; five of the six target species and a further eight species. These additional species were the Common Froglet (*Crinia signifera*), Eastern Banjo Frog (*Limnodynastes dumerilii*), Striped Marsh Frog (*Lim. peronii),* Southern Brown Tree Frog (*L. ewingii*), Rocky River Frog (*L. lesueurii*), Peron's Tree Frog (*L. peronii*), Whistling Tree Frog (*L. verreauxii*) and Haswell's Froglet (*Paracrinia haswelli*). Like the target species, counts for these species were generally low, (≤12), although large choruses of Common Froglet, Eastern Banjo Frog, Rocky River Frog and Haswell's Froglet were detected (Figure 60). There was no clear relationship between fire severity scored onsite and counts across these species, and notably the largest choruses were at sites with the highest fire severity (Figure 62).

Table 24. Detection rate at burnt and unburnt sites where each species had been recorded before the fires, either from the Victorian Biodiversity Atlas or the author's personal observations.

Species	Burnt sites surveyed	Burnt sites detected	Unburnt sites surveyed	Unburnt sites detected
Green and Golden Bell Frog	4	3 (75%)	4	2 (50%)
Blue Mountains Tree Frog	6	3 (50%)	1	1 (100%)
Keferstein's Tree Frog [1]	0	-	3	0 (0%)
Leaf-green Tree Frog	11	8 (72.7%)	0	-
Dendy's Toadlet [2]	4	1 (25%)	0	-
Martin's Toadlet	8	3 (37.5%)	3	1 (33.3%)

[1] Note: surveys for this species were restricted to listening for calls from the adjacent road.

[2] Note: surveys were conducted outside the primary calling season for *P. dendyi* and are not reliable.

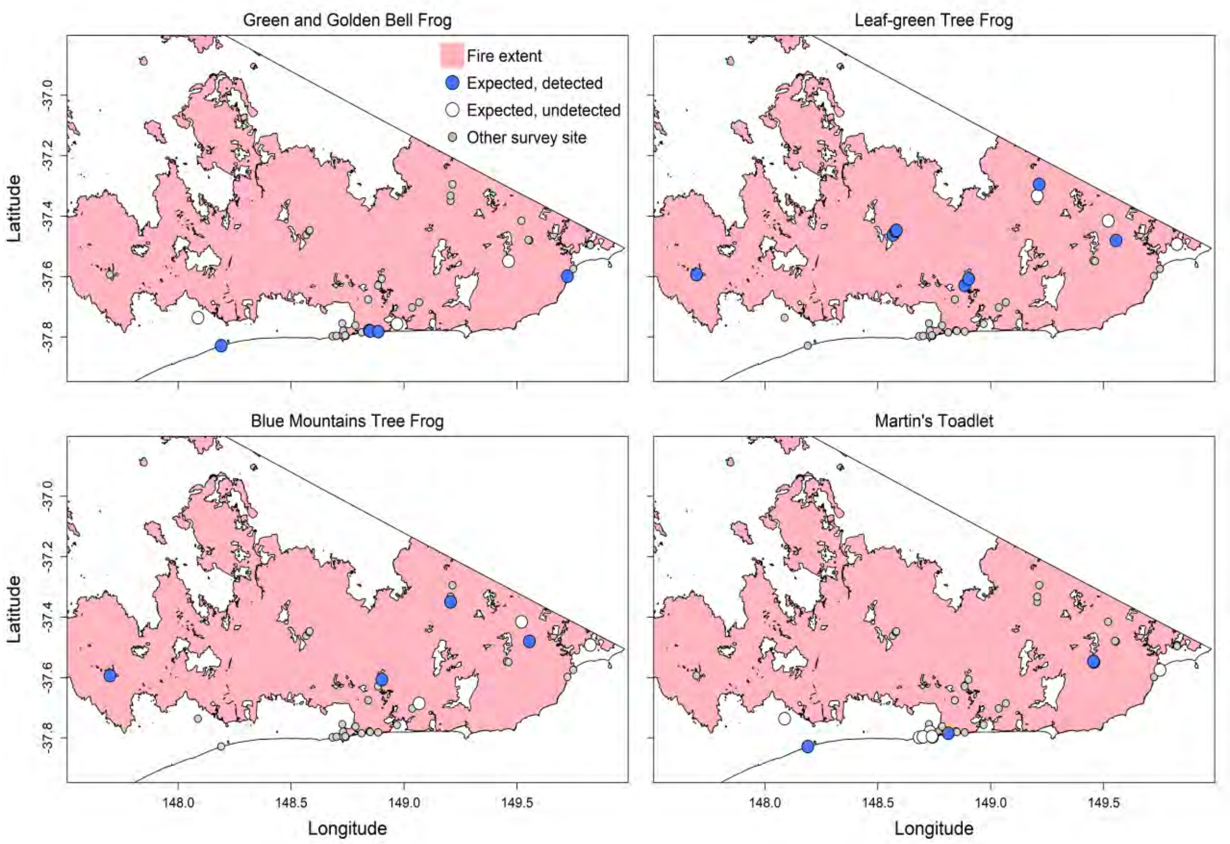

Figure 59. The distribution of sites at which the Green and Golden Bell Frog, Blue Mountains Tree Frog, Leaf-green Tree Frog and Martin's Toadlet were detected.

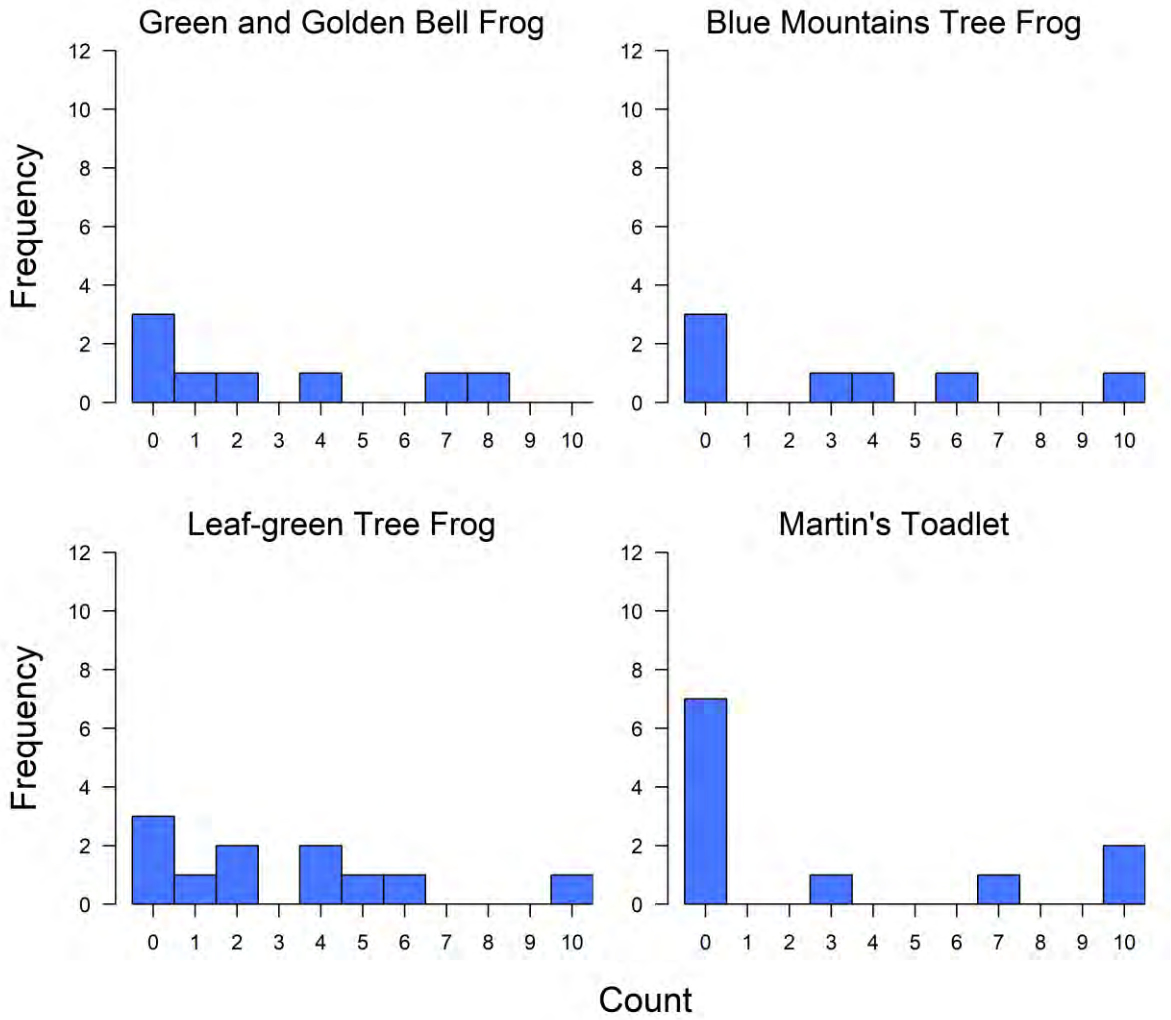

Figure 60. Histograms of counts of the Green and Golden Bell Frog, Blue Mountains Tree Frog, Leaf-green Tree Frog and Martin's Toadlet at sites where these species were expected based on previous records.

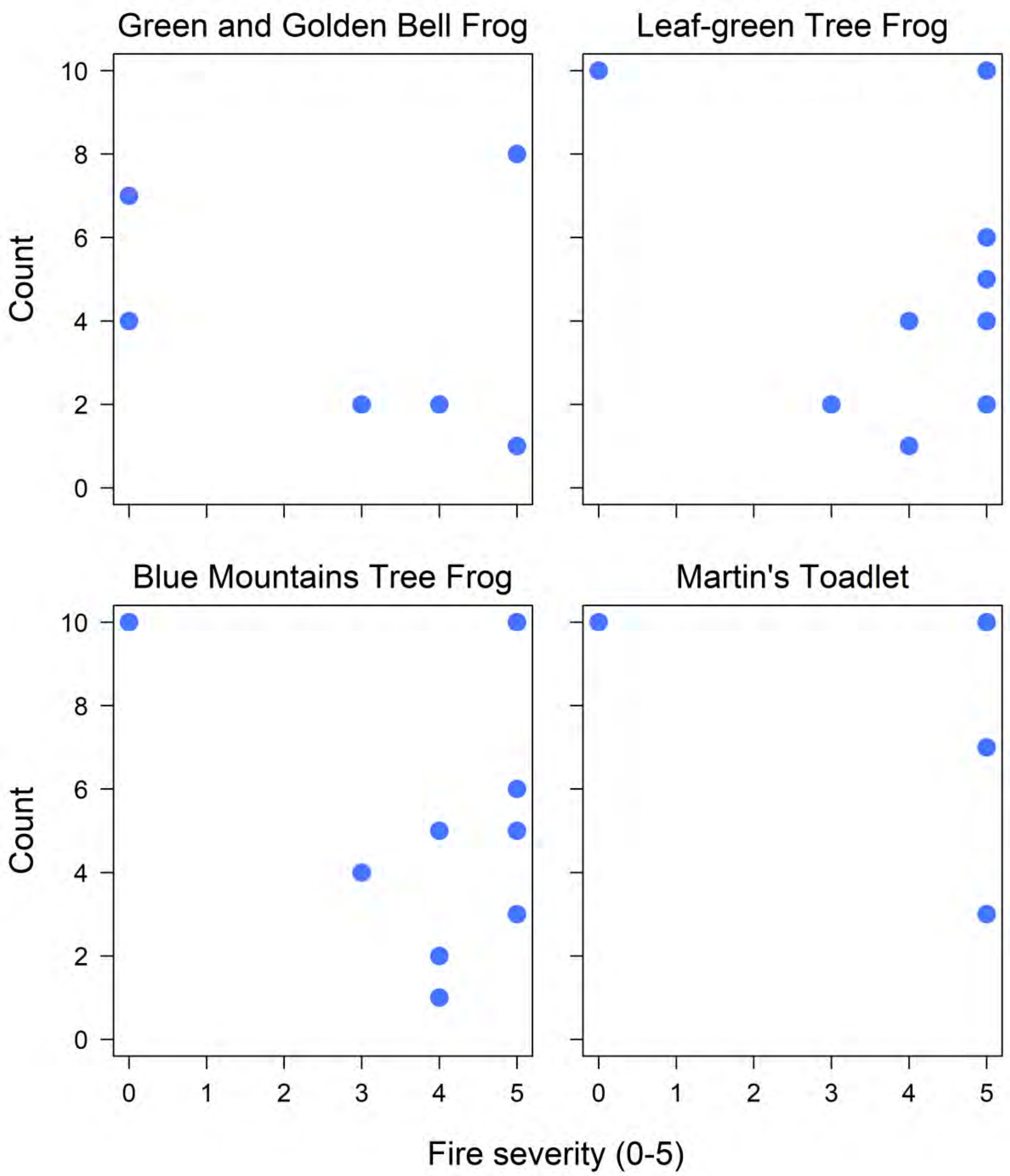

Figure 61. Relationships between fire severity and counts of the Green and Golden Bell Frog, Blue Mountains Tree Frog, Leaf-green Tree Frog and Martin's Toadlet at sites where they were detected. Fire severity is that scored onsite.

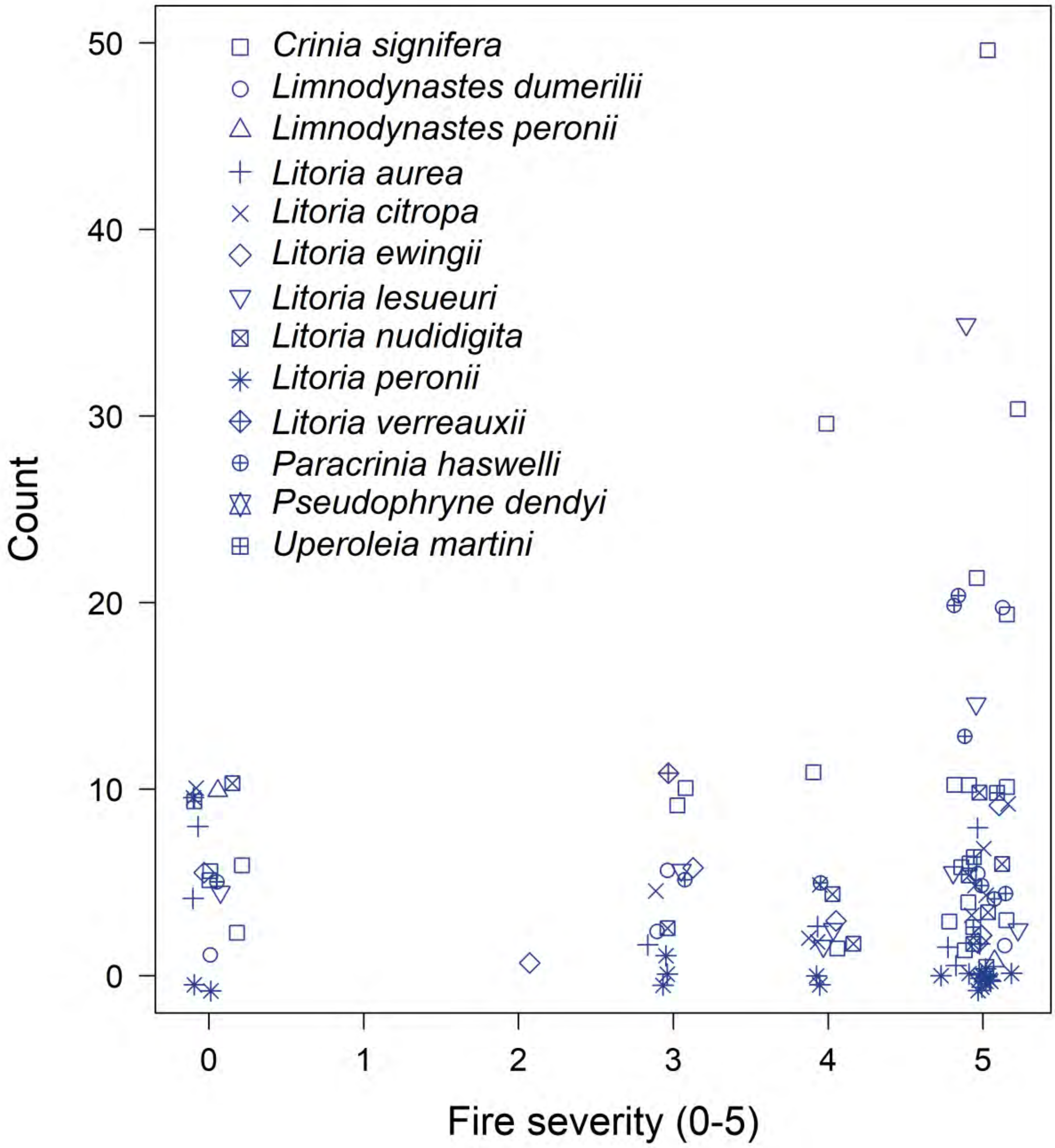

Figure 62. Relationships between counts of all species detected during this study and fire severity.

Risks

Pre-existing risks (i.e. before the bushfires)

- Deer, Pigs and Goats occupying amphibian habitat are known to disturb soil, leading to increased siltation and turbidity, physical trampling of breeding sites and the introduction and spread of weeds and pathogens (possibly including chytrid fungus). Their feeding habits also change the physical structure of riparian vegetation, sun penetration and shelter from wind events.
- Predation of tadpoles and frogs by exotic fish has been observed and is an important ongoing threat to stream-breeding frogs in Gippsland, particularly from introduced Trout (*Oncorhynchus spp.*) and Redfin (*Perca fluviatilis*). Mosquito Fish (*Gambusia affinis*) and European Carp (*Cyprinus carpio*) also threaten wetland-breeding species, particularly *L. aurea*.

- The amphibian chytrid fungus has been a key driver of the decline of Green and Golden Bell Frog, and some *Pseudophryne*; however, its impacts on Dendy's Toadlet are currently unknown.
- The absence of understanding of tolerable fire intervals for any species of frog in Gippsland means that regular prescribed burning may negatively impact these species.
- Weed infestations including Blackberry (*Rubus* sp.), Blue Periwinkle (*Vinca* sp.), pasture grasses and Willows (*Salix* sp.) can change the hydrology and riparian structure of frog habitats.

Additional risks driven by the 2019–2020 bushfires

Weed control issues: In some streams that burned at high intensity, there was no suitable native vegetation remaining for frogs to call from. In these sites, frogs were observed calling and sheltering in weed species, including Blackberry (*Rubus* sp.). Weed spraying is a likely risk in these locations; several dead frogs were observed in the immediate proximity of sprayed weeds at one site.

Program managers reviewed herbicide practice and a decision tool was developed to assist staff and contractors to identify sites where weeds provide important habitat for frogs and at which weed control should be delayed until microhabitats provided by native flora were available.

High densities of feral deer species, namely Hog Deer (*Axis porcinus*) and Sambar Deer (*Rusa unicolor*) were observed in and around water sources, resulting in higher turbidity readings and large wallowing areas created in wetlands. For example, feral deer (including Hog Deer) were significantly affecting the aquatic habitat of recovering sites around Dock Inlet. These findings were discussed with the deer control program managers, resulting in amendments to the program and potential addition of Hog Deer to the list of species controlled.

Introduced fish threaten stream-breeding frogs during the recovery period post fire. Predation on eggs and tadpoles could be more severe during these periods (due to reduced aquatic vegetation cover) and threaten frog populations (with small numbers of adults remaining, populations have a higher risk of extinction if recruitment fails).

It is possible the lowered abundance of frogs resulting from the 2019-20 wildfires could lead to erosion of genetic diversity at these sites, as was documented for several species following the Black Saturday fires of 2009 (Potvin *et al.* 2017). Targeted genetic studies in the breeding seasons ahead should be considered to determine this, with pre-fire data available from numerous sites across East Gippsland following two studies in 2016 and 2017 (J. Melville and J. Sumner, Museums Victoria, pers. comm).

Fire water points (WPs) in the forest are refuges for some frog species. The value of, and potential to manage these refuges as habitat for particular frogs should be evaluated.

Input of ash, silt, and sediment, particularly after rainfall events buries instream habitat, stream banks and sand banks. This is likely to render these areas unusable as frog habitat, potentially leading to longer term loss of breeding for riverine frogs that lay their eggs in the spaces between rocks and shelter sites.

Future directions

Priority actions identified for consideration within DELWP's decision-support tools are as follows:

Further assessment of the post-fire recovery of Martin's Toadlet and Green and Golden Bell Frog. This study revealed that both species have persisted and are breeding at sites that were inundated in the 2020-21 season, however longer-term assessment would be required to confirm species persistence.

Studies investigating whether genetic bottlenecking is occurring would be useful, as this represents a risk for amphibians afflicted by widespread bushfire. Further studies would be needed to identify populations that may need genetic rescue.

Recovery of stream-breeding frogs in higher reaches of catchments is imperilled by trout and redfin. The cessation of stocking of trout in these catchments should be assessed as a potential action to support the recovery of frog populations.

As fire water points (WPs) in the forest are refuges for some frog species, their value as habitat for frogs should be managed in a way that is sympathetic to frog requirements.

Acknowledgements

This project was funded by the Victorian Government's Bushfire Biodiversity Response and Recovery program. Surveys were possible due to support and advice from Parks Victoria and DELWP local staff. Mark Norman and Mark Antos (Parks Victoria), and Tim O'Brien (DELWP) provided advice and support including a review of field activity and safety plans. Dr Joanna Sumner and Dr Jane Melville of Museums Victoria provided survey design advice and expert review, and assisted with ethics permits. Matthew Clancy shared observations of *L. dentata* in East Gippsland both before and after the Black Summer fires. Parks Victoria FSO Joey Williams and volunteer Mark Tscharke are thanks for assisted with remote field work. Videographer Darryl Whitaker documented amphibian recovery for public engagement activities.

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4.3 Reptiles and other frogs

Prepared by Nick Clemann (ARI) and Zak Atkins (Atkins Ecological Contracting Pty Ltd)

Summary of fire impacts

A broad range of threatened reptiles were impacted to varying degrees by the 2019–2020 bushfires (refer to Table 1 in the Introduction). The loss of habitat, and potentially populations, following these bushfires has increased concerns about the persistence of several reptile species in Victoria.

These assessments are designed to complement the assessments of species and sites through the other activities reported in this chapter for Spotted Tree Frogs, Booroolong Frogs and the East Gippsland frogs.

Summary of key findings

In all affected areas, the fires varied in intensity, but the impacts were mostly severe. Consequently, there has been a commensurate loss of reptile and frog fauna.

Short-term survival and persistence can mask longer-term effects, such as genetic 'bottlenecking' (which results when there are only a few surviving founders) and the ecological consequences of dense regrowth of vegetation (which can affect thermoregulation, foraging, etc.).

The effects of the fire are exacerbated in some areas by activities such as 'salvage' logging.

Key recovery actions already underway include genetic analyses to guide conservation management, captive programs for key threatened species [such as the Southern Giant Burrowing Frog (*Heleioporus australiacus flavopunctatus*)], and control of invasive herbivores [such as feral Horses (*Equus caballus*), deer, and Pigs (*Sus scrofa*)].

Background

This report provides the results of on-ground assessment of the bushfire impacts and the resulting status of key threatened alpine reptile species. We undertook a broad assessment for most reptiles in the fire-affected areas, but we paid particular attention to threatened species such as the Alpine Water Skink (*Eulamprus kosciuskoi*), Alpine Bog Skink (*Pseudemoia cryodroma*), Alpine She-oak Skink (*Cyclodomorphus praealtus*), Mountain Skink (*Liopholis montana*) and Alpine Tree Frog (*Litoria verreauxii alpina*).

Between January and April 2020, we surveyed for reptiles and some frogs in all fire-affected parts of north-eastern Victoria, the Victorian Alps, and East Gippsland that we could access. In October 2020, we returned to the north-east and surveyed additional areas that we were unable to access in the first round of surveying. In February 2021, we surveyed key sites (Forlorn Hope Plain and Davies Plain) that were closed during our initial survey period in early 2020.

Methods

All burnt areas in north-eastern Victoria, the Victorian Alps and East Gippsland accessible by four-wheel drive vehicle after the fires were surveyed. To cover so much area in the limited available time, most surveys were carried out close to four-wheel-drive tracks.

After consideration of the available mapping of the fire extent, surveys were rapidly conducted in as much of the fire footprint as possible before the reptile season ended (i.e. before reptiles entered hibernation or became difficult to find due to seasonally reduced activity levels). Some species were targeted, but an effort was made to detect and record all reptile species present through general surveys and also incidentally during surveys for the targeted species. To survey as much of the fire footprint as possible in the short time available, survey efforts concentrated on areas that were within approximately 30 minutes' walk time from vehicle access points.

Based on our long-term monitoring and research of threatened alpine herpetofauna, there was a robust understanding of the distribution and habitat needs of these species, and it was possible to rapidly ascertain whether key habitat within the species' distributions had been burnt, and to make informed assumptions about the probable fire effects on these species. For example, when considering the likely impact of the bushfires on the habitat of two alpine endemic species listed as Endangered under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), it was expected that the Guthega Skink (*Liopholis guthega*) would have higher initial survivorship compared with the Alpine She-oak Skink, because the latter uses ground-level vegetation for shelter, thermoregulation and foraging, whereas the former shelters in burrows or warren systems beneath rocks.

Particular species were targeted for several reasons: much of their Victorian distribution occurs within the 'footprint' of the bushfires [e.g. the Yellow-bellied Water Skink (*Eulamprus heatwolei*)]; the species have declined and are facing ongoing deleterious threats elsewhere in their range, and the burnt areas were previously considered secure or else a stronghold for these species [e.g. Swamp Skink (*Lissolepis coventryi*), Lace Monitor (*Varanus varius*)]; the known or inferred status and trend of these species is of concern (e.g. Swamp Skink); they have specialised habitat preferences [Swamp Skink, Alpine She-oak Skink, Gippsland Water Dragon (*Intellagama lesueurii howittii*)]; or they have particular ecological traits that are of particular concern (e.g. Lace Monitor's reliance on termitaria for egg incubation, alpine reptiles' inability to recolonise 'sky island' habitats that are separated by valleys).

Initial and enduring challenges for assessing reptiles in fire-affected regions of eastern Victoria included the lateness of the season by the time resources were confirmed and it had become relatively safe to enter the fire grounds; track closures and blockages due to the fires (e.g. no access to the eastern alps); and entire reserves that were locked-off for safety reasons (e.g. Mount Mitta Mitta Regional Park and Wabba Wilderness Park).

Between October 2020 and March 2021, fire-affected areas that were inaccessible earlier in 2020 were surveyed in north-eastern Victoria (such as parts of the Burrowa – Pine Mountain National Park (NP) and Mitta Mitta Regional Park) and the eastern alps (Forlorn Hope Plain and Davies Plain). Additionally, the long-term program of work with alpine reptiles and frogs continued, while genetic investigations into three species of reptiles in fire-affected parts of East Gippsland and a captive husbandry program for the Giant Burrowing Frog in collaboration with Zoos Victoria were commenced. These additional projects now provide further insights into the effects of the bushfires on the reptiles and frogs of eastern Victoria. The same methods were used as per earlier surveys.

Although not all parts of East Gippsland were accessible, access to most of the area was possible by vehicle tracks, including a number of locations with habitat suitable for target species (e.g. low-lying peatlands for Swamp Skinks and streamsides for Gippsland Water Dragons). Similarly, access to many of the relevant areas of immediate concern in the central Victorian Alps, such as the Dargo High Plains and the Bogong High Plains, was possible, but not sites in the eastern alps that were burned and where key threatened species occur (or previously occurred, in the case of the Alpine Tree Frog). Because access gates to entire reserves in the north-east of the state were locked (e.g. the Wabba Wilderness Park and the Mount Mitta Mitta Regional Park), surveys in that area were necessarily limited to roadsides on the periphery of the reserves.

Funding support enabled most of the survey gaps to be addressed between October 2020 and March 2021. These additional surveys aided researchers to confirm earlier observations of the effects of the Corryong fire on reptile and frog habitats in far north-eastern Victoria and to assess its effects on the alpine herpetofauna of Davies Plain and Forlorn Hope Plain.

Results

Prior to these bushfires, acute and chronic threatening processes resulted in deleterious trends across most of the reptile fauna of Victoria (as per Clemann 2015). In a similar manner to catastrophic disease outbreaks, such as chytridiomycosis, these fires demonstrated the potential of single large events to rapidly worsen the status of some species, and to rapidly compromise areas previously considered strongholds for certain species or groups (e.g. prior to the 2019–2020 fires, East Gippsland had been considered the stronghold for some species that are rapidly declining elsewhere, such as Swamp Skinks and Lace Monitors). Many populations of Victorian reptiles have become fragmented, and many are on a declining trajectory. Modern molecular techniques and the emerging paradigm of 'genetic rescue' suggest that an urgent priority is 'baselining' the genetic 'health' of selected populations of as many species as possible in order to determine their status and their priority for conservation interventions.

Manageable threatening processes are eliminating, reducing and/or fragmenting many species of Victorian reptiles and frogs, leaving them particularly vulnerable to irretrievable loss when large stochastic events such as these bushfires occur. Cessation of preventable threats across the range of each species would maximise the resilience of populations to events such as these fires. For example, the habitat of Swamp Skinks has been drained, cleared, fragmented, and degraded since the arrival of Europeans, resulting in East Gippsland being considered a remaining stronghold for this species. Events such as these fires demonstrate that such strongholds are not impervious to major threats. Effective conservation of these declining species must involve mitigating threats across the entire range of species.

Heavy rains that ultimately helped extinguish the bushfires also resulted in large inputs of ash and sediment into stream channels. These inputs buried entire cobble banks and sand banks, as well as filling the interstitial spaces between exposed and submerged rocks. These sediments, especially if they are not flushed downstream, may have pronounced impacts on breeding efforts of species such as the Gippsland Water Dragon and the Eastern Long-necked Turtle (*Chelodina longicollis*; which use sandy riparian areas as oviposition sites), as well as obligate stream-breeding frogs, such as the Spotted Tree Frog and the Booroolong Frog, which shelter beneath cobble banks, and deposit eggs under and between submerged rocks. The massive inputs of ash and sediment that were observed immediately after the fires was still evident during the second season of surveys (Figure 63; Figure 64). Sediment loads were also evident well downstream of burnt areas, indicating that the fires may have compromised oviposition sites, even in unburnt areas.

These surveys showed that, in the aftermath of severe fire, standing and fallen timber are often the only shelter available to surviving reptiles and frogs; removal of this timber through 'salvage' logging is likely to further compromise or even doom populations of these herpetofauna, which after the fire are represented by a tiny fraction of the number of individuals that occurred in the area before the fire.

In the immediate aftermath of large fires, species are especially vulnerable to predators, both native and exotic. Equally, large feral herbivores such as Horses and deer consume and trample recovering vegetation. Many reptiles rely on, and are adapted to, vegetation for shelter, thermoregulation, and foraging. At Forlorn Hope Plain in the eastern alps, for the first time in the two decades or so that the authors have been surveying on this plain, no Horses were recorded during this survey. There was a corresponding improvement in the appearance of ground-layer vegetation on this plain, with longer grass and less fresh caving-in of the banks of the small stream that now runs along this plain.

One of the least recognised and understood effects of fire on reptiles and frogs is the combined short- and long-term influence of vegetation loss followed by plant succession over time. Vegetation structure strongly influences thermoregulation, effectiveness of foraging, and the ability to shelter from predators and the elements. Consequently, these rapid and dramatic changes to the thermal environment, sunlight penetration, moisture levels, etc., can greatly affect reptile persistence and abundance in the months and years after a fire. It is important that the effects of vegetation succession are not overlooked, and that the effects of this succession and the changing status of reptile and frog species are assessed over meaningful time frames (at least decades). Long-term monitoring not only provides this information, it also provides irreplaceable pre-impact information for understanding the impacts when the next large fire occurs, as well as information on the potential effects of management actions, emerging threats, and changes in the levels of existing threats.

Apparent recovery of populations of reptiles and frogs can mask deleterious impacts (Potvin et al. 2017), such as inbreeding. Sustained long-term monitoring of selected populations would ensure that the full impacts of events such as the recent bushfires are understood, and that appropriate management is occurring. In the absence of long-term monitoring, we have undertaken genetic analyses of some populations of three fire-affected reptile species in East Gippsland (Swamp Skink, Gippsland Water Dragon and Lace Monitor; This approach is described in the 'Herpgen' concept [N. Clemann, Z. Atkins, P. Robertson, D. Gilbert, R. Hartley and M. Amor, unpubl. report]); however, there is no substitute for long-term monitoring.

The ability to understand the impacts of events such as fire on most Victorian reptiles, as well as the effect of management actions, is compromised by a lack of current pre-impact data on populations. The few species that are the subject of long-term monitoring (e.g. the Guthega Skink and the Alpine She-oak Skink) demonstrate the benefits of long-term datasets, ongoing monitoring, and improved understanding of species and their habitats. For these two species, it has been possible to determine the impacts of these fires, both immediately and over time, with a high degree of certainty. Monitoring of all species and populations is not possible. However, ongoing monitoring of a priority subset that represent key factors (e.g. a geographic or biophysical region, an ecological cohort, species especially susceptible to key threats) would improve the capacity to rapidly and definitively evaluate the impacts of acute and chronic threatening processes, as well as the results of management actions. Furthermore, this information would provide the basis for strong inferences about co-occurring species and unmonitored populations.

Our experience in the aftermath of these fires has demonstrated that inspection of firegrounds by relevant taxon experts as soon as possible is critically important. Successional vegetation changes are very rapid (starting in the first few weeks), and rapid responses such as epicormic sprouting, bracken growth, and basal sprouting can mask important observations about the initial impact, and they can make it very difficult to determine probable presences and absences of fauna. The first few weeks after fire provides a short 'window' within which survivors are highly visible (or easily found under superficial shelter), and it is then that the potential losses are most reliably determined. Early assessment by taxon experts is therefore important for understanding immediate impacts.

By rapidly and widely affecting a large and comparatively untouched part of Victoria, these fires have demonstrated the vulnerability of Victorian reptiles. Our surveys highlight the fact that all extant components of a species' range, including those that may otherwise be considered 'secure', are important for the overall conservation of a species.

Figure 63. Examples of ash and sediment input into river channels in East Gippsland. From left to right, upper row: beside Tambo River, 11 March 2020; Tambo River, 11 March 2020, with sediment and ash covering a sand bank; muddy sediment with animal track beside the Errinundra River, 12 March 2020; muddy sediment beside the Errinundra River, 12 March 2020; sediment forming 'islands' in the Errinundra River, 12 March 2020. Lower row: a small stream in north-eastern Victoria, almost completely choked with post-fire sediment inputs; close-up photo of the sediments in this stream (pocket-sized notebook and pencil for scale) (photos: Nick Clemann).

Figure 64. Mud banks and sediment covering sand banks, cobble banks and frog breeding habitats in the Tambo River, East Gippsland on 15 November 2020 (photos: Nick Clemann)

Risks

Pre-existing risks (i.e. before the bushfires)

Pest predators and herbivores

Timber harvesting

Clearing of native vegetation

Planned burning

Prior to these fires, acute and chronic threatening processes such as clearing of native vegetation have resulted in deleterious trends across most of the reptile fauna of Victoria. These threats, their impacts, and their effects on reptile populations is detailed in Clemann (2015).

Many populations of Victorian reptiles and frogs have become fragmented, and many—perhaps most—are on a declining trajectory.

Additional risks driven by the 2019–2020 bushfires

The 2020–2021 bushfires demonstrated the potential of single large events to rapidly worsen the status of some species, and to rapidly compromise areas previously considered strongholds for certain species or groups.

These fires have exacerbated the impacts of feral predators and herbivores, and vice versa.

Input of ash, silt and sediment buried many stream banks, cobble banks and sand banks, as well as covering bedrock (including spaces in and between rocks that are used as oviposition sites by some riverine frogs). The cobble banks are used for shelter by riverine frogs, and the sand banks are used for egg-laying by Gippsland Water Dragons and turtles. Unfortunately, observations made 15 months after the 2020–2021 bushfires indicated that in most places in which it was deposited, this sediment has not yet been flushed through. This suggests that the probable burial of many reptiles and frogs is likely to be exacerbated by the longer-term loss of egg-laying and shelter sites. These inputs of ash and sediment affected habitats downstream of the burnt areas, so even stream channels in unburnt areas may now have degraded or destroyed egg-laying and shelter habitats.

Future directions

Priority actions identified for consideration within DELWP's decision-support tools are as follows:

Long-term monitoring of a priority subset of species, populations and areas would provide improved understanding of the impacts of events such as these fires, pre-impact data for future events, allow us to evaluate and adapt management actions, and help identify emerging, worsening or reducing threats.

Effective control of invasive vertebrates [especially horses (*Equus caballus*), deer and pigs (*Sus scrofa*)] and control of weeds.

For threatened high-elevation reptiles, such as the Alpine Water Skink and Alpine Bog Skink, removal of horses from alpine and sub-alpine areas is likely to be an important action. The removal of deer is also likely to be important, but experience working in areas that have deer but no horses, versus areas that have both, show that horses currently cause more rapid, severe, and widespread damage to reptile and frog habitat than deer.

Intense and sustained suppression of red foxes (*Vulpes vulpes*) and cats (*Felis catus*) will benefit most reptile species, particularly in the aftermath of fires.

Modern molecular techniques and the emerging paradigm of genetic rescue suggest that baselining the genetic health of selected populations of as many species as possible is a high priority.

Acknowledgements

This project was funded by the Victorian Government's Bushfire Biodiversity Response and Recovery program.

In late January 2021, staff from ARI–DELWP engaged with locals in Mallacoota to discuss the probable fire impacts on reptiles and frogs, and to listen to their observations about fauna and ecosystems. One of the locals, Bryce Watts-Parker, was particularly helpful in explaining the pre- and post-fire status of reptiles and frogs in this area and led us to key populations of species. Bryce also aided us with transport and accommodation.

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Aquatic species

Searching for fish to extract from fire and post-fire rainfall-affected Euchre Creek, Lind National Park, East Gippsland, 19 February 2020 (photo: Tarmo A. Raadik)

5.1 Fish, crayfish and mussels

Prepared by Tarmo A. Raadik (ARI) for all species except Macquarie Perch (*Macquaria australasica*), which was prepared by Zeb Tonkin (ARI) and Glen Johnson (FFR Hume).

[This section includes post-fire assessments for the following species: Cann Galaxias (*Galaxias* sp. 17), Dargo Galaxias (*Galaxias mungadhan*), East Gippsland Galaxias (*Galaxias aequipinnis*), McDowall's Galaxias (*Galaxias mcdowalli*), Roundsnout Galaxias (*Galaxias terenasus*), Yalmy Galaxias (*Galaxias* sp. 14), Gippsland Blackfish (*Gadopsis* sp. SEV), Arte Spiny Crayfish (*Euastacus* sp. 1), Cann Spiny Crayfish (*Euastacus* sp. 2), East Gippsland Spiny Crayfish (*Euastacus bidawalus*), Orbost Spiny Crayfish (*Euastacus diversus*), Variable Spiny Crayfish (*Euastacus yanga*), West Snowy Spiny Crayfish (*Euastacus* sp. 3), Macquarie Perch (*Macquaria australasica*), Mallacoota Burrowing Crayfish (*Engaeus mallacoota*), Austral Mussel (*Hyridella australis*), Depressed Mussel (*Hyridella depressa*) and Glenelg Freshwater Mussel (*Hyridella glenelgensis*).]

Summary of bushfire impacts

Fire can increase water temperature to fatal levels and (due to the loss of vegetation and the effects of the heat on the soil structure) increase the amount of ash and sediment flowing into rivers during post-fire storms, clogging up streams and impacting on breeding success, in-stream food, and habitat availability.

Threatened freshwater species with highly restricted distributions and low dispersal ability are at most risk from the impacts of fire. The extensive bushfires in 2019–2020 burnt throughout the catchment of the entire known distribution of many such species, and heavy rains following the fires further threatened species by washing ash, sediment, and toxic chemicals into rivers and streams.

The percentage of the modelled habitat for each of these species in Victoria that was within the fire extent varied from 16% (Dargo Galaxias) to 100% (East Gippsland Galaxias). For a full list of the aquatic species of concern identified in *Victoria's bushfire emergency – biodiversity response and recovery, version 2* (DELWP 2020), see Table 1.

Summary of key findings

All target aquatic species in moderate- to high-intensity burn areas were found to have declined in abundance, with some by up to 70%.

The impact of fire on populations of aquatic species could not be separated from that due to sediment input into streams, as debris flow and in-stream sedimentation events had already occurred before post-fire reconnaissance could be conducted.

As at least one individual of each species was captured during post-fire reconnaissance of sites, all target aquatic species had, nevertheless, persisted following the fire. However, due to the ash and debris inflow, they were at risk of smothering or choking from debris flow and in-stream sedimentation, and/or poor water quality.

Reconnaissance was invaluable in obtaining information about the level of need for aquatic fauna extraction at impacted sites. However, it was sensible from an efficiency and risk reduction perspective for staff involved to undertake these activities together, rather than to complete the reconnaissance and return later to extract the animals.

Reconnaissance data support the time-critical need to extract impacted populations as soon as possible after a fire has passed—for insurance before post-fire rainfall events occur (i.e. preferentially within 1 week). In this project, reconnaissance and extraction activities were able to commence 2 weeks after the project was initiated, but rainfall and in-stream sedimentation events had already occurred.

Reconnaissance allowed direct observation of the devastating post-fire impact that sedimentation events can have on aquatic fauna. Sites in the direct path of a high-intensity rainfall event in East Gippsland (Euchre Creek, Martins Creek) were found to be: devoid of two of the target aquatic fauna Gippsland Blackfish (*Gadopsis* sp. SEV) and Orbost Spiny Crayfish (*Euastacus diversus*); heavily eroded; sediment infilled (bed and banks); covered in ash, organic detritus, and timber debris; and carrying exceedingly high suspended sediment loads.

Some adult Short-finned Eels (*Anguilla australis*), and adult and juvenile galaxiids, collected from a few streams (e.g. Euchre Creek, Yalmy River, Back Creek) were found to have abrasions along their sides.

These streams were impacted by in-stream sedimentation, and the individuals may have been injured by large soil particles in the water column.

Background

Due to a large proportion of their natural range being within the fire footprint, their rarity, and a high probability of being impacted by post-fire conditions, 18 species of freshwater aquatic fauna (eight species of freshwater fish, seven species of freshwater crayfish and three species of freshwater mussels) were identified as being of high priority for post-fire surveillance and potential extraction (Table 1, Table 25). Fish species identified were represented by one large-bodied species in north-eastern Victoria (Macquarie Perch), two medium-sized species of river blackfish (one in each of south-western and south-eastern Victoria) and five small-bodied, critically endangered, species of galaxiids in East Gippsland. The freshwater crayfish included seven narrow-range endemic species of spiny crayfish (*Euastacus* species) and one species of burrowing crayfish (Mallacoota Burrowing Crayfish; Table 1, Table 25). The freshwater mussels (*Hyridella* spp.) had small ranges in coastal streams of eastern Victoria (two species) or in western Victoria (one species, in the Glenelg River).

Table 25. High-priority aquatic species affected by fire, including background information

Species	Background	Number of populations and distribution
Cann Galaxias *Galaxias* sp. 17	small native, non-migratory freshwater fish recently identified as a valid species, awaiting formal description inhabits flowing creeks and small rivers found in low abundance critically endangered Victorian endemic	occupies a very small range two small, isolated populations in the mid to upper Cann River system a third population in Buldah Creek extinct ~2018 due to trout [Brown Trout (*Salmo trutta*), Rainbow Trout (*Oncorhynchus mykiss*)] incursion and predation no connectivity between populations due to trout in intervening waters
Dargo Galaxias *Galaxias mungadhan*	small native, non-migratory freshwater fish able to persist above the snowline inhabits flowing creeks: historically probably also small- to medium-sized rivers critically endangered Victorian endemic	occupies a very small range small, isolated subpopulations exist in the headwater reaches of the Dargo and Little Dargo rivers, which are remnants of a much larger historical population, fragmented by introduced trout two larger 'main' populations, one on the Dargo High Plains, and one near Dinner Plain no connectivity between any subpopulations due to trout in intervening waters
East Gippsland Galaxias *Galaxias aequipinnis*	small native, non-migratory freshwater fish inhabits flowing creeks and small rivers critically endangered Victorian endemic	occupies a very small range single, small, global population, recently fragmented into two subpopulations by introduced trout, in the upper Arte River system no connectivity between subpopulations due to trout in intervening waters
McDowall's Galaxias *Galaxias mcdowalli*	small native, non-migratory freshwater fish inhabits flowing creeks and small rivers critically endangered Victorian endemic	occupies a very small range single, small, global population in the headwater reaches of the Rodger River no connectivity between subpopulations due to trout in intervening waters
Roundsnout Galaxias *Galaxias terenasus*	small native, non-migratory freshwater fish most of its distribution is in New South Wales (NSW) inhabits flowing creeks and rivers endangered in Victoria entire Victorian range burnt during the 2019–2020 bushfire season	occupies a very small range single, small population in the Genoa River near the border with NSW
Yalmy Galaxias *Galaxias* sp. 14	small native, non-migratory freshwater fish recently identified as a valid species, awaiting formal description habitat specialist, prefers cobble areas without silt or sand in flowing water	occupies a very small range single, small, global population, restricted to the lower reaches of the Rodger/Yalmy/Serpentine system north of Orbost upstream distribution restricted by introduced trout

Species	Background	Number of populations and distribution
	inhabits lower reaches of flowing creeks and rivers found in low abundance critically endangered Victorian endemic entire Victorian range burnt during the 2019–2020 bushfire season	
Gippsland Blackfish (eastern lineage) *Gadopsis* sp. SEV	medium-sized native, non-migratory freshwater fish habitat specialist, preferring areas of dense in-stream cover in still to flowing water inhabits lower to mid reaches of creeks and rivers rapidly declining in range and abundance recently identified as a valid species, awaiting formal description Victorian endemic	range extends across Gippsland, from the La Trobe system in the west to the Cann River in the east consists of two genetic lineages, with the eastern lineage restricted to the Snowy, Bemm and Cann river catchments both lineages have suffered a major, and ongoing, reduction in size and number of populations; the eastern lineage has declined the most
Yiritja (South-west River Blackfish) (south-western lineage) *Gadopsis* sp. SWV	medium-sized native, non-migratory freshwater fish habitat specialist, preferring areas of dense in-stream cover in still to flowing water inhabits lower to mid reaches of creeks and rivers rapidly declining in range and abundance recently identified as a valid species, awaiting formal description Victorian endemic	range extends across Hopkins River and Portland Coast catchments; only three isolated, small populations known has suffered a major, and ongoing, reduction in size and number of populations
Macquarie Perch *Macquaria australasica*	medium- to large-sized native, riverine freshwater fish long-lived, generalist schooling species that can form dense aggregations for several months during the spawning season (November) considered endangered Murray–Darling endemic that has undergone significant range reduction and population decline	formerly widespread throughout the Murray–Darling Basin in Victoria now restricted to 11 highly fragmented north-eastern Victorian locations Upper Buffalo River population represents a small refuge population of a once broader Ovens River catchment population
Arte Spiny Crayfish *Euastacus* sp. 1	small species of freshwater spiny crayfish recently identified as a valid species, awaiting formal description inhabits small flowing streams, occasionally found foraging on land along the banks threatened Victorian endemic entire Victorian range burnt during 2019–2020 bushfire season	occupies a very small range restricted to the Goolengook River system (including the Arte River system), on the west side of the Bemm River catchment
Cann Spiny Crayfish *Euastacus* sp. 2	small species of freshwater spiny crayfish recently identified as a valid species, awaiting formal description inhabits small flowing streams, occasionally wandering along the banks threatened Victorian endemic entire Victorian range burnt during 2019–2020 bushfire season	occupies a very small range restricted to the mid to upper tributaries of the Cann River system
East Gippsland Spiny Crayfish *Euastacus bidawalus*	small species of freshwater spiny crayfish inhabits small flowing streams, occasionally wandering along the banks endangered entire Victorian range burnt during 2019–2020 bushfire season	occupies a small range restricted in Victoria to the eastern side of the Cann River catchment, including eastward to the Genoa/Wallagaraugh rivers

Species	Background	Number of populations and distribution
Ngeerang Yarram (Glenelg Spiny Crayfish) *Euastacus bispinosus*	large species of freshwater crayfish inhabits small and large freshwater streams endangered now found in low abundance eastern part of range burnt during 2019–2020 bushfire season	in Victoria restricted to the Glenelg River and Fitzroy River systems
Orbost Spiny Crayfish *Euastacus diversus*	small species of freshwater spiny crayfish inhabits small flowing streams, occasionally wandering along the banks endangered Victorian endemic almost entire Victorian range burnt during 2019–2020 bushfire season	restricted to the Brodribb River catchment (Snowy River catchment) to the north-east of Orbost, north of the Princes highway also found in headwater reaches of the Rodger and Yalmy rivers, and the Bendoc River near Bendoc number of populations unknown, as spiny crayfish can cross catchment divides by walking overland, thereby maintaining connectivity
Variable Spiny Crayfish *Euastacus yanga*	small species of freshwater spiny crayfish inhabits small flowing streams, occasionally wandering along the banks found at low elevations generally found in low abundance endangered in Victoria entire Victorian range burnt during 2019–2020 bushfire season	occupies a small range restricted in Victoria to far East Gippsland, being found in the Genoa/Wallagaraugh River and Wingan River systems
West Snowy Spiny Crayfish *Euastacus* sp. 3	small species of freshwater spiny crayfish recently identified as a valid species, awaiting formal description inhabits small flowing headwater streams threatened Victorian endemic potentially entire Victorian range burnt during 2019–2020 bushfire season	occupies a very small range restricted to the Basin Creek system near Tulloch Ard, north-east of Buchan
Mallacoota Burrowing Crayfish *Engaeus mallacoota*	small species of burrowing crayfish usually found in low abundance inhabits burrow systems in the riparian zone next to small streams in sandy soil, living most of its life underground critically endangered Victorian endemic entire Victorian range burnt during 2019–2020 bushfire season	occupies a very small range only known from Double Creek and Davis Creek near Mallacoota connectivity between burrows and subpopulations is unknown
Austral Mussel *Hyridella australis*	moderate-sized species of freshwater mussel inhabits flowing rivers, burrowing into sandy substrate essentially sedentary as adults, feed by filtering water considered rare and possibly threatened in Victoria entire Victorian range burnt during 2019–2020 bushfire season	extensive distribution in streams along the east coast of Australia occupies a very small range in Victoria known from far East Gippsland, in the Genoa and Wallagaraugh catchments, though recent population status unknown
Depressed Mussel *Hyridella depressa*	moderate-sized species of freshwater mussel inhabits flowing rivers, burrowing into sandy substrate essentially sedentary as adults, feed by filtering water can be locally very abundant, though patchy rare and possibly threatened in Victoria almost entire Victorian range burnt during 2019–2020 bushfire season	extensive distribution in streams along the east coast of Australia occupies a small range in Victoria restricted to East Gippsland, from the lower reaches of the Mitchell River catchment (north of Bairnsdale) to the NSW border near Genoa extent of upstream distribution poorly known, as is connectivity between separate river systems
Glenelg Freshwater Mussel *Hyridella glenelgensis*	small, fragile freshwater mussel restricted to flowing reaches of small streams in sandy substrate	restricted to one large and two small populations in tributaries of the lower Glenelg River system very small distribution, and low abundance of individuals

Species	Background	Number of populations and distribution
	essentially sedentary as adults, feed by filtering water very rare, critically endangered Victorian endemic 90% of entire range threatened by post-fire impacts as located downstream of a fire in the mid-catchment during 2019–2020 bushfire season	

Methods

Locations surveyed

Locations where aquatic fauna were assessed are provided in Table 26. In addition to these locations, and where possible (i.e. vehicle access allowed), qualitative, visual assessments of post-fire catchment vegetation condition (with respect to its ability to intercept rainfall and overland water flow) were made upstream from the aquatic assessment locations. These assessments contributed to the specific location evaluations by adding information about the risk of debris flow and in-stream sedimentation for the aquatic fauna.

Site selection was based on an extensive history of monitoring of the target species, and therefore known key locations with previous data were selected. For some species, particularly the galaxiids, this constituted a single known population.

Assessment locations in coastal Gippsland were all north of the Princes Highway (with the exception of sites around Mallacoota) and were distributed from the upper reaches of the Mitchell River Basin near Mount Hotham (target species e.g. Dargo Galaxias), eastward through the Tambo River Basin (mussels and galaxiids), the Snowy River Basin (galaxiids, spiny crayfish, and mussels) and the East Gippsland Basin, to the border with NSW north-east of Genoa (galaxiids, blackfish, spiny crayfish, burrowing crayfish, and mussels). In western Victoria, assessments related to the Glenelg Freshwater Mussel were confined to the Crawford River, which was impacted by a fire in the Crawford River Regional Park; assessments related to the Glenelg Spiny Crayfish and the South-west River Blackfish were confined to Killara (Darlots Creek) and Tae Rak (Lake Condah), which were both impacted by the Budj Bim bushfire. Macquarie Perch surveys were undertaken in the Upper Buffalo River, in north-eastern Victoria.

Table 26. Proposed locations for reconnaissance of selected aquatic fauna

Species	System	Location
Cann Galaxias	Cann River system, mid to upper reaches	Back Creek catchment, Noorinbee North Lockup Creek and Whitegum Creek catchments, south of Buldah
Dargo Galaxias	Dargo River, headwaters	Lightbound Creek, Dargo High Plains Road Precipice Creek, above and below Carmichael Falls, Dinner Plains
East Gippsland Galaxias	Goolengook River (Bemm River system)	Arte River upper reaches, Metal Link Track Little Arte River, off Pikes Hill Track
McDowall's Galaxias	Rodger River (Snowy River system)	Rodger River, Deddick Track and Waratah Flat Track, Snowy River National Park (NP)
Roundsnout Galaxias	Genoa River	Genoa River, Yambulla Peak Track
Yalmy Galaxias	Rodger River (Snowy River system)	Yalmy River, Yalmy Road Serpentine Creek, Yalmy Road
Gippsland Blackfish	Cann River system, mid to upper reaches	Back Creek, mid catchment, Noorinbee North Buldah Creek, North Buldah Trail Cann River, upstream of Buldah
South-West River Blackfish	Fitzroy River	Darlots Creek and Lake Condah
Macquarie Perch	Upper Buffalo River	Upstream of Lake Buffalo
Arte Spiny Crayfish	Goolengook River (Bemm River system)	Arte River upper reaches, Metal Link Track Little Arte River, off Pikes Hill Track
Cann Spiny Crayfish	Cann River, mid to upper reaches	Lockup Creek, south of Buldah Cann Swamp Creek, south of Buldah
East Gippsland Spiny Crayfish	Genoa River	Genoa Creek, Genoa Creek Track Buldah Creek, north of Buldah Thurra River, upstream of Princes Highway Karlo Creek, upstream of Princes Highway Dingo Creek, Lind NP
Glenelg Spiny Crayfish	Fitzroy River	-Darlots Creek and Lake Condah
Orbost Spiny Crayfish	Rodger River (Snowy River system)	Rodger River, Deddick Track and Waratah Flat Track, Snowy River NP
Variable Spiny Crayfish	Genoa River	Genoa River tributary, Wangarabell Road Maramingo Creek, Sandy Waterholes Road
West Snowy Spiny Crayfish	Snowy River	Basin Creek headwaters, Tulloch Ard
Mallacoota Burrowing Crayfish	Davis Creek	Double Creek, upstream of Mallacoota Road Davis Creek, mid to upper reaches, Mallacoota
Austral Mussel	Genoa River	Genoa River and Wallagaraugh River catchments
Depressed Mussel	East Gippsland, Tambo River, Nicholson River	Thurra River, just upstream of Princes Highway Wingan River, at Princes Highway Cann River, at Cann River Tonghi Creek, Princes Highway Bemm River, Combienbar Road and Princes Highway Brodribb River, pumping station Snowy River, at Long Point and Sandy Point Tambo River, Evans Pool Nicholson River, upstream of Sarsfield
Glenelg Freshwater Mussel	Glenelg River	Crawford River, from Dartmoor upstream to The Boulevard

Survey methods

Survey methods employed for aquatic species (Stoessel et al. 2021) consisted of the following:

Galaxiids, spiny crayfish and Gippsland Blackfish – electrofishing – Fish and spiny crayfish were collected by an active survey method using a purpose-built, commercially available, portable backpack electrofishing unit. The operator applied an electric current to the water from an anode pole, which stuns the fish and disturbs crayfish from the substrate; the fish and crayfish are then picked up by the operator using a net on the anode pole, assisted by a second person with a dipnet. Collected fauna were placed into a bucket, identified to species, and counted; if necessary, they were also measured for length [fork length or total length for fish (in millimetres), and Occipital Carapace Length (mm) for crayfish] and weighed (in grams). Once recovered, they were returned to the site of capture. Electrofishing was undertaken in an upstream direction during daytime, with the operator targeting all areas and habitats with the anode.

This survey method was developed by ARI–DELWP following previous fires in Victoria at which post-fire reconnaissance and fauna extraction were undertaken (i.e. 2003, 2006, 2009–2010, 2014).

Freshwater mussels – hand searches – Freshwater mussels were detected by sweeping or brailing over the substrate on the stream bed using the fingers and palm of one hand to feel for mussels. Any mussels detected were placed into a bucket of freshwater for later identification. This was usually undertaken by two people for a minimum of 30 minutes (i.e. sampling for 1 person-hour) and involved frequent shifting along the stream to detect appropriate habitat. Where mussels were abundant at a site, only a small number were extracted; the target amount for extraction was collected by sampling many habitat patches (in order to maximise genetic diversity within the sample by collecting widely separated individuals).

Macquarie Perch – Thirteen locations along the length of the Upper Buffalo River were surveyed. At each location, a series of fyke nets were installed (see Figure 75) and checked at prescribed intervals, with all fish and other fauna (e.g. Platypus) being recorded. All Macquarie Perch captured were weighed (in grams) and measured [total length (in millimetres)], and a genetic sample (caudal fin clip) was taken for later analysis. All fauna fish were released alive at the point of capture.

Riparian and catchment vegetation assessment and potential for debris flow and in-stream sedimentation assessment

To assess the risk of debris flow and in-stream sedimentation impacting target aquatic fauna, a general qualitative inspection of the in-stream and riparian zone condition was undertaken. This focused on the status of the remaining riparian vegetation, particularly on its ability to intercept rainfall and overland flow. Sites considered low-impact areas were lightly burnt, with canopy leaves and understorey vegetation scorched but present, and with timber debris remaining on the forest floor. Sites considered high-impact areas were where canopy leaves, understorey, groundcover plants, and most of the timber debris on the forest floor had been burnt away. The assessment also included observation of recent (post-fire) bank and in-stream sedimentation or erosion events, either at or upstream of the assessment site. Catchment steepness was also important, though steepness at assessment sites was not always indicative of the steepness of the burnt catchment upstream of the assessment site. For most sites, upstream catchment steepness was assessed during broader assessment of catchments, if possible, and from digital terrain models.

Debris flow and in-stream sedimentation risk was considered low if the assessment location plus upstream catchment were lightly burnt and had a gentle slope, and therefore a low probability of overland water flow during intense rainfall events. The risk ranged up to extremely high, as in locations at which most or all the vegetation in the catchment had been burnt away, including canopy cover and forest floor debris, leaving very little to no structure to intercept the erosive potential of falling rain and to constrain overland water flow.

Overall aquatic fauna risk assessment

At each assessment location, the decision to extract or leave target aquatic fauna was based on a combination of the degree of risk of debris flow and in-stream sedimentation (considered equal to the risk of losing animals) combined with the potential extinction risk to the species (based on the number of separate populations, the size of those populations, etc.), if further, post-fire, impacts were to be expected.

For many species, particularly the galaxiids, most exist as a single, small, global population in a short headwater reach of a river system. Consequently, the normal extinction risk can be very high, particularly following a major disturbance such as fire, and extreme if the vegetation across the entire population has been impacted and there is the potential for debris flow/in-stream sedimentation.

Results

The major post-fire threat to aquatic fauna is from debris flow across fire-modified soils in exposed catchments during intense, localised rainfall events. This is likely to lead to in-stream sedimentation, which can physically smother and choke aquatic organisms (an acute impact). It is critical that aquatic fauna assessments for threatened target species are conducted as soon as practical post-fire, before rain events potentially impact burnt catchments. This is particularly pertinent for species with a high risk of extinction, such as those with a single population or a few small, isolated populations.

Preparation for reconnaissance (and extraction if needed) of aquatic fauna commenced on 9 January 2020 at a workshop in Melbourne led by DELWP to develop a biodiversity response to the ongoing fires. Unfortunately, this was also the date of the first major post-fire rainfall event over the burnt Gippsland catchments, and two more rainfall events occurred before logistical issues (project and site access approvals, and funding) could be overcome to allow field teams onto the fire ground in early February.

Aquatic reconnaissance commenced in north-eastern Victoria in December 2019, at the Crawford River on 3 February 2020, in Gippsland on 11 February 2020, and in south-western Victoria in September 2020. The assessment results are summarised in Table 27.

Table 27. Summary of aquatic fauna reconnaissance results

Target species	Species or community condition 1 (good) to 5 (not found)	Fire impact 1 (no impact) to 5 (severe impact)	Existing threats that pose a threat to recovery	Comments
Cann Galaxias	3 (Back Creek) Suspected 4–5 in upper Cann River, based on fire intensity	3 (Back Creek) Suspected 4–5 in upper Cann River from fire-intensity mapping	Observed and suspected lack of catchment vegetation to intercept rainfall or surface run-off, leading to in-stream sedimentation/debris events occurring	Assessed Back Creek during late February—impacted by fire and by post-fire in-stream debris/sedimentation event; thick, black sediment sludge over stream bed and banks; water highly turbid; difficult to access upper areas of catchments, as track blocked or no roads Fish abundance reduced by ~50% compared with previous monitoring data—fish salvaged, as high risk of additional sedimentation events occurring Unable to access locations in the upper Cann River catchment, north and south of Buldah (Buldah Creek, Cann River mainstem, Lockup and Whitegum creeks), as catchment very heavily burnt, bridges damaged, and tracks blocked
Dargo Galaxias	2 Suspected 3–4 over majority of population	2–5	Lack of catchment vegetation to intercept rainfall or surface run-off—a lower risk than elsewhere, but the majority (>95%) of the species' distributiion heavily burnt further downstream in these systems	Assessed in Lightbound Creek and Precipice Creek headwaters in early February, but difficult to access further downstream; headwaters lightly burnt, but heavily burnt a short distance further downstream Evidence of localised sediment input, particularly in Precipice Creek Fish abundance reduced by ~30% compared with previous monitoring data—fish extracted from both systems, as high risk of additional sedimentation events occurring
East Gippsland Galaxias	3	4–5	Lack of catchment vegetation to intercept rainfall or surface run-off, leading to in-stream sedimentation/debris events	Difficulty accessing the upper areas of the catchment, where the fish are found, due to severity of catchment burn and damaged bridges and blocked tracks—could not access Little Arte River Assessed Arte River during February—impacted by intense fire and by post-fire in-stream debris/sedimentation events; thick black sticky sludge coating stream bed and banks; water highly turbid Fish abundance reduced by ~30% compared with previous monitoring data—fish salvaged, as high risk of additional sedimentation events occurring
McDowall's Galaxias	3	3–5	Lack of catchment vegetation to intercept rainfall or surface run-off, leading to in-stream sedimentation/debris events	Tried to access Rodger River at Waratah Flat in early February, but delay in opening track; accessed site by 20 February 2020 Rodger River impacted by fire and by post-fire in-stream debris/sedimentation event; thick black sticky sludge over the substrate in pools; evidence of recent bank erosion Fish abundances reduced by ~60% compared with previous monitoring data; smaller size classes missing. Fish salvaged, as high risk of additional sedimentation events occurring Difficult to access upper areas of catchment, as tracks blocked, but accessed later (April); upper catchment not as heavily burnt

Target species	Species or community condition 1 (good) to 5 (not found)	Fire impact 1 (no impact) to 5 (severe impact)	Existing threats that pose a threat to recovery	Comments
Roundsnout Galaxias	Unknown Suspected 3–4, from fire-intensity mapping	Suspected 3–5, as whole upper catchment burnt	Suspected lack of catchment vegetation to intercept rainfall or surface run-off, leading to in-stream sedimentation/debris events	No access into Genoa River along Yambulla Peak Track, which was blocked by fallen timber, as it was of low priority for opening; no availability of helicopter transport. The Genoa River has had several sediment/debris flow events following rainfall in the catchment, which would suggest that the galaxiid population is affected; assessment would require surveillance in the NSW portion of the catchment, where the bulk of the population is located.
Yalmy Galaxias	4–5	4–5	Lack of catchment vegetation to intercept rainfall or surface run-off, leading to in-stream sedimentation/debris events	Assessed Yalmy River and Serpentine Creek during early February. Both systems impacted by fire and by post-fire in-stream debris/sedimentation events; thick, black, sticky sludge covering stream bed and banks; water highly turbid; no access found to upper areas of catchment Fish abundance reduced by 100% in Serpentine Creek, and by ~60% in Yalmy River; fish salvaged, as high risk of additional sedimentation events occurring Only seven individuals found and extracted, of which six were juveniles with damage along their flanks from sediment abrasion
Gippsland Blackfish—eastern lineage	3 (Back Creek) Suspected 4–5 in upper Cann River, based on fire intensity	3 (Back Creek) Suspected 4–5 in upper Cann River, from fire-intensity mapping	Lack of catchment vegetation to intercept rainfall or surface run-off, leading to in-stream sedimentation/debris events	Information as for Cann Galaxias (see above) Fish abundance in Back Creek reduced by ~50% compared with previous monitoring data; fish salvaged, as high risk of additional sedimentation events occurring Assessment also made at Euchre Creek in Lind NP in mid-February, on day following intense, localised rainfall event. The storm had caused a massive debris flow/sedimentation event, with all banks eroded, water with very high turbidity level, stream bed infilled with sticky black sediment, and banks also covered with sediment. Fish abundance reduced by 100% No access to additional assessment sites for this species, as tracks blocked by fallen timber and bridges damaged
Macquarie Perch	4 (very few individuals located)	4–5 (sediment impact)	In the first 9 months post fire, a lack of catchment vegetation to intercept rainfall or surface run-off, leading to in-stream sedimentation/debris events	Despite post-fire reconnaissance and fish salvage in the immediate post-fire period demonstrating good Macquarie Perch survival, only three fish were recorded in the December 2020 surveys. High sediment and ash levels generated by rain events in the weeks and months post fire are likely responsible for the decline in the Macquarie Perch population. Salvaged fish, together with an additional 150 advanced fingerlings, were returned to the Upper Buffalo in July 2020. An additional 6000 fingerlings were stocked in January 2021, and up to 400 juveniles and adult fish were translocated into the Upper Buffalo from Dartmouth Dam in May 2021.

Target species	Species or community condition 1 (good) to 5 (not found)	Fire impact 1 (no impact) to 5 (severe impact)	Existing threats that pose a threat to recovery	Comments
Arte Spiny Crayfish	4 (very few individuals located)	3–5	Lack of catchment vegetation to intercept rainfall or surface run-off, leading to in-stream sedimentation/debris events	Information as for East Gippsland Galaxias (see above) Crayfish abundance reduced by ~60% compared with previous monitoring data; crayfish salvaged, as high risk of additional sedimentation events occurring Only three individuals were found to salvage.
Cann Spiny Crayfish	Suspected 4	Suspected 3–5, from fire-intensity mapping	Lack of catchment vegetation to intercept rainfall or surface run-off, leading to in-stream sedimentation/debris events	No access into locations in the mid to upper Cann River system, as very high-intensity burn blocked tracks and damaged bridges; it was suspected that all sites were impacted by the same post-fire in-stream debris/sedimentation events as Cann River, as thick, black, sticky sludge covered the stream bed and banks, and the water was highly turbid further downstream.
East Gippsland Spiny Crayfish	1 to 5 Burnt areas with 3–5; some unburnt areas with 1–5	2–5	Lack of catchment vegetation to intercept rainfall or surface run-off, leading to in-stream sedimentation/debris events	Difficult to access many catchments upstream of the Princes Highway, due to blocked tracks in heavily burnt areas; in particular, the upper Cann River was inaccessible. Many streams were impacted by fire and by post-fire sedimentation/debris flow events; thick, black, sticky sludge covered the stream bed and banks, and the water was highly turbid; the habitat was deemed too degraded to be able to locate crayfish at the time. The species was only found at Karlo Creek just upstream of the Princes Highway; the catchment was heavily burnt, and there was evidence of post-fire in-stream sedimentation events; crayfish salvaged, as high risk of additional sedimentation events occurring. A few assessment locations were lightly impacted, yet crayfish were absent, possibly due to other recent fires and drought.
Orbost Spiny Crayfish	3	3–5	Lack of catchment vegetation to intercept rainfall or surface run-off, leading to in-stream sedimentation/debris events	Information as for McDowall Galaxias (see above) Crayfish abundance reduced by ~35% compared with previous monitoring data; crayfish salvaged, as high risk of additional sedimentation events occurring
Variable Spiny Crayfish	4–5	4–5	Lack of catchment vegetation to intercept rainfall or surface run-off, leading to in-stream sedimentation/debris events	The area near Genoa and further north and eastward was able to be accessed during mid- and late February, though many tracks remained blocked. Streams within the catchment were very heavily Impacted by fire and post-fire debris/sedimentation—Genoa River had brown silt on the substrate and along the banks, and highly turbid water, and the rest of the catchment had very recent erosion points, with stream channels infilled with sand and silt. Accessed locations (Maramingo Creek and tributaries, Wallagaraugh River and tributaries, Genoa River tributaries) were sampled for crayfish. The species was only located in Genoa Creek at one location, in a heavily burnt catchment, and all were juveniles; crayfish salvaged, as high risk of additional sedimentation events occurring.

Target species	Species or community condition 1 (good) to 5 (not found)	Fire impact 1 (no impact) to 5 (severe impact)	Existing threats that pose a threat to recovery	Comments
West Snowy Spiny Crayfish	Suspected 2–3	Suspected 2–3, based on fire-intensity mapping	Possible in-stream sedimentation/debris flow events, due to lack of catchment vegetation	Access could not be organised into the upper reaches of the catchment, due to blocked tracks, though this area appeared to be less intensively burnt than elsewhere; suspected lower impact on fauna, so resources used elsewhere.
Mallacoota Burrowing Crayfish	2–3	4–5	Lack of catchment vegetation to intercept rainfall or surface run-off, leading to in-stream sedimentation/debris events; that said, crayfish restricted to stream edges and appeared to be commencing burrow rehabilitation, though no activity in other burnt areas	Accessed catchments in mid-February Only lower reaches of Double Creek assessed, as no access into mid- to upper reaches (see habitat assessment comment below). No active chimneys (made of soil by burrowing crayfish) were found. Davis Creek and Double Creek, near Mallacoota, were heavily impacted by fire; shade was lost in many areas, and some shallow, previously swampy areas were found to be dry. Active burrowing crayfish soil chimneys were found, and individuals were caught; the species was verified as present during the repeat reconnaissance in late February 2020. There was a risk of sedimentation events, as the soil was loose and sandy, though the catchment slope was low, and run-off events were expected to have a lower frequency/impact. Salvage of animals was not deemed necessary, due to the low catchment relief; in addition, some remnant ground cover and scorched canopy vegetation remained next to the stream where active crayfish burrows were present in wet areas, and there was a lower risk of sedimentation events.
Austral Mussel	Suspected 4–5, based on burn intensity	4–5, based on fire intensity mapping	In-stream sedimentation/debris flow events, due to lack of catchment vegetation	Many likely areas of catchments north-east of Genoa were assessed in mid- to late February 2020 and found to be heavily burnt, with evidence of recent debris flow/in-stream sedimentation events. No mussels were found; however, access was difficult, due to blocked tracks. Old records indicate that the species was found in the very north-east of the Genoa catchment (Wallagaraugh River tributaries), but there have been no recent collections due to a lack of focus on, and funding for, this species.

Target species	Species or community condition 1 (good) to 5 (not found)	Fire impact 1 (no impact) to 5 (severe impact)	Existing threats that pose a threat to recovery	Comments
Depressed Mussel	2–4	2–5	In-stream sedimentation/debris flow events, due to lack of catchment vegetation	Stream systems were assessed along the Princes Highway during mid- to late February 2020, as there was little to no access to upstream catchments. Many streams were impacted by fire and sedimentation/debris flow events; thick, black, sticky sludge covered the stream bed and banks, and the water was highly turbid. The species was assessed at many locations, but only found in the Thurra River, Tonghi Creek (one dead shell only), Brodribb River (at the pump station), Snowy River (at Long and Sandy points) and Nicholson River (dead shells only). Of these locations, high numbers of live mussels were only found in the Thurra, Brodribb and Snowy systems, and due to a high risk of additional sedimentation events occurring, mussels were salvaged from one Snowy River site and the Thurra River. At Sandy Point (Snowy River), mussels were found to have climbed out of the normally sandy substrate on the stream bed and pushed upwards through a 300–400-mm layer of thick, black, sticky sediment to access the water column; this sediment provided little lateral stability for the mussels, compared with the sand, and could be easily scoured during higher flow events; the mussels, therefore, were at risk of being washed downstream and potentially killed.
Glenelg Freshwater Mussel		1— see comment	In-stream sedimentation/debris flow events, due to lack of catchment vegetation further upstream	The area of riparian zone burnt by the fire was upstream of the section of stream where the Glenelg Freshwater Mussel exists. However, the mussels can be impacted by in-stream sedimentation/debris flows during post-fire rainfall events, which travel downstream of the fire impact zone and affect the stream system.

Post-fire in-stream disturbance was visible at nearly all sites visited in Gippsland in mid- to late February 2020, having occurred during the three rainfall events before field reconnaissance commenced. Evidence of recent high stream flow consisted of:

in-stream log jams

debris line of logs

smaller timber debris left suspended in the riparian vegetation along the stream banks

highly turbid water

active areas of bank erosion

smothering and infilling of the stream-bed substrate by a thick layer of black, sticky, almost oily sediment composed of a mix of silt, sand, pebbles, organic debris, and ash.

Stream banks, sometimes up to 2–3 m above water level, were also covered by a thick layer of black sediment.

Continuing debris flow/in-stream sedimentation events were observed across catchments into March, April and May, during work undertaken on the aquatic species and impacted streams under two Biodiversity Response Plan projects. Post-fire in-stream disturbance associated with the Budj Bim fire was not observed until following a significant rainfall event in October: the water quality declined significantly, and evidence of impacts on the two target species was observed (the spiny crayfish observed were out of the water, and the fish observed were unhealthy).

Fauna extraction occurred in Gippsland, north-eastern Victoria and south-western Victoria at the same time as reconnaissance: it was deemed urgent to undertake prompt assessment and management of aquatic fauna populations post-fire, due to the high probability of rainfall events occurring and leading to debris flow/in-stream sedimentation. This increased the complexity of the field work, but was a critical strategy, as the impacted aquatic fauna deemed to be at high risk of additional impacts could be immediately salvaged without the need for a separate trip.

Various images of aquatic habitat conditions are provided in the following figures (Figure 65 to Figure 75).

Figure 65. Precipice Creek, north branch, upstream of Carmichael Falls—habitat of Dargo Galaxias; 5 February 2020 (photo: Tarmo A. Raadik)

Figure 66. Davis Creek, upstream of Pipeline Track, Mallacoota—dried and burnt habitat of Mallacoota Burrowing Crayfish; 18 February 2020 (photo: Tarmo A. Raadik)

Figure 67. Euchre Creek, Lind National Park, following intense, post-fire rainfall event—erosion, sedimentation, poor water quality; 19 February 2020 (photo: Tarmo A. Raadik)

Figure 68. Euchre Creek, Lind National Park, covered in ash; 19 February 2020 (photo: Tarmo A. Raadik)

Figure 69. Martins Creek, rainforest reserve, following high-intensity rainfall event; 19 February 2020 (photo: Tarmo A. Raadik)

Figure 70. Deposited sediment on bank of Snowy River, Sandy Point; 27 February 2020 (photo: Tarmo A. Raadik)

Figure 71. Snowy River tributary, Buchan–Orbost Road; 27 February 2020 (photo: Tarmo A. Raadik)

Figure 72. Example of black, sticky, oily deposit on the stream bed and banks of sediment-impacted East Gippsland streams; February 2020 (photo: Tarmo A. Raadik)

Figure 73. Darlots Creek Budj Bim Cultural Heritage Landscape (photo: Nicole Hudson)

Figure 74. Macquarie Perch post-fire salvage, Upper Buffalo River (photo: Glen Johnson)

Figure 75. Macquarie Perch fyke net survey, Upper Buffalo River (photo: Glen Johnson)

Risks

Pre-existing risks (i.e. before the bushfires)

Pre-fire, the main threats to aquatic fauna were:

Drought causing reduced water volume, flow, and wetted habitat—affecting all species

Introduced predators [i.e. introduced trout and Redfin (*Perca fluviatilis*)]—primarily affecting galaxiids and Macquarie Perch; possibly also spiny crayfish

In-stream sedimentation resulting from soil erosion from timber harvesting operations—affecting galaxiids, blackfishes, Macquarie Perch, spiny crayfish

High extinction risk from stochastic events due to small geographical ranges (entire species at high risk of disturbance); isolated populations (loss of genetic connectivity); small number of populations (a single or a few remaining populations); or small effective population size (loss of genetic diversity and declining evolutionary potential)—affecting all species

Loss of in-stream and riparian vegetation (including woody debris) from land clearing for agriculture—affecting primarily South-west River Blackfish and Glenelg Spiny Crayfish, but also Gippsland Blackfish.

Mechanical disturbance (physical crushing, soil disturbance, loss of overhead vegetation) from machinery operating over streams and drainage lines—affecting Mallacoota Burrowing Crayfish

Cumulative impacts on riparian habitat from earlier landscape-scale fires impacting entire catchment of fish populations—affecting Macquarie Perch (Alpine 2003 fire and post-fire sedimentation events)

Reduction in groundwater levels decreasing groundwater outflow, reducing or eliminating perennially flowing stream reaches—affecting Glenelg Freshwater Mussel.

Additional risks driven by the 2019–2020 bushfires

The impact of the bushfires has severely exacerbated the impacts of in-stream sedimentation and population factors, further reducing species' resilience and increasing their risk of extinction. This is particularly a concern for species already in decline, e.g. existing as a single, small population, or with just a few small, isolated populations.

Future directions

Priority actions identified for consideration within DELWP's decision-support tools are as follows:

Galaxiids

Short-term (while catchments recover, and sedimentation abates):

Undertake predator control if required—ensure trout do not invade impacted populations.

Undertake in-stream barrier inspections—where smaller in-stream barriers prevent trout impacting populations, ensure natural or constructed barriers maintain their ability to prevent upstream passage of predators.

Undertake captive breeding, if required, to assist population recovery.

Long-term:

Improve the resilience of species.

Understand species' population genetic diversity; improve the genetic diversity; and increase the size and number of populations, where needed, to improve evolutionary potential.

Undertake captive breeding or wild-to-wild translocation, to support restocking, genetic top-up, or translocation.

Locate and evaluate potential translocation sites (consider geographical spacing).

Establish additional populations within a species' likely former range (by captive breeding or wild-to-wild translocation of individuals) to reduce extinction risk.

Undertake ongoing predator surveillance and control (where required).

Spiny Crayfish

Short term (while catchments recover, and sedimentation abates):

Undertake predator control, if required, to reduce predator density.

Undertake captive breeding, if required, to assist population recovery.

Undertake water quality monitoring program and development of intervention protocols, including refuge pool aeration.

Long term:

Improve the resilience of species.

Understand species' population genetic diversity, and improve diversity (where needed), to improve evolutionary potential.

Undertake captive breeding to support restocking, genetic top-up, or translocation.

Locate and evaluate potential translocation sites (consider geographical spacing).

Establish additional populations to spread the extinction risk, by captive breeding or wild-to-wild translocation.

In the future, undertake weed management, revegetation, and cultural fire management to reduce the effects of any future bushfires on fish and on water quality.

Blackfish (both locations)

Short term (while catchments recover, and sedimentation abates):

Install habitat structures to mitigate loss of in-stream woody debris habitat by sediment smothering.

Undertake captive breeding, if required, to assist population recovery.

Undertake water quality monitoring program and development of intervention protocols, including refuge pool aeration.

Long term:

Improve the resilience of species.

Understand species' population genetic diversity, and improve diversity (where needed), to improve evolutionary potential.

Undertake captive breeding to support restocking, genetic top-up, or translocation.

Locate and evaluate potential translocation sites (consider geographical spacing).

Establish additional populations to spread the extinction risk, by captive breeding or wild-to-wild translocation.

Undertake woody debris reinstatement to improve adult and juvenile habitat quality and quantity.

In the future, undertake weed management, revegetation, and cultural fire management to reduce the effects of any future bushfires on fish and on water quality.

Freshwater Mussels

Short term (while catchments recover, and sedimentation abates):

Not required

Long term:

Improve the resilience of species.

Understand species' population genetic diversity, and improve diversity (where needed), to improve evolutionary potential.

Undertake captive breeding to support restocking, genetic top-up, or translocation.

Locate and evaluate potential translocation sites (consider geographical spacing).

Establish additional populations to spread the extinction risk, by captive breeding or wild-to-wild translocation.

Macquarie Perch

Improve the species' genetic diversity, resilience, and population numbers via the supplementation of Macquarie Perch including:

Stocking of hatchery-bred fingerlings (Victorian Fisheries Authority)

Translocation of juvenile to adult fish from the Dartmouth Dam population (DELWP Hume Region, ARI–DELWP, and the North East Catchment Management Authority (NECMA)).

Undertake monitoring and surveillance to determine the effectiveness of the supplementation program.

Undertake community engagement to raise local/regional awareness of the species' conservation status and program.

Acknowledgements

This project was funded by the Victorian Government's Bushfire Biodiversity Response and Recovery program.

The aquatic fauna survey methods and the approach for galaxiids, blackfish, Macquarie Perch, crayfish and mussels have been developed by the ARI–DELWP in response to previous fire events.

Reconnaissance in Gippsland was undertaken by Tarmo Raadik, Daniel Stoessel, Michael Nicol and James Shelley (all ARI–DELWP), in north-eastern Victoria by Jarod Lyon and Jason Lieschke (both ARI–DELWP), in south-western Victoria in the Crawford River by Tarmo Raadik and James Shelley, and in Darlots Creek by Jodie Honan, Shea Rotumah and Nicky Hudson (Gunditj Mirring Traditional Owners Aboriginal Corporation).

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Stoessel, D.S., Raadik, T.A. and Shelley, J.J. (2021). *Emergency extraction, temporary housing and return of small-bodied aquatic species following the 2019/20 megafire.* Client Report for Biodiversity Division. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

5.2 Yiritja (South-west River Blackfish) and Ngeerang Yarram (Glenelg Spiny Crayfish)

Prepared by the Gunditj Mirring Traditional Owners Aboriginal Corporation (GMTOAC)

Cultural Intellectual Property within this chapter remains within the control of GMTOAC.

Gunditj Mirring Traditional Owners Aboriginal Corporation RNTBC (GMTOAC) represent Gunditjmara native title rights and interests in far south-western Victoria. Gunditjmara have an ongoing connection to Country, including freshwater, estuarine, marine and coastal places and natural resources. GMTOAC have an obligation to care for these places and animals and all the things that support them, while continuing cultural practices.

In 2019–2020, the bushfires affected over 7000 ha of the Budj Bim World Heritage Area (Figure 76). This included Indigenous Protected Areas (IPAs) cared for by GMTOAC, and the banks of Tae Rak (Lake Condah) and Killara (Darlots Creek).

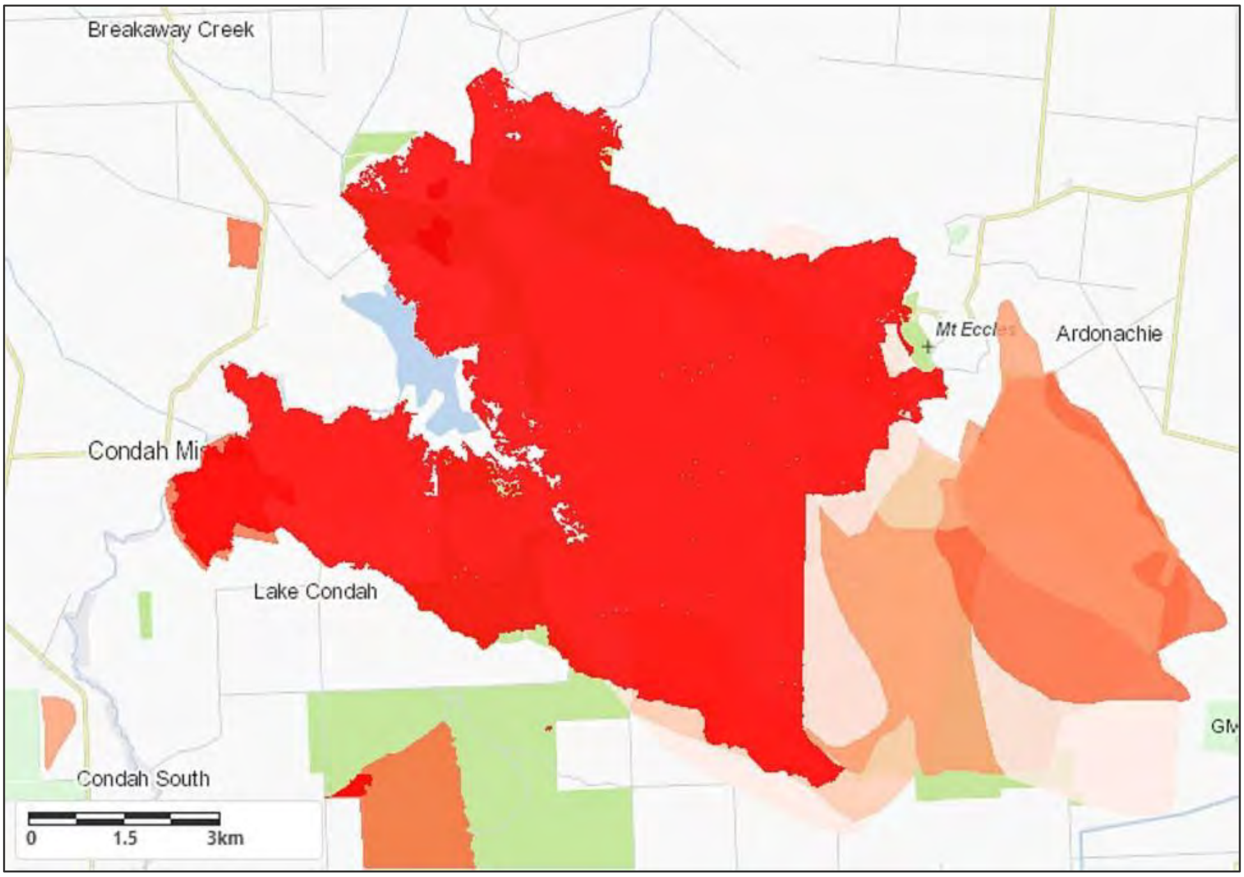

Figure 76. Budj Bim landscape showing the extent of the 2019–2020 bushfires in reds (pinks represent older bushfires, and green represents unburnt Crown land) (Mapshare, 2021)

DELWP provided funding to GMTOAC to monitor two culturally important species following the Budj Bim fires:

- Yiritja (South-west River Blackfish) – A medium-sized, non-migratory freshwater fish that has been identified recently and is awaiting formal description. It is rapidly declining in range and abundance, and the largest population was impacted by the 2019–2020 bushfires. Of the three small, isolated populations in south-western Victoria, the Darlots Creek population is the largest. It is endemic to Victoria and is considered Critically Endangered.
- Ngeerang Yarram (Glenelg Spiny Crayfish) – A large, long-lived freshwater spiny crayfish inhabiting cool, shaded, flowing waterways with high water quality and intact riparian vegetation. Restricted to the Glenelg and Fitzroy River systems in south-western Victoria, and spring-fed coastal streams in south-eastern South Australia. It is considered nationally Endangered.

The objectives of this assessment were to:

Assess the status of the target species at key locations, including assessment of the bushfire impacts.

Review the status of any existing threats and identify any new threats to populations due to the bushfires.

Provide advice to the DELWP Biodiversity Division for prioritisation of potential management actions.

Methods

A pilot method for sampling and recording these species in the IPA waterways was developed (DELWP 2020). GMTOAC staff developed and conducted the surveys to grow 'in-house' skills in setting up and conducting fish surveys. These staff included: Shea Rotumah (Country and Engagement Officer), Jodie Honan (Ecology and Documentation) and Nicky Hudson (Water Officer). Survey practices were culturally informed, and also considered ARI knowledge and protocols shared by Tarmo Raadik (ARI). Family and Gunditjmara community members helped with several surveys.

Survey sites were based on cultural choices and areas affected by the bushfires. Surveys were conducted between April and October 2020 under General (Research) Permit RP1408 from the Victorian Fisheries Authority.

Results

A wide variety of species were captured using fyke nets (Table 28), and the number and variety of species captured varied widely across locations.

Table 28. Species caught during surveys (*introduced species)

Gunditjmara name Common name(s)	**Scientific name**	**Conservation listings**
Ngeerang Yarram Glenelg Spiny Crayfish	*Euastacus bispinosus*	Endangered (National; EPBC Act) Endangered (Victoria; FFG Act)
Black Yabby	*Geocharax* species	Endangered (Victoria; FFG Act)
Burrowing Crayfish (confirming identification)	Either *Engaeus sericatus* or *Engaeus strictifrons*	Vulnerable (Victoria; FFG Act) Endangered (Victoria; FFG Act)
Yapeetch Freshwater Crab	*Amarinus* sp.	
Kooyang Short-finned Eel	*Anguilla australis*	
Galaxiid species (confirming identification)	Several species have been recorded	Includes one Endangered listing (Victoria; FFG Act)
Southern Pygmy Perch	*Nannoperca australis*	
Yarra Pygmy Perch	*Nannoperca obscura*	
Tuupon Tupong	*Pseudaphritis urvillii*	
Yiritja River Blackfish	*Gadopsis* sp. SWV (South West Victoria)	Critically Endangered (Victoria)
Redfin, European Perch, English Perch*	*Perca fluviatilis**	
Tench*	*Tinca tinca**	

EPBC Act = Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*; FFG Act = Victoria's *Flora and Fauna Guarantee Act 1988*.

Figure 77. Checking nets at an upstream site on Killara

Yirritja and Tupong:

Eight healthy Yirritja (Figure 78), and five healthy Tupong were captured during the surveys. These covered a good size range, similar to that seen in previous surveys (see Miller et al. 2018). Yirritja were only caught at one location.

Ngeerang Yarram:

Only four of the 30 Ngeerang Yarram (Figure 79) caught were females. This is of concern, as other studies (e.g. Honan and Mitchell 1995b) have found that female crayfish are usually active and easily caught during the breeding season (April to November). This needs further investigation.

Kooyang:

Only one Kooyang was captured during the surveys. The low number was surprising to the Gunditjmara who were fishing.

Galaxiid species:

Five galaxiid species, including an undescribed species, have been recorded from the Budj Bim landscape (Miller et al. 2018; Tarmo Raadik, pers. comm.).

Pygmy perch:

Only three Yarra Pygmy Perch were captured during surveys, compared with several hundred Southern Pygmy Perch. Southern Pygmy Perch were the most common species captured during surveys.

Exotic fish:

Two introduced fish species were captured: Redfin and Tench. These large, predatory species affect the ecology of the waterway. Both the Redfin (Figure 80) and Tench were carrying eggs.

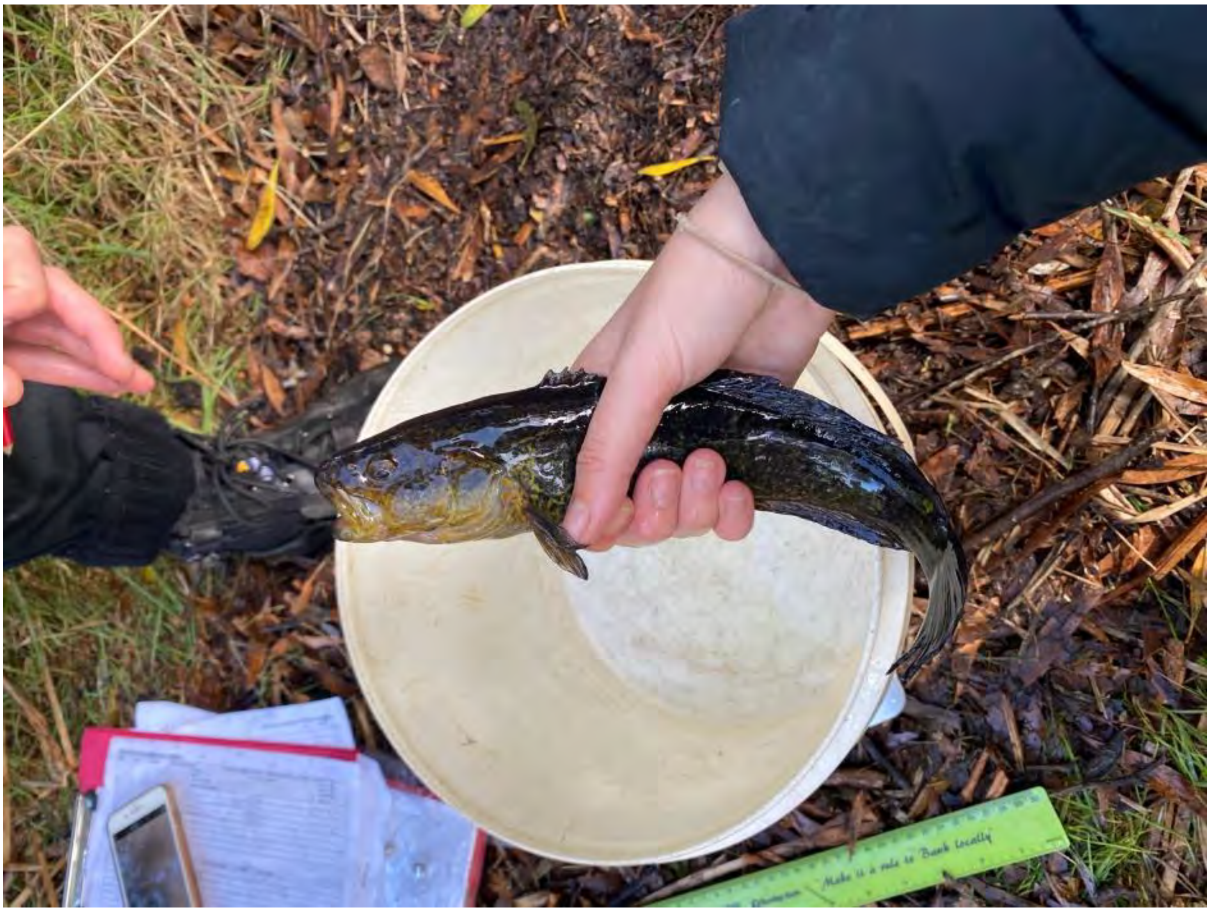

Figure 78. Yirritja (South-west River Blackfish)

Figure 79. Ngeerang Yarram (Glenelg Spiny Crayfish)

Figure 80. Redfin with abundant eggs caught in Killara

Water quality

The observed behaviour of fish indicated to GMTOAC staff that there was an issue with water quality. Water quality tests indicated poor water quality with low dissolved oxygen. Water testing was continued over the summer, and repeated low levels of dissolved oxygen and high levels of the nutrient phosphorus were detected. Both Ngeerang Yarram and Yiritja require higher dissolved oxygen levels, particularly as they are bottom dwellers and do not move up to the surface, where oxygen is generally higher. A separate study of water quality (GMTOAC, in prep.) is investigating the reasons why the dissolved oxygen levels are so low. Draft protocols have been developed in case of a fish kill.

Future directions

Priority actions identified for consideration within DELWP's decision-support tools are as follows:

Continue Gunditjmara leading and undertaking the surveys, including:

ecological surveys investigating habitat requirements of key species

streamside vegetation surveys

seasonal fish monitoring, targeting lower flow seasons.

Develop a water quality monitoring program and intervention protocols, including refuge pool aeration and managing the phosphorus budget.

Investigate ways to reduce Redfin and Tench numbers.

Use cultural fire to keep bushfires away from the banks of Killara.

Revegetate to provide shade for aquatic habitats.

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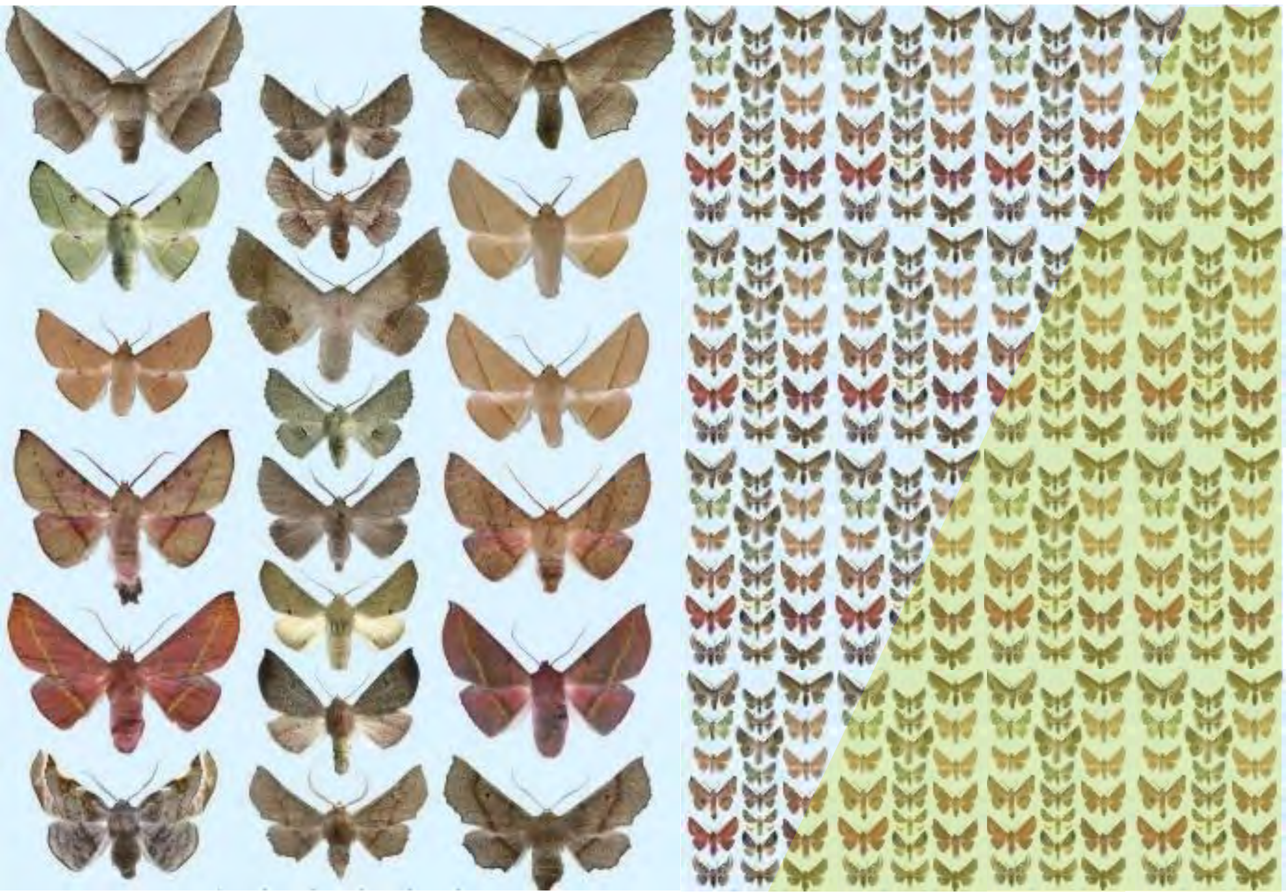
Terrestrial invertebrates



6.1 Invertebrate traits database and collation of existing invertebrate data

Prepared by David Bryant (ARI) and Matthew Bruce (ARI)

Summary of bushfire impacts

Till now there has been little information available with which to assess the impact of fires on Victoria's invertebrates, because they have not been systematically studied or surveyed. As a prerequisite for identifying the species most likely to be impacted by bushfires, and subsequently to assess future bushfire impacts, this project aimed to gather similar trait data to that which exists for other biotic groups, to support the long-term management of invertebrates.

Summary of key findings

Traits were populated against 124 'priority' species across five phyla and eight classes.

The traits database will begin to inform the modelling of future fire impacts on invertebrates and their recovery from fire; in addition, the accumulation of invertebrate records will form a baseline from which to inform impacts on species in the event of future events, such as large bushfires.

The traits database revealed groups of species that might be particularly vulnerable to fire, such as species with limited distributions (short-range endemics), those that are poor dispersers, and those that lack the ability to escape the fire front or shelter in situ.

More than 330,000 invertebrate records were acquired for upload to the Victorian Biodiversity Atlas (VBA; DELWP 2020).

The gathering of this information is a key step in aiding the long-term management of invertebrates, in accordance with the vision and commitments of Protecting Victoria's Environment – Biodiversity 2037 (Biodiversity 2037). Where practical, this database should be built upon through further systematic data curation, targeted collection, and collaborations.

Background

Invertebrates are not currently included in DELWP's decision-making process because there has been inadequate information for analysis. This project sought to fill the gap in our invertebrate knowledge by gathering similar data to that which exists for other biotic groups. This information will be vital for the long-term management of invertebrates, in accordance with the primary vision and commitments of Biodiversity 2037 (DELWP 2017). The project involved:

Developing a list of traits for selected invertebrates occurring in Victoria

Collating data on invertebrate distributions and traits and entering these into the VBA (DELWP 2020), following quality assurance processes.

Development of a traits database

Priority invertebrate species list – For this project, we used a pre-existing list of priority invertebrate species—species likely to require urgent management intervention or on-ground assessment following bushfires. The list was compiled as part of the Australian Government's bushfire response. They developed an initial list of invertebrates based on pre-fire conservation status, previous state/territory/agency work on the species, and the advice of experts with knowledge of invertebrate groups. The final list was developed by overlaying each species' range with the extent of the fires to determine the overlap, and it comprised 191 priority species from New South Wales (NSW), the Australian Capital Territory, Victoria and South Australia (Department of Agriculture, Water and the Environment 2020). For the present project, we removed species that are not known to occur in Victoria. During the trait elicitation, the experts were also asked to add species to the list if they considered their inclusion to be warranted, and to provide a rationale as to why particular species should be considered 'priority' species and what special features (e.g. critical pollinator; taxonomic distinctiveness) were relevant.

Choice of traits – A post-fire assessment project in South Australia, funded by the Australian Government, used functional traits to assess species considered sensitive to the impacts of the 2020 Kangaroo Island bushfires. The traits selected had wide applicability to the form and life history of a broad range of invertebrates. Recognising the work that had already been done in selecting these traits, and the similarity in the questions being asked, these traits were sent out to experts for comment as to their perceived suitability for a broader suite of invertebrates and habitats. This resulted in the selection of seven traits for this project, based on a species' ability to survive the fire (e.g. make use of shelter), to find resources post fire (e.g. to obtain habitat and dietary requirements) and to recolonise (e.g. mobility, reproductive potential) (Table 29).

Table 29. Functional traits chosen for post-fire assessment of invertebrates occurring in Victoria

Trait	Explanation	Relevance to fire	Options
Microhabitat (shelter site)	The space a species uses for shelter	Affects its ability to survive the immediate fire event	deep burrow shallow burrow in/under logs under bark in soil in leaf litter (on ground) in water in vegetation in wood (e.g. trunks) no shelter
Habitat specialisation	How specialised a taxon is with regards to its habitat	Affects its ability to persist at the impacted site after the fire event in a heavily disturbed environment; may also affect recolonisation potential	dependent upon particular habitat features relatively habitat generalist
Dietary specialisation	How specialised a taxon is with regards to its diet	Affects its ability to persist at the impacted site after the fire event	generalist diet narrow dietary range
Ecological dependency	Whether or not the taxon is dependent upon another animal or plant species in some form of obligate mutualism	Affects its ability to persist at the impacted site after the fire event	dependent upon another animal or plant species no obligate mutualism
Diapause	Whether or not the species can undergo a period of diapause and for what duration	Affects its ability to persist until environmental conditions become more favourable after the fire event	can shut down for many months can shut down for days to weeks active daily
Reproductive potential	The number of young an adult female can produce in a year	Affects its ability to repopulate a fire-impacted area	1–10 young 10–100 young 100–1000 young >1000 young
Dispersal ability	The average dispersal distance of an individual in a year	Affects its ability to repopulate a fire-impacted area	>10 km 1–10 km 100–1000 m >1000 m

Expert elicitation – To populate traits against the species in the 'priority species' list, an expert elicitation process was undertaken. Experts with familiarity with the selected species or their broader taxonomic grouping, were asked to populate the traits against those taxa. Experts from various agencies and backgrounds were invited to populate fields in a spreadsheet, each with drop-down lists specific to a trait.

The expert elicitation process resulted in traits being populated for all but three species, two spiders and a fly, on the initial list of 118 priority species across 20 different taxonomic groupings, as per the federal list (Table 30). Eight additional species were proposed for inclusion; two species were removed, as they were not considered to occur in Victoria.

The traits of several taxonomic groups were populated by multiple experts (in which case, all information was retained); others were populated by a single expert. Experts were also asked to add extra detail, where known. For example, if a species was known to have a specialised diet, the diet was recorded. Not all experts were confident in populating all trait fields for each species. The result was a final count of 124 species with traits populated across 20 different groups (Table 30).

Table 30. Taxon groupings from the priority species list, and the number of species within each grouping that had traits populated against them

Taxon group	Phylum Class	Number of priority species initially listed	Number of taxa with traits populated	Comments
Freshwater mussels	Mollusca Bivalvia	2	2	
Land snails	Mollusca Gastropoda	15	21	Six species added
Copepods	Arthropoda Hexanauplia	1	1	
Decapods	Arthropoda Malacostraca	15	15	One species was not considered to occur in Victoria; one species was added.
Isopods	Arthropoda Malacostraca	1	1	
Spiders, harvestman, pseudoscorpions	Arthropoda Arachnida	2	0	
Dragonflies	Arthropoda Insecta	6	5	One species was not considered to occur in Victoria.
Caddisflies	Arthropoda Insecta	7	7	
Mayflies	Arthropoda Insecta	1	1	
Stoneflies	Arthropoda Insecta	5	5	
Grasshoppers and crickets	Arthropoda Insecta	4	4	
Beetles	Arthropoda Insecta	11	11	
Flies	Arthropoda Insecta	16	16	
Lacewings	Arthropoda Insecta	1	1	
Butterflies and moths	Arthropoda Insecta	25	26	One species added
Ants, wasps and bees	Arthropoda Insecta	1	1	
Cockroaches	Arthropoda Insecta	1	1	
Planarians (flatworms)	Platyhelminthes Rhabditophora	2	2	
Velvet worms	Onychophora Udeonychophora	3	3	
Soil-dwelling worms	Annelida Clitellata	1	1	

Collation of existing invertebrate data

Callout for datasets: – A request was sent out to invertebrate experts for submission of invertebrate datasets for upload to the VBA (DELWP 2020). Emphasis was put on datasets that had both data with the required data standards for the VBA (DELWP 2020), as well as being in a digital format (for the immediate practicalities of data compilation). Follow-up correspondence was undertaken to maximise the number of datasets contributed.

The project involved significant correspondence between DELWP and other parties, including invertebrate and data experts from:

DELWP Knowledge and Decision Systems

ARI–DELWP

Museums Victoria

Deakin University

La Trobe University

Monash University

The University of Melbourne

Western Sydney University

Private experts

Environmental Protection Authority

Entomological Society of Victoria

Curation of datasets into a VBA-compatible format – More than 330,000 invertebrate records were acquired for upload to the VBA from three datasets (Table 31). The datasets received were curated to enable VBA upload. Different templates are required for freshwater and terrestrial fauna, but both require species to be matched to VBA taxon codes and sites to be validated. Datasets will be uploaded to the VBA once the required data standards and formatting are achieved.

Table 31. Invertebrate datasets acquired for VBA upload

Data source	Taxonomic groups covered	Taxonomic resolution	Area of Victoria covered by dataset	Size of dataset
EPA Victoria	Aquatic invertebrates	Species	All	308,000 records
DELWP–ARI	Aquatic invertebrates	Genus	Catchments in the north-east	20-year dataset from a mix of rotating and fixed sites
Private citizen	Lepidoptera—moths	Species	All	395 spp., >16,000 records

Future directions

Inference about fire effects on terrestrial invertebrates is hampered by a lack of species location data and of taxonomic resolution. Nevertheless, the three invertebrate datasets obtained and uploaded for this project have considerably increased the number of invertebrate taxonomic records in the VBA. The traits database revealed groups of species that might be particularly vulnerable to fire, such as species with limited distributions (short-range endemics), those that are poor dispersers, and those that lack the ability to escape the fire front or shelter *in situ*. These groups should be considered in decision-making and prioritisation processes for future surveys, as are those that have vital ecological functions, such as pollinators.

Those personnel engaged were helpful and enthusiastic about future involvement in this area. Importantly, some of the obstacles to further data collection were identified, and potential solutions were raised. An awareness of such issues will be invaluable in enlarging and refining the invertebrate component of the VBA.

The project has led to an increased awareness of some of the issues that limit the transfer of data on invertebrates, both between experts, and from the experts to the VBA. It has contributed to the establishment of a network of Victorian invertebrate experts.

The traits database will begin to inform the modelling of impacts on invertebrates and of their recovery from fire, while the accumulation of invertebrate records will inform impacts on species in the event of future events, such as large fires.

The gathering of this information is a key step in aiding the long-term management of invertebrates, in accordance with the vision and commitments of Biodiversity 2037. Where practical, this database should be built upon through further systematic data curation, targeted collection, and collaborations.

Acknowledgements

Geoff Sutter (ARI–DELWP) contributed to the traits database and data gathering. We thank Ken Walker (Museum Victoria), Adnan Moussalli (Museum Victoria), Beverley Van Praagh (INVERT-ECO), Ross Field, Kate Umbers (University of Western Sydney), Tarmo Raadik (ARI–DELWP), Mandy Reid (Museum Australia), Paul Sunnucks (Monash University) and Diane Crowther (ARI–DELWP) for their expertise and input into populating the traits database. Libby Rumpff (University of Melbourne) and John Woinarski (Charles Darwin University) kindly provided advice on trait elicitation and made available their recent work on Kangaroo Island. We also thank Peter Marriott (Entomological Society), Leon Metzeling (EPA Victoria), Penelope Greenslade (Federation University) and Diane Crowther (ARI–DELWP) for allowing us to upload their data into the VBA and for answering the numerous queries along the way. Mel Hardie (DELWP) assisted with all questions relating to the VBA, and Stephen Sims was tireless in his ongoing efforts in curating the data into a format that could be uploaded to the VBA.

This project was funded by the Victorian Government's Bushfire Biodiversity Response and Recovery program.

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6.2 Native bees

Prepared by Matthew Bruce (ARI), Ken Walker (Museums Victoria) and David Bryant (ARI)

Summary of bushfire impacts

The impact of bushfires on bee communities can be broadly divided into two categories: the impact on food plants, and the impact on nesting habitat. Bee species that are restricted to food plants that are killed or which take several years to flower after fire are likely to be particularly negatively affected, and some bees with highly specific foraging requirements may be vulnerable to extinction. In contrast, bees that can forage on weedy species may not be as negatively affected. Approximately 70% of Australian native bee species nest underground in soil, and about 30% nest above ground in hollow stems, twigs, and beetle holes in trees. Depending on fire severity, below-ground-nesting bees may be shielded from the direct impacts of fire, whereas above-ground nesters may have no place of shelter during the fire and may also lose their nesting sites.

Summary of key findings

Native bees were identified as a group for this post-fire assessment, due to their range of life-history traits and because they are a widespread and important group of insects.

In all, 1106 native bee specimens were collected from 67 species. Twenty-five species were found in burnt areas (from 65 samples), and 54 species were found in unburnt areas (from 61 samples) in eastern and north-eastern Victoria. (Note, a sample refers to a survey at a site at a particular time; sites were visited multiple times.)

Most species in burnt areas were collected from plants in the daisy family (Asteraceae), including weedy species.

Bee abundance and species richness was higher at unburnt locations than at burnt locations.

Species restricted to eucalypts and related species for their food plants were not collected from burnt areas—probably due to the lack of flowering eucalypts after the fires.

Very few above-ground nesting bees were found in the burnt areas. This could be because they had nowhere to shelter, because nesting locations were destroyed by the fire, or because there was a lack of their preferred food plants.

Many of the East Gippsland native bee species should now be recognised as short-range endemics.

Background

An estimated 87.5% of flowering plants (angiosperms) require some form of animal pollination (Ollerton et al. 2011). Bees are one of the most important groups of insects that visit flowers for both nectar and pollen, and which provide pollination services to flowering plants. Many other insects (including a wide variety of flying groups such as flies, butterflies, and beetles) also pollinate plants when they visit flowers to collect nectar as a sugar source to provide essential energy.

Pollinators can be divided into three major groups: polylectic pollinators are animals that visit a wide variety of flowering plants, oligolectic pollinators are restricted to visiting only a few species of flowering plants, while monolectic pollinators are restricted to just one flowering plant genus (Bogusch et al. 2020; Cane 2021). The majority of native Australian bees are polylectic, some are oligolectic, and a very few are monolectic. Examples of monolectic bees are the two Colletidae bee genera, *Cladocerapis* and *Filiglossa*, which exclusively visit *Persoonia* (Geebung) species. The Halictidae bees are best described as polylactic, while most of the wide variety of Australian Euryglossine bees (family Colletidae) are restricted to visiting plants belonging to the Myrtaceae family. In Australia, almost 1700 native bee species have been described, and five different families are represented, of which four (Apidae, Colletidae, Halictidae and Megachilidae) occur in eastern Victoria. According to the Atlas of Living Australia (ALA) (ALA 2020), for the Gippsland and East Gippsland areas, almost 250 species of native bees have been recorded, from just under 5000 individual records.

The impact of bushfires on bee communities can be broadly divided into two categories: the impact on food plants, and the impact on nesting habitat. Oligolectic and monolectic species, particularly those restricted to plants that are killed or which take several years to flower after fire (e.g. Myrtaceae specialists), are likely to be particularly negatively affected. Polylectic bees, particularly species such as Halictine bees that can forage on weedy species, such as *Hypochaeris radicata*, may not be as negatively affected (Johanson et al. 2019). Indeed, bees with more specific foraging requirements may be more vulnerable to extinction (Bogusch et al. 2020). Approximately 70% of Australian native bee species nest underground in soil, and about 30% nest above ground in hollow stems, twigs, and beetle holes in trees. Depending on fire severity, below-ground-nesting bees may be shielded from the direct impacts of fire, whereas above-ground nesters may suffer from the direct impacts of fire and from burnt nesting sites. Nevertheless, fire may create more opportunities for nesting. For example, *Exoneura bicolor* can take advantage of the abundance of nesting sites in the grasstree species *Xanthorrhoea minor* for up to 8 years after a planned fire (Silberbauer 1992). Higher abundances and diversity of bees have been found in areas burnt by bushfires (5 to 14 years post fire) compared with unburnt areas, with more bare ground being available for ground-nesting bees (Burkle et al. 2019). Furthermore, a positive relationship has been found between bee diversity and bushfire severity (Galbraith et al. 2019). However, another study found lower bee diversity and abundance in a burnt area (8 years post fire) compared with an adjacent unburnt area (Potts et al. 2001).

This study attempted to assess how native bee communities were affected by the 2019–2020 bushfires in Victoria. This was done by sampling bee populations within the burnt areas and adjacent unburnt locations across the fire footprint. As understorey species generally recover to flowering stage more quickly after fire, it was expected that Myrtaceae specialists will have been more acutely affected. Ground-nesting bees should be less affected than those nesting above ground, due to the removal of above-ground nesting sites by the fire and the ability of below-ground species to survive in situ.

Methods

The study area encompassed all of the 2019–2020 fire extent and the adjacent unburnt areas in north-eastern Victoria and East Gippsland. The fires burnt approximately 1.5 million hectares of forest and woodland across these two regions (Geary et al. 2021). Burn status was initially determined from remotely sensed data (Collins et al. 2021) and confirmed in the field. Due to the requirements of bee sampling, particularly the need for plants to be in flower, it was not possible to allocate exact sampling locations prior to field sampling. Instead, sampling was guided by locations identified in another study on the impact of the 2019–2020 fires on native snails (A. Moussalli, pers. comm.). Additional sites were opportunistically selected in the field when encountering appropriate flowering vegetation. Attempts were made to maintain a minimum spatial separation of 200 m between sites, to ensure independence.

Field sampling was conducted on three separate occasions from February to April 2021, approximately 13 to 15 months after the fires. Originally, two sampling trips of 12 days each were planned, in February and March; however, the first trip was cut short due to a snap lockdown in response to a COVID-19 outbreak in Victoria, with the lost 7 days of collecting instead carried out in early April.

Field sampling was conducted using a standard technique, sweep netting, which involves sweeping flowering vegetation with a net, capturing insects that were on the flowers. All native bees collected were euthanised for identification; all other insects were released at the site. Also recorded were the GPS coordinates, start and finish times, time spent sampling, ambient temperature, dominant plants in flower, and burn status. A total of 141 samples were taken from 106 locations. Where possible, each site was sampled on at least two occasions (31 locations). Sites were not sampled twice if there was no flowering vegetation on subsequent visits. Specimens were identified to the lowest possible taxonomic rank, typically species. Specimens were assigned to one of four nesting guilds: below-ground, above-ground in cavities, above-ground in wood and above-ground in hollow stems.

All collected bees were lodged in the entomology collection of Museums Victoria, and all specimens were registered using the code prefix “BFBS” (Bushfire Bee Survey) and can be searched for at Museums Victoria’s Collections Online with this URL: https://collections.museumsvictoria.com.au/search?query=BFBS

Results

Summary of samples and species

Asteraceae was the dominant plant family from which bees were sampled and the only plant family that was regularly encountered with flowers in burnt areas (Table). During surveys, 1106 specimens of native bees were collected from 67 species (Table). Twenty-five species were found in burnt areas and 54 species were found in unburnt areas (Figure 81). According to the ALA, there are approximately 135 species known from the study area. However, the search was restricted to the survey months of February, March and April, and 75 species were recorded in the survey area from 556 records.

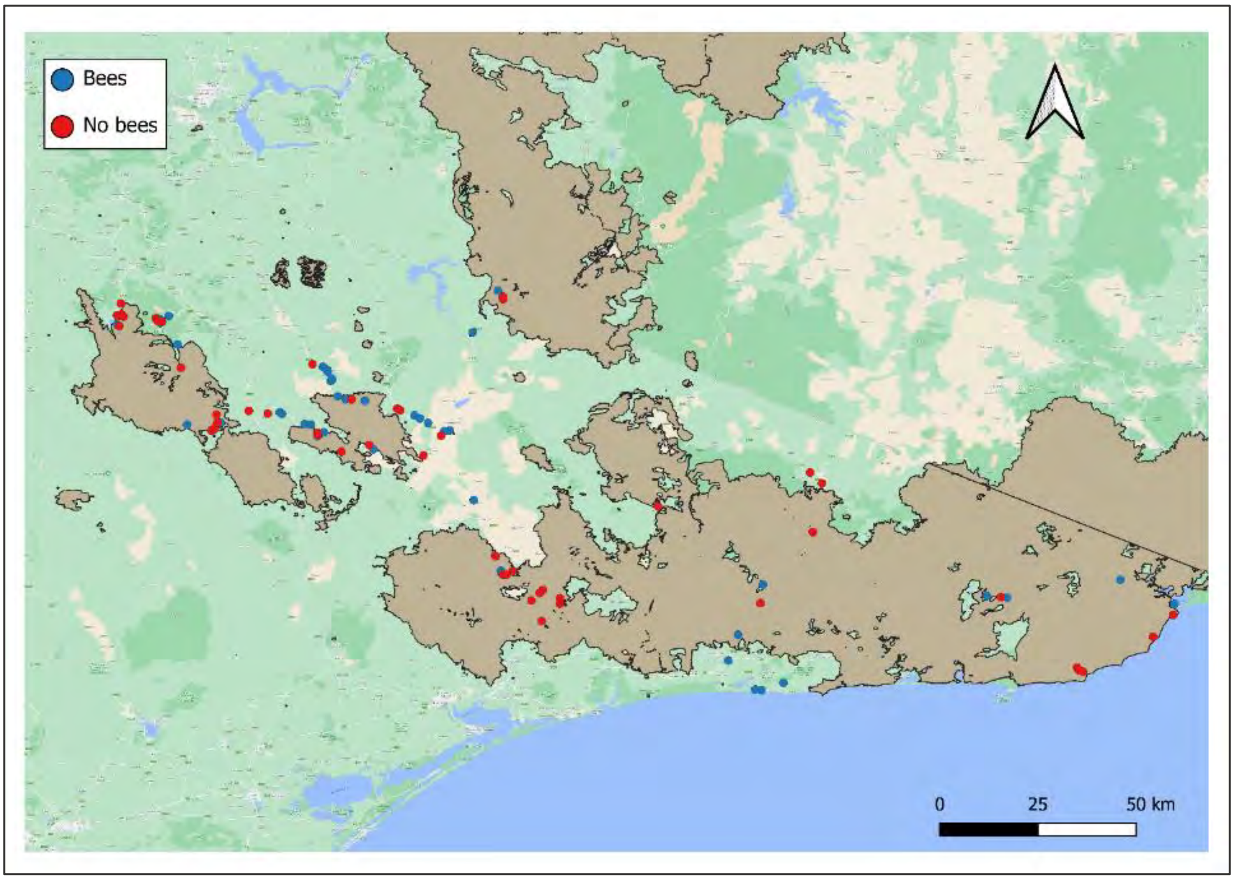

Figure 81. Sample sites where native bees were or were not detected

Table 32. Number of samples by burn status and plant family

Fire	Asteraceae	Campanulaceae	Fabaceae	Goodeniaceae	Myrtaceae	Pittosporaceae	Rosaceae
Burnt	53	7	1	4	0	0	0
Unburnt	45	0	0	0	13	2	1

The number of species collected may have been impacted by the sampling period (February to April), as several species are known to be active only in spring and summer within the study area (for example, species with collection records outside our study sampling period include *Callomelitta nigra*: November; *Megachile ferox*: January, September and December; *Paracolletes crassipes*: December; *Trichocolletes sericeus*: October to November).

Exoneura bicolor (26 samples, 202 individuals), *Homalictus* (*Homalictus*) *punctatus* (7 samples, 232 individuals) and *Lasioglossum* (*Parasphecodes*) *subrussatum* (14 samples, 114 individuals) were the most collected species. Specimens from all four bee families were collected. Colletidae bees were collected in both burnt and unburnt areas from three subfamilies. Colletidae subfamilies Colletinae and Hylaeinae were collected in both burnt and unburnt areas (though only one specimen of Hylaeinae in the burnt zone), but no Euryglossinae bees were collected in the burnt area due to the survey team being unable to find a single flowering Myrtaceae in the burnt areas. Figure 82 shows examples of the bee species collected in this study.

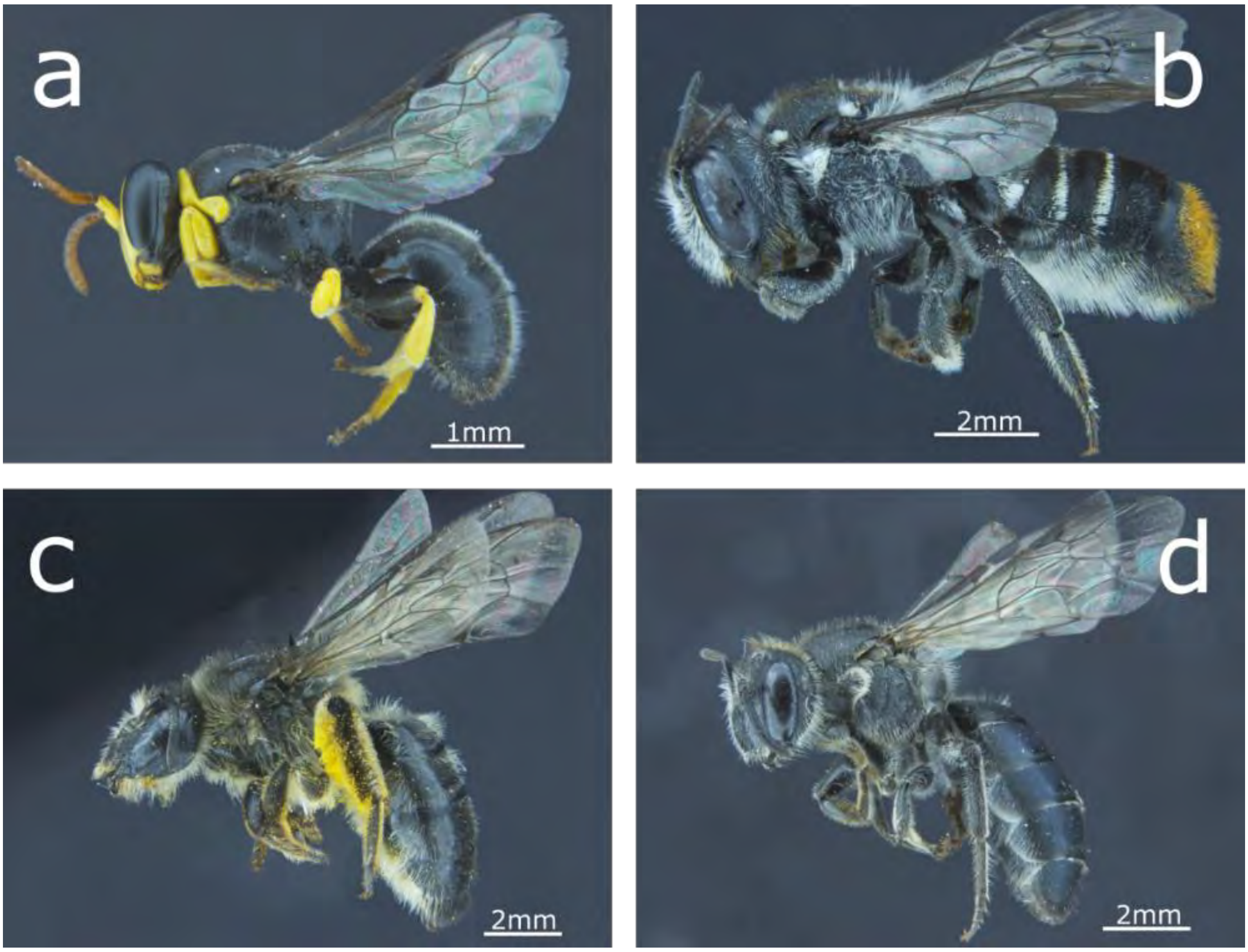

Figure 82. Examples of bees from this study. (A) *Hylaeus amiculus*, (B) *Megachile oblonga*, (C) *Leioproctus obscurus* and (D) *Euryglossa ephippiata* (photos: K. Walker).

Table 33. Details of native bee species sampled in this study. ‘Samples’ refers to the number of samples from which at least one individual of that species was detected.

Species	Family	Subfamily	Nesting	Samples	Number	Fire		Plant family					
						Burnt	Unburnt	Asteraceae	Campanulaceae	Goodeniaceae	Myrtaceae	Pittosporaceae	Rosaceae
Amegilla chlorocyanea	Apidae	Apinae	Below ground	1	1	X			X				
Callohesma calliopsiformis	Colletidae	Euryglossinae	Above ground – cavity nesting	2	2		X				X		
Callomelitta picta	Colletidae	Colletinae	Above ground in wood	4	12		X				X		
Euryglossa ephippiata	Colletidae	Euryglossinae	Above ground – cavity nesting	1	1		X				X		
Euryglossina (*Euryglossina*) *hypochroma*	Colletidae	Euryglossinae	Above ground – cavity nesting	1	1		X				X		
Euryglossina (*Euryglossina*) *proctotrypoides*	Colletidae	Euryglossinae	Above ground – cavity nesting	2	4		X				X		
Euryglossina (*Euryglossina*) sp. n. “barb”	Colletidae	Euryglossinae	Above ground – cavity nesting	1	2		X				X		
Euryglossula chalcosoma	Colletidae	Euryglossinae	Above ground – cavity nesting	1	1		X				X		
Exoneura bicolor	Apidae	Xylocopinae	Above ground – hollow stems	26	202	X	X	X	X				X
Exoneurella lawsoni	Apidae	Xylocopinae	Above ground – hollow stems	1	2	X		X					
Goniocolletes fimbriatinus	Colletidae	Colletinae	Below ground	1	1		X				X		
Homalictus (*Homalictus*) *brisbanensis*	Halictidae	Halictinae	Below ground	1	2		X						X
Homalictus (*Homalictus*) *punctatus*	Halictidae	Halictinae	Below ground	7	232		X				X		
Homalictus (*Homalictus*) *sphecodoides*	Halictidae	Halictinae	Below ground	7	12	X	X	X				X	X
Hylaeus (*Edriohylaeus*) *ofarrelli*	Colletidae	Hylaeinae	Above ground – cavity nesting	1	1		X				X		
Hylaeus (*Euprosopis*) *honestus*	Colletidae	Hylaeinae	Above ground – cavity nesting	4	15		X	X			X		
Hylaeus (*Euprosopis*) *elegans*	Colletidae	Hylaeinae	Above ground – cavity nesting	1	1		X				X		
Hylaeus (*Gnathoprosopis*) *amiculus*	Colletidae	Hylaeinae	Above ground – cavity nesting	3	18		X				X	X	
Hylaeus (*Hylaeorhiza*) *nubilosus*	Colletidae	Hylaeinae	Above ground – cavity nesting	2	3		X				X	X	

Species	Family	Subfamily	Nesting	Samples	Number	Fire		Plant family					
						Burnt	Unburnt	Asteraceae	Campanulaceae	Goodeniaceae	Myrtaceae	Pittosporaceae	Rosaceae
Hylaeus (*Prosopisteron*) *aralis*	Colletidae	Hylaeinae	Above ground – cavity nesting	1	1		X				X		
Hylaeus (*Prosopisteron*) *brevior*	Colletidae	Hylaeinae	Above ground – cavity nesting	3	23		X				X		
Hylaeus (*Prosopisteron*) *cliffordiellus*	Colletidae	Hylaeinae	Above ground – cavity nesting	2	4	X	X	X			X		
Hylaeus (*Prosopisteron*) *littleri*	Colletidae	Hylaeinae	Above ground – cavity nesting	1	2		X				X		
Hylaeus (*Prosopisteron*) *minusculus*	Colletidae	Hylaeinae	Above ground – cavity nesting	1	1		X				X		
Hylaeus (*Prosopisteron*) *quadratus*	Colletidae	Hylaeinae	Above ground – cavity nesting	2	2		X				X		
Hylaeus sp. n. A44	Colletidae	Hylaeinae	Above ground – cavity nesting	1	1		X				X		
Hyphesma atromicans	Colletidae	Euryglossinae	Above ground – cavity nesting	4	26		X				X		
Lasioglossum (*Australictus*) *plorator*	Halictidae	Halictinae	Below ground	4	11	X	X	X					
Lasioglossum (*Austrevylaeus*) *disclusum*	Halictidae	Halictinae	Below ground	3	9		X	X					
Lasioglossum (*Austrevylaeus*) sp. INT	Halictidae	Halictinae	Below ground	6	9	X	X	X					
Lasioglossum (*Callalictus*) *callomelittinum*	Halictidae	Halictinae	Below ground	1	1		X	X					
Lasioglossum (*Chilalictus*) *asperithorax*	Halictidae	Halictinae	Below ground	3	11	X		X					
Lasioglossum (*Chilalictus*) *brazieri*	Halictidae	Halictinae	Below ground	1	2	X		X					
Lasioglossum (*Chilalictus*) *brunnesetum*	Halictidae	Halictinae	Below ground	3	6	X		X					
Lasioglossum (*Chilalictus*) *calophyllae*	Halictidae	Halictinae	Below ground	1	1		X				X		
Lasioglossum (*Chilalictus*) *clelandi*	Halictidae	Halictinae	Below ground	10	27	X	X	X	X				
Lasioglossum (*Chilalictus*) *erythrurum*	Halictidae	Halictinae	Below ground	1	3	X		X					
Lasioglossum (*Chilalictus*) *hemichalceum*	Halictidae	Halictinae	Below ground	1	1	X		X					
Lasioglossum (*Chilalictus*) *instabilis*	Halictidae	Halictinae	Below ground	1	1		X	X					

Species	Family	Subfamily	Nesting	Samples	Number	Fire		Plant family					
						Burnt	Unburnt	Asteraceae	Campanulaceae	Goodeniaceae	Myrtaceae	Pittosporaceae	Rosaceae
Lasioglossum (*Chilalictus*) *lanarium*	Halictidae	Halictinae	Below ground	11	31	X	X	X	X	X		X	
Lasioglossum (*Chilalictus*) *mundulum*	Halictidae	Halictinae	Below ground	7	13	X	X	X	X		X		
Lasioglossum (*Chilalictus*) *opacicolle*	Halictidae	Halictinae	Below ground	4	21	X	X	X					
Lasioglossum (*Chilalictus*) *repraesentans*	Halictidae	Halictinae	Below ground	1	1	X		X					
Lasioglossum (*Chilalictus*) sp. n.	Halictidae	Halictinae	Below ground	1	1		X	X					
Lasioglossum (*Chilalictus*) *tamburinei*	Halictidae	Halictinae	Below ground	1	1	X		X					
Lasioglossum (*Parasphecodes*) *altichum*	Halictidae	Halictinae	Below ground	12	74	X	X	X					
Lasioglossum (*Parasphecodes*) *hilactum*	Halictidae	Halictinae	Below ground	3	8		X	X					
Lasioglossum (*Parasphecodes*) *lacthium*	Halictidae	Halictinae	Below ground	7	44	X	X	X					
Lasioglossum (*Parasphecodes*) *lithuscum*	Halictidae	Halictinae	Below ground	3	52		X	X					
Lasioglossum (*Parasphecodes*) sp. BP-1	Halictidae	Halictinae	Below ground	3	6	X	X	X					
Lasioglossum (*Parasphecodes*) *subrussatum*	Halictidae	Halictinae	Below ground	14	114	X	X	X				X	
Lasioglossum (*Parasphecodes*) *sulthicum*	Halictidae	Halictinae	Below ground	4	9	X	X	X	X		X		X
Lasioglossum (*Parasphecodes*) *taluche*	Halictidae	Halictinae	Below ground	2	2	X	X	X				X	
Lasioglossum (*Parasphecodes*) *turneri*	Halictidae	Halictinae	Below ground	4	8		X				X		X
Lasioglossum (*Parasphecodes*) *waterhousei*	Halictidae	Halictinae	Below ground	1	2	X		X					
Leioproctus (*Leioproctus*) *alleynae*	Colletidae	Colletinae	Below ground	2	4		X				X		X
Leioproctus (*Leioproctus*) *amabilis*	Colletidae	Colletinae	Below ground	3	8		X				X		
Leioproctus (*Leioproctus*) *carinatus*	Colletidae	Colletinae	Below ground	1	1		X				X		
Leioproctus (*Leioproctus*) *clarki*	Colletidae	Colletinae	Below ground	1	4		X				X		

Species	Family	Subfamily	Nesting	Samples	Number	Fire		Plant family					
						Burnt	Unburnt	Asteraceae	Campanulaceae	Goodeniaceae	Myrtaceae	Pittosporaceae	Rosaceae
Leioproctus (*Leioproctus*) *obscurus*	Colletidae	Colletinae	Below ground	8	30		X	X			X		
Leioproctus (*Leioproctus*) *plumosus*	Colletidae	Colletinae	Below ground	1	1		X				X		
Leioproctus (*Leioproctus*) *providus*	Colletidae	Colletinae	Below ground	1	1		X				X		
Lipotriches (*Austronomia*) *australica*	Halictidae	Halictinae	Below ground	1	2	X		X					
Lipotriches (*Austronomia*) *flavoviridis*	Halictidae	Halictinae	Below ground	1	1		X				X		
Megachile (*Hackeriapis*) *oblonga*	Megachilidae	Megachilinae	Above ground – cavity nesting	2	2		X	X			X		
Megachile ordinaria	Megachilidae	Megachilinae	Above ground – cavity nesting	1	1		X	X					
Paracolletes rebellis	Colletidae	Colletinae	Below ground	1	10		X				X		

Fire impacts on abundance, species richness, and nesting guilds

At locations where native bees were detected, evidence was found that bee abundance and species richness were lower in burnt areas than in unburnt areas. The bee fauna at burnt locations was dominated by below-ground-nesting bees, but the abundance of this guild was lower at burnt locations than at unburnt locations (Table 34).

Table 34. Mean sample abundance and species richness (± standard error) of native bees at burnt and unburnt locations where the dominant plant family was Asteraceae, calculated from samples where at least one native bee was detected. We detected too few above-ground-nesting species to reliably report their abundance.

Fire	All-bee abundance	All-bee species richness	Below-ground-nesting bee abundance
Burnt	8.4 ± 2.4	2.3 ± 0.4	7.0 ± 2.3
Unburnt	19.8 ± 6.3	3.5 ± 0.5	12.8 ± 3.6

The situation for above-ground-nesting bees was more concerning. Species nesting above ground in cavities and wood were largely absent from burnt locations. The above-ground hollow-stem fauna was more frequently detected at burnt locations (compared with other above-ground species), but was dominated by one species, *Exoneura bicolor* (Table 33).

Table 35. Number of samples from which above-ground-nesting bees were detected, classified according to burn status; the total number of samples taken in each fire category is provided for comparison.

Fire	Above-ground cavity	Above-ground hollow stem	Above-ground in wood	Total samples
Burnt	1	9	0	75
Unburnt	15	18	4	66

Short-range endemics

The results from this assessment suggest that many of the East Gippsland native bee species should now be recognised as short-range endemics, “which are species with naturally small distributions and, by their very nature, most likely to be threatened by habitat loss, habitat degradation and climate change” (Harvey et al. 2011).The widespread fires of 2019–2020 potentially had significant effects on the viability of these species. Many of the short-range endemic bee species already had restricted distributions and restricted floral preferences, but our sampling efforts found that some of these species may now have even more reduced and restricted distributions due to recent fire effects on the available nesting sites and available floral resources. In this study, 27 of the 67 collected species were collected at only one site, and an additional 19 species were collected at three or fewer sites. Of concern is that ALA records show that all 27 of the single-site species were previously recorded at several sites within the survey area. The 19 species that were found at three or fewer sites have previously been collected at four or more sites. For example, *Paracolletes rebellis* (Colletidae), a ground-nesting species restricted to foraging on Myrtaceae flowers, has previously been recorded from four locations in eastern Victoria, but was found at only one location (near Benambra) during this survey. The one collection of this species was made on 19 March 2021 on a flowering eucalypt; this same tree was still in flower when revisited on 7 April 2021, but no specimens of *P. rebellis* were collected. Another rare Victorian species collected was *Exoneurella lawsoni* (Apidae). This species is an above-ground hollow-stem–nesting species, as is the most-collected species in this survey, *Exoneura bicolor*. *Exoneurella lawsoni* has previously been collected only four times in Victoria in the Gippsland region. This survey collected two specimens at the one location (22 March 2021, north of Orbost) in the burnt zone. No additional specimens were collected when the area was revisited in early April 2021. *Lasioglossum* (*Parasphecodes*) *lithuscum* had previously been collected from a range of high-altitude areas across eastern Victoria, but this study only found this species at Mount Hotham during both the March and April sampling. Encouragingly, at least one species had range extensions. For example, the undescribed species

Euryglossina sp. n. "barb", an obligate Myrtaceous foraging bee, had previously been recorded only once at Colquhoun State Forest, 11 km west of Nowa Nowa, but in this study it was recorded 11 km east of Marlo on a flowering eucalypt.

Risks

Pre-existing risks (i.e. before the bushfires)

As for many terrestrial invertebrates, the biggest threat to native bee conservation is a basic lack of understanding of their distribution and their responses to threats, including fire. Known risks to native bees include competition from introduced species, particular the European Honeybee (*Apis mellifera*), as well as loss of preferred food plants, habitat loss, and fragmentation of populations.

Additional risks driven by the 2019–2020 bushfires

Few bees from above-ground-foraging guilds were found in burnt areas. It is unclear whether these groups will return to burnt areas when additional plant species (particularly myrtaceous species) return and flower. Additionally, species that are considered short-range endemics are at risk from future disturbance events such as fire, due to their narrow geographical range. Furthermore, a recent conservation status assessment has recommended that several Victorian bee species be listed as endangered or threatened (Dorey et al. 2021). These species were not detected in this study.

Future directions

This study can be considered a snapshot of the situation just over a year after the 2019–2020 bushfires in Victoria. Some preliminary evidence was found that native bees were negatively impacted by these fires, and that above-ground-nesting bees may have been particularly badly impacted. Subsequent studies after more vegetation, particularly *Eucalyptus*, has resumed flowering would likely improve our understanding of the longer-term impacts of the bushfires on native bees. This would provide information on whether the bee groups absent in this study have been able to re-establish after resources have become available. Consideration should also be given to sampling in multiple seasons, to have a chance of finding species that are active at different times of the year. In the design of future studies, it would be useful to consider fire severity and distance from the fire edge when selecting sampling locations.

A more thorough understanding of bee responses to fire is likely to come from multiple lines of evidence, via a combination of landscape-scale and more focused studies. In this initial work, maximised spatial coverage was emphasised, but this came at the expense of more detailed understanding, and meant there was less control over external sources of variation. Smaller-scale studies, for example those employing experimental burn plots or taking advantage of planned burns, may have more control over covariates, which may help illuminate the mechanisms involved in bee fire responses. However, the ability to make inferences about other areas and taxonomic groups will be limited.

Acknowledgements

This project was funded through the Victorian Government's Bushfire Biodiversity Response and Recovery program. The field survey and data collection was undertaken by Ken Walker (Museums Victoria), Dave Bryant (ARI–DELWP) and Matt Bruce (ARI–DELWP). Ken Walker identified bee specimens. Anne Buchan (DELWP) facilitated funding for this work, and Ella Loeffler (DELWP) provided project support. Adnan Moussalli (Museums Victoria) supplied the site locations that guided where samples were to be collected. Arn Tolsma (ARI–DELWP) provided helpful comments on the text. This work was conducted under the Victorian *National Parks and Wildlife Act 1974* permit number 10008640.

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Flora

Rush Lily (*Sowerbaea juncea*) resprouting profusely in burnt coastal heathland (photo: Annette Muir)

Flora species and communities were targeted for assessment, and the findings are reported in the following sections:

7.1 Threatened flora species

7.2 Vegetation types: seven Ecological Vegetation Classes

7.3 Rainforest surveys

7.4 Limestone Pomaderris Shrubland

7.1 Threatened flora species

Prepared by Arn Tolsma, Annette Muir and Judy Downe (ARI–DELWP), and Andre Messina and Neville Walsh (Royal Botanic Gardens Victoria)

Summary of key findings

Over three-quarters of the threatened plant species searched for were found, and were regenerating successfully post fire.

A total of 287 populations of threatened plant species were assessed, comprising 126 different species. Of these, 108 species were found to be successfully regenerating from seedlings or resprouts.

There were 18 species not found, but it is still too early to determine whether this was due to a lack of regeneration, inaccuracy of location records, or simply insufficient time elapsed since the fire to allow detection and positive identification.

Immediate threats to populations were generally minor. Deer activity was usually low or absent, but will increase with time since fire. Weeds present were considered low threat at the time of sampling.

A long fire-free period is now required to allow many species to reach viable reproductive maturity.

Background

The extensive bushfires of 2019–2020 burnt approximately 1.5 million hectares in eastern Victoria. Across south-eastern Australia, the bushfires affected the ranges of 587 plants listed as threatened under national legislation (Gallagher et al. 2021). Populations of many Victorian Rare or Threatened (VROT) species were known to be within the fire area, including those listed under the Commonwealth *Environment Protection and Biodiversity Act 1999* (EPBC Act) or the Victorian *Flora and Fauna Guarantee Act 1988* (FFG Act).

The post-fire responses of many of these species have not been adequately documented, so there is uncertainty about their responses to the 2019–2020 fires. Basic life-cycle information, such as the time required for species to reach viable reproductive maturity, may also be lacking. Time to reproductive maturity of key species is used to help determine minimum and maximum tolerable fire intervals for fire planning in Victoria (Cheal 2010). The life history attributes (or vital attributes) of plant species can be used to predict and interpret their responses to fire (Noble and Slatyer 1980; Whelan et al. 2002; Keith et al. 2007) and are critical for conservation planning. Attributes most relevant to this study were the mode of regeneration [resprouting from fire-resistant parts (resprouters), recruitment solely from seed banks (obligate seeders), or a combination of both] and time to reproductive maturity.

Following fire, plants may be subject to various pressures that affect their recovery. These include grazing or browsing (Leigh and Holgate 1979; Robertson 1985; Tolhurst and Oswin 1992), weed invasion (Meredith 1987; Milberg and Lamont 1995), drought, erosion, and another fire before species can produce adequate stores of viable seed (Gill 1981; Noble and Slatyer 1981). Potential threats to the long-term persistence of populations of VROT plants burnt in 2019–2020 are largely unknown, but it is important to identify them to ensure that appropriate management decisions can be made to protect the populations.

Accordingly, surveys were undertaken by the ARI–DELWP and Royal Botanic Gardens Victoria (RBGV) in East Gippsland and north-eastern Victoria between June 2020 and March 2021. The aim was to assess the persistence of rare and threatened plants in the bushfire areas, their post-fire recovery, their life-cycle attributes, and the post-fire threats that might affect their recovery and persistence. This chapter presents the methods for and the results of the threatened species surveys, according to their life forms and reproductive strategies. Additional information on recovery and threats to various vegetation types and rainforest is presented in Section 7.2 (Vegetation types), 7.3 (Rainforests) and 7.4 (Limestone Pomaderris Shrubland).

Methods

Locations surveyed

Survey sites were located on public land (state forest and national park) in fire-affected eastern Victoria (Figure 83).

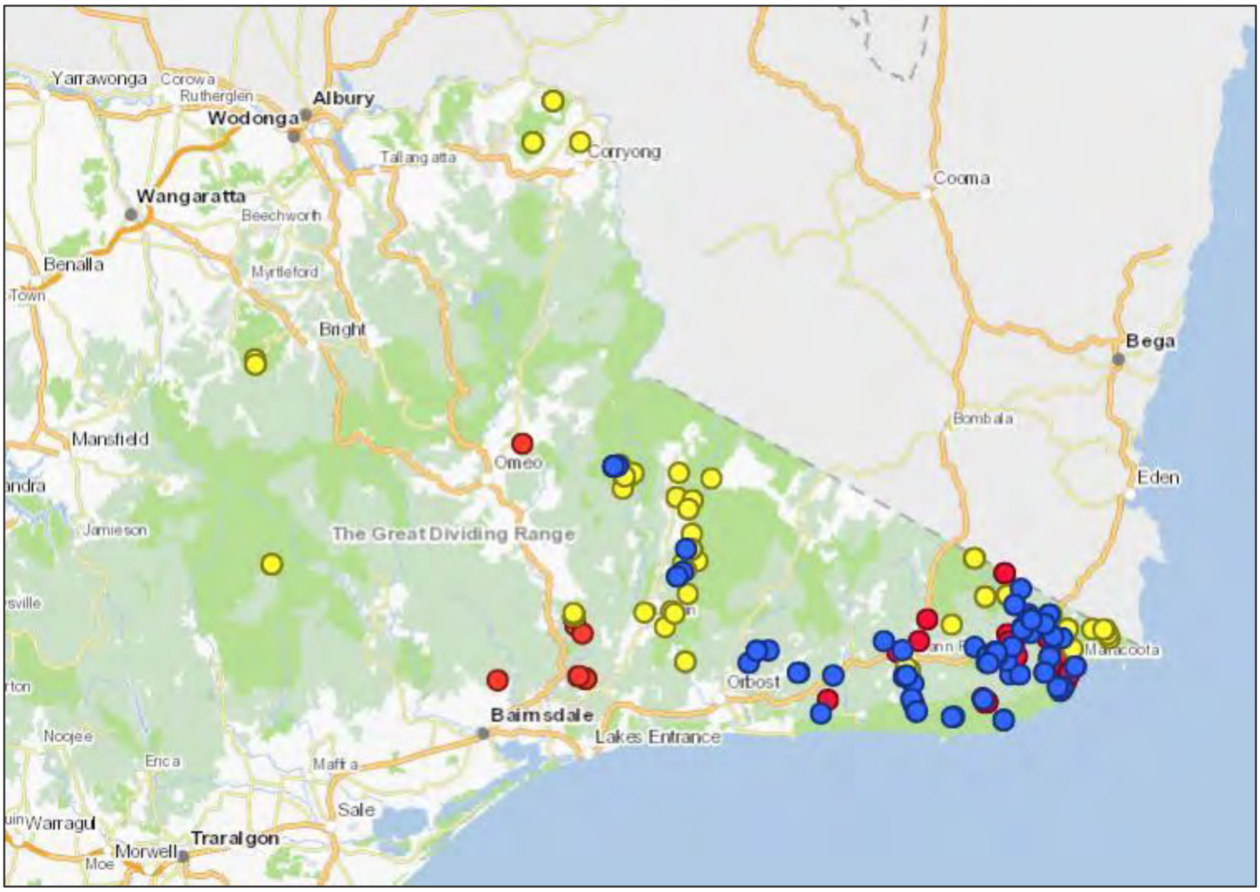

Figure 83. Locations of threatened plant populations assessed after the 2019–2020 fires. Blue dots are sites assessed by the ARI–DELWP; yellow dots are sites assessed by the Royal Botanic Gardens Victoria; red dots are sites assessed by local volunteers.

Survey methods

The methods used for this project were adapted from those used for previous surveys of threatened species (Coates et al. 2004; Kohout et al. 2009; Tolsma et al. 2012).

A total of 154 plant species of concern to DELWP, partner organisations or species experts had previously been identified as potentially at risk from the fires (DELWP 2020a). However, this represented only a subset of the threatened species within the fire area, so prioritisation for this project focused on identifying threatened species with the greatest proportion of their known populations at risk. VROT vascular plants and ferns that were potentially burnt were determined by intersecting their habitat distribution models with the fire extent model (as at 10 March 2020, DELWP, unpubl. data). Victorian Biodiversity Atlas (VBA 2021) records for the resulting 688 species were then overlain on the fire-severity model to identify recorded (known) populations within areas burnt at high severity (crown burnt or crown scorched categories), under the assumption that these populations would be the most severely affected. This process identified 489 species that had at least one known population burnt at high severity. To ensure that the assessments focused on the taxa at most risk, those species for which burnt populations made up at least half of their total VBA populations were selected for further consideration. Some species originally identified as being of particular concern to DELWP, partner organisations or species experts (DELWP 2020a), and that were filtered out by this process, were reinstated. This resulted in a provisional shortlist of 155 species, totalling 3464 records.

Relevant data for these records were then extracted from the VBA database and corporate spatial layers, including location, date of record, locational accuracy, time since previous fire, and distance from a track or road. Records were removed from further consideration if they were duplicates (the latest one being retained), if the locational accuracy was worse than 15 m (mostly pre-GPS records, for which populations were unlikely to be readily found), or if the location was further than 300 m from any track (hence impractical to assess within the limited time available). Records were then mapped in GIS to enable logical clusters of priority records to be identified [to optimise field assessments, and to minimise overlap by the two organisations (ARI–DELWP and RBGV)].

Searches were undertaken between June 2020 and March 2021 for known populations of species on the shortlist, so that the timing of the searches coincided as much as possible with flowering times for the largest number of species. Using GPS waypoints and maps, the point location of each record was found and temporarily marked with flagging tape, and the general area was thoroughly searched for the target species. If the species was found, detailed notes were made of population size and extent, mode of regeneration, whether flowering or fruiting at the time, and other relevant information such as estimated fire severity, habitat type, and landform. Sightings of other (non-target) rare or threatened species were also documented. The general area around the record location was then examined to determine whether there were any obvious potential threats to the recovery or persistence of the population, such as high-threat weeds, plant-to-plant competition, deer activity, heavy browsing, erosion, or roadworks.

If enough plant species were identifiable at a site, a floristic quadrat survey was conducted to characterise the vegetation and supplement the VBA data. An area of 20 m × 20 m (consistent with most VBA quadrats) was established around the point location. All vascular plant species rooted in or overhanging the quadrat, including canopy trees, were recorded, and their percentage overlapping cover (1%, 2%, then to nearest 5%) was estimated. The cover of elements of the ground layer, such as bryophytes, coarse woody debris, and bare ground, was also estimated, as was total tree canopy cover.

All incidental and quadrat data were provided to the VBA to supplement the existing data and help refine habitat distribution models. Plant life strategy data, based on field observations, were compared with those in Vital Attribute and Flora Attribute databases (DELWP, unpubl.), with new or revised information incorporated as required.

Additional recovery data for orchids and other species were provided by local volunteers (especially Gary Backhouse and James Turner), who had been monitoring known populations prior to the fire. Some recovery data were also obtained from opportunistic observations by the survey teams.

Limitations

Not all threatened species known to occur in the bushfire-affected areas were surveyed. For the species that were surveyed, time constraints meant that not all known or potential sites were visited. Changes in population size were not able to be estimated because of a lack of pre-fire data.

Results and discussion

A total of 287 populations of threatened plant species were assessed, comprising 126 different species (Table , Figure 83). Of the 126 species searched for, 108 species (86%) were found, and were successfully regenerating from post-fire seedlings or resprouts. Orchids were well represented in the successful surveys, reflecting both their rarity (leading to higher priority for searching) and the interest from the volunteers who contributed data for local populations. Updated vital attribute (post-fire recovery strategy) data for species found were incorporated into the Flora Attributes database held by the Ecological Analysis and Synthesis program, ARI–DELWP.

There were 18 species that could not be found by the assessment teams, but it is still too early to determine whether this was due to a lack of regeneration by the species in question, insufficient time elapsed since the fire to allow detection and positive identification, or simply inaccuracy of relevant location records. Over half of the species not able to be found at the time of the survey were shrubs, and six of those shrub species are believed to be killed by fire and to rely on seedling regeneration (Flora Attributes database, ARI–DELWP unpubl.). However, it was not possible to confidently identify many small seedlings observed at burnt sites, or to distinguish them from more common taxa. Given that shrubs were the life forms most affected by the fires (Godfree et al. 2021), future surveys are recommended for taxa not found to date; later surveys may have more success at confirming the presence of those threatened species, once there is sufficient plant material, and possibly flowers, to allow identification. Forb species were also difficult to find, especially when of small size.

Table 36. Summary results of post-fire surveys for threatened plant species

	Number found	Number not found	Total
All species	108	18	126
Shrub species	61	10	71
Orchid species	24	1	25
Other species	23	7	30

A major challenge encountered was the locational accuracy of some plant population records in the VBA, which had been relied upon for selecting populations to search for. Despite choosing records with a putative accuracy of 15 m or better, it was clear on reaching some sites that the habitat at the point location was inconsistent with the habitat preferences for the species, forcing the search of a larger area than planned. This made it difficult to find the species, considerably slowed down field work, and ultimately reduced the number of species populations able to be assessed. Future surveys would benefit from consultation of the original survey documentation for VBA species records (species and habitat notes, maps, etc.) during site selection and from elimination of populations with coordinates not established by reliable GPS data.

Life forms

The most common life forms surveyed were terrestrial orchids, resprouter shrubs and obligate seeder shrubs, with a smaller number of annual and perennial forbs, epiphytic orchids, trees, ferns, sedges and lilies (Table 37). This reflects the proportions of these species listed as threatened at the federal or state level, but also the large survey efforts by dedicated volunteers searching for orchids.

Table 37. Threatened species surveyed, summarised by life form and reproductive strategy

Life forms	Species found	Species not found	Species total
Shrubs—resprouters	26	4	30
Shrubs—obligate seeders	35	6	41
Orchids—terrestrial	20	1	21
Orchids—epiphytic	4	0	4
Forbs—perennial	11	3	14
Forbs—annual	3	0	3
Sedges and lilies	2	2	4
Ferns	1	2	3
Trees	6	0	6

Resprouter shrubs

(Table 38, Figure 84a, b)

A large proportion of Australian woody plant species resprout after fire (Clarke et al. 2015), although some species may decline with high-intensity fire or repeated fires because of less-protected buds or depletion of carbohydrate stores (Enright et al. 2011; Clarke et al. 2012).

Our surveys support this, as about 90% of shrub species found during the surveys with the presumed capacity to resprout after fire were observed to be recovering in this manner (Table 38). Two EPBC-listed species, Betka Bottlebrush (*Callistemon kenmorrisonii*) and Colquhoun Grevillea (*Grevillea celata*), were resprouting at sites where they had been previously recorded. Seedling germination was also observed for some shrub species, as resprouting is not necessarily an exclusive strategy for regeneration. Almost no shrubs were observed to be flowering, which means they had not reached reproductive maturity. Exceptions to this included the fast-growing resprouters.

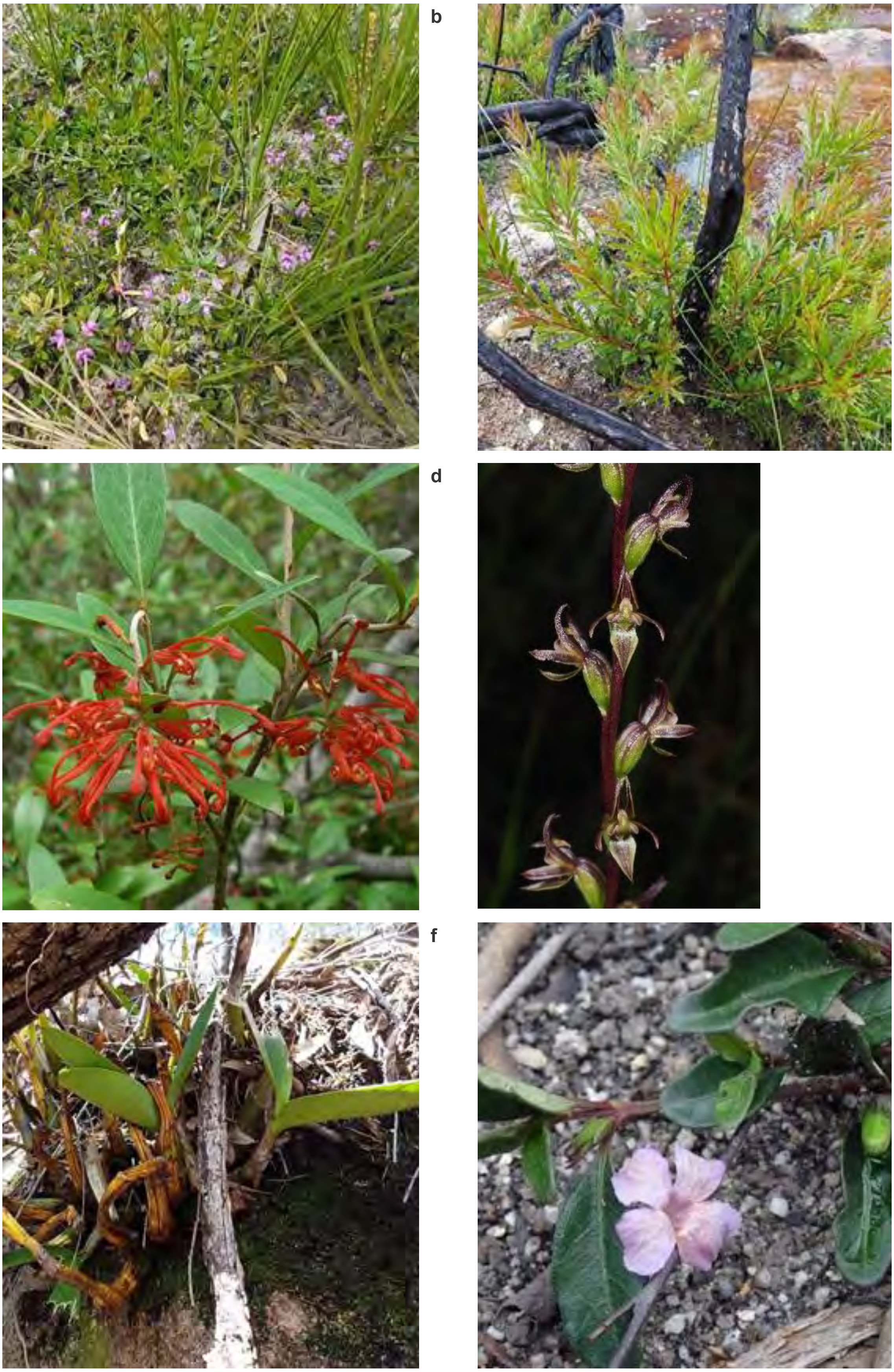

Figure 84. Some examples of threatened species found in the surveys of the 2019–2020 fire area (a) *Mirbelia rubiifolia*—resprouter shrub (photo: Annette Muir); (b) *Callistemon kenmorrisonii*—resprouter shrub (photo: Annette Muir); (c) *Grevillea polychroma*—obligate seeder shrub (photo: John Eichler); (d) *Prasophyllum parviflorum*—terrestrial orchid (photo: Gary Backhouse); (e) *Dendrobium speciosum*—epiphytic orchid (photo: Annette Muir); (f) *Brunoniella pumilio*—perennial forb (photo: Judy Downe)

Obligate seeder shrubs

(Table 39, Figure 84c)

Woody species that are killed by fires and regenerate entirely by seed (i.e. obligate seeders) are susceptible to local population extinctions when the intervals between fires are shorter than the time needed to accumulate seed banks (Whelan 1995; Clarke et al. 2015).

Thirty-five of the 41 obligate seeder shrub species searched for were found (Table 39). It is likely that some of the species were missed because of the difficulty in identifying very young seedlings, and these records will need checking in subsequent years. The timing of surveys is important, as many of the surveys conducted in December 2020 to March 2021 found plants that were not found during surveys conducted earlier in 2020. The EPBC-listed Genoa River Correa (*Correa lawrenceana* var. *genoensis*) was not found in the searches, but another EPBC-listed species, Leafy Nematolepis (*Nematolepis frondosa*) was found.

Terrestrial orchids

(Table 40, Figure 84d)

Most threatened ground orchids appear not to have been adversely affected by the bushfires (Table 40), with flowering in most species probably enhanced by fire (through temporary removal of competing vegetation) and good winter–spring rainfall (G. Backhouse, pers. comm.). Increased light due to reduction in tree canopies and increased nutrients in the ash-bed are also likely to contribute to the enhanced orchid flowering (Jones 1988). Several Greenhood orchid species [*Pterostylis acuminata, P. tunstallii, P. alveata* (montane)] that flower in autumn and early winter were absent from most sites and in much lower numbers than would be expected at other sites, but these species are known to be rainfall-responsive, so their absence was likely due to the dry conditions, with well below average rainfall in late summer to early winter, rather than to any effects from the fires (G. Backhouse, pers. comm.).

Epiphytic orchids

(Table 41, Figure 84e)

Evergreen tree and rock orchids (*Dendrobium speciosum*, Cane Rock Orchid and especially *Dendrobium striolatum*, Streaked Rock Orchid and *Plectorrhiza tridentata*, Common Tangle Orchid) have been slightly to badly affected by fire (Table 41), with few to many plants killed and, in the case of *P. tridentata*, some areas of rainforest habitat burnt (G. Backhouse, pers. comm.). These species are particularly vulnerable because all plant parts are aerial and, despite having the capacity to resprout after low-intensity fire, they have no protection from intense bushfires. Further, many of their host trees may be killed (Duncan 2012). Their recovery then depends on re-establishment of the rainforest canopy and and suitable environmental conditions.

Perennial and annual forbs

(Tables 42 and 43, Figure 84f, Figure 85a,b)

Almost all the targeted forb species were found during the surveys, and most were flowering (Tables 42 and 43). This reflects their capacity to resprout or germinate from seed, and their short reproductive maturity periods.

Sedges and lilies

(Table 44, Figure 85c)

Sedges and lilies were resprouting strongly after the bushfires (Table 44). Species that were not found may have been missed due to difficulties in identification without flowers.

Ferns

(Table 45, Figure 85c)

Only one of the three fern species was found (Table 45), which may be indicative of the sensitivity of their damp habitats to severe fire.

Trees

(Table 46)

Tree species assessed were resprouting strongly after the bushfires, from epicormic or lignotuberous buds, and some were producing seedlings (Table 46).

The following tables (Table 38 to Table 46) should be interpreted with the following information:

Sites searched: known species records (VBA), known sites visited by volunteers, and incidental locations found during the surveys

Plants found: not all populations were found for each species

Seedling or resprout: mode/s of post-fire regeneration as determined from field observations

'Flowering' was recorded as "yes" if species were in flower at the time of assessment. Absent values are assumed to be "no".

Fire severity: fire severity experienced at most sites for a species. High-severity fire defined as >50% of the canopy consumed or >80% of the canopy scorched. Moderate-severity fire is defined as 20–80% of the canopy scorched. Low-severity fire is defined as >80% unburnt canopy (DELWP 2020b). Blank cells indicate missing data.

Further searches needed: species known from only a few locations and not found in surveys, or found at low numbers at sites, or identification uncertain due to immaturity

Indication of 'resprout' or 'unburnt' does not imply that all plants in a population have resprouted or were unburnt. Losses of individuals within a population may still be significant, and their restoration to previous numbers may depend on future seedling recruitment.

A question mark (for example, "found: yes?") indicates uncertainty that can only be resolved by future surveys.

Figure 85. Further examples of threatened species found in the surveys of the 2019–2020 fire area: (a) *Goodenia heterophylla*—perennial forb (photo: Annette Muir); (b) *Brachyscome salkiniae*— perennial forb (photo: Annette Muir); (c) *Sowerbaea juncea*—lily (photo: Annette Muir); (d) *Sticherus flabellatus*—fern (photo: Judy Downe)

Table 38. Shrubs—presumed resprouters (see previous page for explanatory text)

Species name	EPBC listed	Sites searched	Plants found	Seedling or resprout	Flowering	Fire severity	Further searches needed
Astrotriche sp. 3		1	Yes	Resprout	No	High	
Astrotriche sp. 5		1	Yes	Seedling		High	
Baeckea linifolia		3	Yes	Resprout	No	High	
Banksia croajingolensis		2	Yes	Resprout	No	High	
Boronia ledifolia		2	Yes	Seedlings	No	High	Yes
Bossiaea ensata		5	Yes	Resprout	No	High	
Callistemon kenmorrisonii	Yes	1	Yes	Resprout	Yes	High	
Callistemon subulatus		3	Yes	Resprout	Yes	Low	
Dampiera fusca		2	Yes	Seedling		Moderate	
Dampiera purpurea		3	Yes	Seedling		High	
Dodonaea rhombifolia		3	Yes	Seedling/resprout		High	
Eupomatia laurina		2	Yes	Resprout	No	High	
Ficus coronata		2	Yes (few)	Seedlings	No	High	Yes
Gompholobium inconspicuum		1	No			High	Yes
Grevillea celata	Yes	1	Yes	Resprout	No	Moderate	
Hibbertia hermanniifolia subsp. *recondita*		2	Yes	Seedling	No	High	
Hibbertia notabilis		1	Yes	Resprout		Moderate	
Hibbertia rufa		2	No			High	Yes
Leptospermum jingera		1	No			High	Yes
Leptospermum trinervium		1	Yes	Resprout	No	Moderate	
Leucopogon riparius		1	Yes	Resprout	No	Moderate	
Mirbelia rubifolia		3	Yes	Resprout	No	High	
Monotoca rotundifolia		2	Yes	Unburnt	No	Moderate	
Muehlenbeckia rhyticaria		1	Yes	Resprout	No	High	

Species name	EPBC listed	Sites searched	Plants found	Seedling or resprout	Flowering	Fire severity	Further searches needed
Olax stricta		2	No			High	Yes
Persoonia levis		6	Yes	Resprout	No		
Pittosporum revolutum		2	Yes	Unburnt	Yes		
Symplocos thwaitesii		1	Yes?				
Tetratheca subaphylla		4	Yes	Resprout	No	High	Yes
Westringia cremnophila		1	Yes	Resprout		High	

Table 39. Shrubs—presumed obligate seeders (see explanatory text before Table 38)

Species name	EPBC listed	Sites searched	Plants found	Seedling or resprout	Flowering	Fire severity	Further searches needed
Acacia caerulescens	**Yes**	1	Yes	Seedling		High	
Acacia cognata		2	Yes	Seedling		Moderate	
Acacia irrorata		1	Yes	Seedling	No	High	
Acacia lanigera gracilipes		3	Yes	Seedling/resprout	No	High	
Acacia lucasii		2	Yes	Seedling/resprout		High	
Acacia phlebophylla		1	Yes	Seedling		High	
Acacia subporosa		3	Yes	Seedling		Low	
Adriana tomentosa		2	Yes	Seedling		High	
Banksia canei		2	Yes	Seedling		High	
Beyeria lasiocarpa		1	No			High	Yes
Cassinia maritima		1	Yes	Seedling		Low	
Cassinia scabrida		1	Yes	Seedling		High	
Cassinia venusta		1	Yes	Seedling		Moderate	
Correa lawrenceana var. *genoensis*	Yes	3	No			High	Yes
Darwinia camptostylis		1	No			High	Yes
Grevillea brevifolia		1	Yes	Seedling		High	
Grevillea jephcottii		2	Yes	Seedling		High	
Grevillea polychroma		3	Yes	Seedling		High	Yes
Hovea magnibractea		1	Yes	Seedling		High	
Myoporum floribundum		1	Yes	Seedling		High	
Nematolepis frondosa	Yes	3	Yes	Seedling		High	Yes
Nematolepis squamea subsp. *retusa*		1	Yes	Seedling/resprout		Low	
Olearia rugosa subsp. *angustifolia*		3	Yes	Seedling	No	Low	
Olearia rugosa subsp. *distalilobata*		1	Yes	Seedling/resprout		Moderate	

Species name	EPBC listed	Sites searched	Plants found	Seedling or resprout	Flowering	Fire severity	Further searches needed
Ozothamnus argophyllus		4	Yes	Seedling	No	High	
Persoonia asperula		2	Yes	Unburnt		Low	
Phebalium glandulosum subsp. *riparium*		2	Yes	Seedling/resprout		Moderate	
Phebalium squamulosum subsp. *argenteum*		1	Yes	Seedling		High	
Podolobium ilicifolium		3	Yes	Seedling/resprout		Moderate	
Pomaderris aurea		1	No			High	Yes
Pomaderris brunnea	Yes	1	Yes	Unburnt			
Pomaderris buchanensis		2	Yes	Seedling/resprout		High	
Pomaderris costata		1	Yes	Unburnt			
Pomaderris ligustrina subsp. *ligustrina*		2	Yes	Unburnt mature		Unburnt	
Pomaderris oblongifolia		3	Yes	Resprout		Moderate	
Poranthera corymbosa		1	No			High	Yes
Prostanthera incisa		1	Yes	Seedling/resprout		Moderate	
Prostanthera walteri		3	Yes	Seedling	No	High	Yes
Pultenaea subspicata		1	Yes	Seedling/resprout		Moderate	
Pultenaea vrolandii		1	Yes	Resprout		High	
Spyridium cinereum		3	No			High	Yes

Table 40. Orchids—terrestrial (see explanatory text before Table 38)

Species name	EPBC listed	Sites searched	Plants found	Seedling or resprout	Flowering	Fire severity	Further searches needed
Caladenia ancylosa		2	Yes	Resprout	Yes	Low	
Caladenia oreophila/fitzgeraldii?		1	Yes	Resprout	Yes	High	
Caladenia peisleyi		1	Yes	Resprout	Yes	High	
Caladenia tessellata		5	Yes	Resprout	Yes	High	
Calochilus pulchellus		1	Yes	Resprout	Yes	High	
Corunastylis pumila		2	Yes	Resprout	Yes	burnt	
Glossodia minor		4	Yes	Resprout	Yes	High	
Prasophyllum appendiculatum		6	Yes	Resprout	Yes	High	
Prasophyllum parviflorum		3	Yes	Resprout		High	
Prasophyllum patens (= sp. aff. *odoratum* L)		2	Yes	Resprout	Yes	Moderate	
Prasophyllum sp. aff. *odoratum* I		4	No			Low	Yes
Prasophyllum odoratum		2	Yes	Resprout	Yes		
Pterostylis acuminata		2	Yes	Resprout		High	
Pterostylis pedoglossa		1	Yes	Resprout	Yes	Burnt	
Pterostylis alveata		1	Yes	Resprout	Yes	Moderate	
Pterostylis tunstallii		5	Yes	Resprout		Moderate	
Thelymitra incurva		6	Yes	Resprout		High	
Thelymitra longiloba		3	Yes	Resprout	Yes	High	
Thelymitra malvina		5	Yes	Resprout	Yes	High	
Thelymitra matthewsii		2	Yes	Resprout		Burnt	

Table 41. Orchids—epiphytic (see explanatory text before Table 38)

Species name	EPBC listed	Sites searched	Plants found	Seedling or resprout	Flowering	Fire severity	Further searches needed
Dendrobium speciosum		5	Yes (most killed)	Resprout	No	High	Yes
Dendrobium striolatum		3	Yes (most killed)	Resprout	No	High	Yes
Plectorrhiza tridentata		4	Yes	Resprout	No	Low	Yes
Sarcochilus australis		2	Yes	Unburnt?	No	Low	Yes

Table 42. Forbs—perennial (see explanatory text before Table 38)

Species name	EPBC listed	Sites searched	Plants found	Seedling or resprout	Flowering	Fire severity	Further searches needed
Brachyscome salkiniae		5	Yes	Resprout	Yes	Low	
Brachyscome riparia		1	Yes	Unburnt	Yes		
Brunoniella pumilio		3	Yes	Resprout	Yes	High	
Goodenia bellidifolia subsp. *bellidifolia*		1	No			Moderate	Yes
Goodenia heterophylla subsp. *heterophylla*		1	Yes	Seedling	Yes	High	Yes
Goodenia macmillanii		1	No			Moderate	
Goodenia stelligera		5	Yes	Resprout	Yes	High	
Haloragodendron baeuerlenii		2	Yes	Seedling		High	
Lobelia purpurascens		3	Yes	Resprout	Yes	Low	
Pelargonium helmsii		2	Yes	Seedling	Yes	High	
Schelhammera undulata		3	Yes	Resprout	Yes	High	
Scutellaria mollis		2	No			High	Yes
Stylidium laricifolium		1	Yes	Resprout, seedling	No	Low	
Viola improcera		2	Yes	Seedling		High	

Table 43. Forbs—annual (see explanatory text before Table 38)

Species name	EPBC listed	Sites searched	Plants found	Seedling or resprout	Flowering	Fire severity	Further searches needed
Actinotus forsythii		1	Yes	Seedling	Yes	High	
Chenopodium erosum		1	Yes	Seedling	Yes	High	
Irenepharsus magicus		1	Yes	Seedling	Yes	Low	

Table 44. Sedges and lilies (see explanatory text before Table 38)

Species name	EPBC listed	Sites searched	Plants found	Seedling or resprout	Flowering	Fire severity	Further searches needed
Lepidosperma limicola		2	Yes	Resprout	No	High	
Lepyrodia anarthria		1	No			High	Yes
Schoenus melanostachys		1	No			Low	
Sowerbaea juncea		6	Yes	Resprout	Yes	High	

Table 45. Ferns (see explanatory text before Table 38)

Species name	EPBC listed	Sites searched	Plants found	Seedling or resprout	Flowering	Fire severity	Further searches needed
Adiantum formosum		1	No			High	Yes
Lindsaea microphylla		1	No			High	Yes
Sticherus flabellatus var. *flabellatus*		1	Yes	Resprout		High	

Table 46. Trees (see explanatory text before Table 38)

Species name	EPBC listed	Sites searched	Plants found	Seedling or resprout	Flowering	Fire severity	Further searches needed
Alectryon subcinereus		1	Yes	Unburnt			Yes
Eucalyptus fraxinoides		1	Yes	Seedling/resprout		Moderate	
Eucalyptus glaucescens		1	Yes	Resprout		High	
Eucalyptus kybeanensis		1	Yes	Seedling/resprout	No	High	
Eucalyptus mitchelliana		1	Yes	Resprout		High	
Eucryphia moorei		1	Yes	Unburnt			

Risks

Pre-existing risks (i.e. before the bushfires)

The species that were targeted for this project were subject to several threatening processes prior to the bushfires of 2019–2020.

Previous fire regimes can affect the presence of threatened species' populations. Obligate seeder shrubs are vulnerable to decline if interfire intervals are shorter than the time to develop adequate seedbanks (Whelan 1995). Resprouter species can also decline with frequent or severe fires (Clarke et al. 2012). Given that some of the population records were recorded up to 40 years prior to the surveys, some populations may have disappeared prior to the bushfires if they had experienced inappropriate fire regimes, but this could not be confirmed. The National Recovery Plans for the EPBC-listed species Leafy Nematolepis and Genoa River Correa list frequent or severe fire as threatening processes (Carter and Walsh 2006c, 2010).

Prior to the bushfires, much of the vegetation in south-eastern Australia was under stress from drought and high temperatures (Godfree et al. 2021). Rainfall in the 3 years leading up to the bushfires was well below average in East Gippsland (BoM 2020). These dry conditions are likely to have affected the survival of individual plants, as well as the production of seeds needed for post-fire recruitment (Enright et al. 2015).

Numbers of Sambar Deer (*Cervus unicolor*) have increased in recent years, and they have a significant impact on ecosystems by rubbing and breaking shrubs and small trees, browsing and trampling, creating wallows, and interfering with post-fire regeneration (Menkhorst and Knight 2001; Peel et al. 2005; Davis et al. 2016). Consequently, "Reduction in biodiversity of native vegetation by Sambar (*Cervus unicolor*)" is listed as a threatening process under Victoria's FFG Act 1988 (DELWP 2016). Damage to Buff Hazelwood (*Symplocus thwaitseii*) by Sambar Deer was documented in the FFG Action Statement (DSE 2003).

The impacts of weeds on threatened species at a few sites have been noted for Genoa River Correa (Carter and Walsh 2010) and Buff Hazelwood (DSE 2003). Disturbance caused by timber harvesting may have interrupted the reproductive life cycles and persistence of some populations (Blair et al. 2016). Plants which occur near tracks may also have been damaged by roadworks (Carter and Walsh 2006a, 2006b).

Additional risks driven by the 2019–2020 bushfires

Threat assessments were made at 191 sites, and these showed that post-fire threats to individual plant populations were generally minor at the time of the assessment. The most common threats are presented in Table 47.

Deer activity was usually low or absent immediately around the sites assessed, although 15 sites had a moderate level of activity. These included sites for Elegant Daisy (*Brachyscome salkiniae*), Tangle Orchid, Green Wattle (*Acacia irrorata*) and Snowy River Pomaderris (*Pomaderris oblongifolia*). The first two species are unlikely to be affected because of their small stature (and note that the orchid was not found at the time), while Green Wattle is unlikely to be affected, given the abundance of plants regenerating (around 1000 plants in a 50 m by 10 m area). The Snowy River Pomaderris population was variably browsed, with some plants eaten to near ground level and others browsed but to approximately 1 m high. The only site with high deer activity was an unburnt site on the Snowy River where *Phebalium glandulosum* subsp*. riparium* was being severely grazed. This species is a member of the Rutaceae family, which includes some species [e.g. Shiny Nematolepis (*Nematolepis wilsonii*), Yellow-wood (*Acronychia oblongifolia*)] that are known to be preferentially browsed or damaged by deer (Peel et al. 2005; Murphy et al. 2006). As this site was just outside the fire scar, it is possible that it is acting as a refuge area for deer. Large fires can have a major impact on deer populations in forests (Forsyth et al. 2011, 2012). The low deer activity observed may thus reflect mortality from fire, but also the effectiveness of the post-fire aerial shooting program that was undertaken across eastern Victoria, with over 4300 deer culled (DELWP, unpubl. data). Nonetheless, as forest structure regains its suitability for these large browsing animals, populations are likely to increase again without ongoing control measures (see Section 7.3, Rainforest surveys).

European Rabbit (*Oryctolagus cuniculus*) activity was observed at a small number of sites, and Pig (*Sus scrofa*) activity was observed at three sites near Mount Elizabeth. A substantial amount of feral Horse (*Equus caballus*) activity was noted along roadsides on the Nunniong Plateau, albeit not in the sites. This is of great concern, given the damage feral Horses can inflict on ecosystems, especially in the eastern Victorian high country (Parks Victoria 2021).

Erosion was mostly low or not observed, although 28 sites had moderate severity (localised) erosion. Such erosion is expected, given the severity of the fires and the limited regeneration of the ground cover. One site for Weeping Boobialla (*Myoporum floribundum*) along the Snowy River had areas of soil movement down the steep, rocky slope, but much of this area is prone to such erosion, and there was no evidence that plants were being directly affected at the site.

Weeds were generally a minor component of the vegetation, and at most sites were absent or in low abundance (Table 47). High abundance of weeds was noted on a roadside near Buchan, a well-known site for *Acacia caerulescens*, and near the Buchan River – Snowy River confluence, a site that has been grazed in the past and is a known site for *Pomaderris buchanensis*. A moderate abundance of weeds was noted at five sites. These included sites for Genoa River Correa and the fern Black Stem (*Adiantum formosum*), neither of which were found at the time. Weeds observed at the study sites were all low-threat species, such as Spear Thistle (*Cirsium vulgare*) or Cat's-ear (*Hypochaeris radicata*), and are of little concern. Nonetheless, high-threat species such as Blackberry (*Rubus fruticosus* spp. agg.) were noted across the fire area, especially in damp vegetation types (see Section 7.3, Rainforest surveys), and are likely to be a problem for some plant populations, as they were after the 2009 fires (Tolsma et al. 2012). Blackberry can form a dense, impenetrable thicket (Richardson et al. 2007) and smother other vegetation.

Dense plant–plant competition (with the potential for less common species to be outcompeted) was observed at 14 sites, including two for Leafless Pink-bells (*Tetratheca subaphylla*) and a site for *Goodenia macmillanii*; neither species were found at these sites. These sites were in tall mixed forest, with dense regeneration of eucalypts from seed. Most sites with moderate competition were either in damp situations near rivers and streams or near roadsides, which also tend to have high moisture and nutrient availability due to road run-off.

Road or track work was identified as a potential threat to populations at 22 sites, as known populations were often in highly accessible locations near the forest edge. A possible *Phytophthora cinnamomi* infestation was noted at one site in heathland with a record of Gippsland Banksia (*Banksia croajingolensis*), a species that is likely to be prone to *P. cinnamomi*, but the Banksia was not found at the time of survey.

Table 47. Common threats in 191 sites, by estimated severity, where applicable (see key below table). Data for plant–plant competition and track or road work were presence/absence only.

Threat	High (H)	Moderate (M)	Low (L)	Not noted
Erosion	0	28	68	95
Deer	1	15	28	147
Weeds	2	5	54	130
Plant–plant competition	14			177
Track or road work	22			169

Erosion	H	Extensive and severe; affecting large area
	M	Obvious; severe local impact, but restricted to localised area
	L	Obvious but low impact; restricted to small localised areas
Deer	H	Many trees and shrubs ringbarked; wallows
	M	Scats; some obvious tracks, browsing, rubbing
	L	Some scats or a faint track
Weeds	H	Obvious; high cover; large proportion contributed by high-threat weeds
	M	Obvious without active searching; high-threat weeds may be present
	L	Cover very low; not obvious without active searching; no high-threat weeds.

Additional risks driven by the 2019–2020 bushfires

The greatest threat to many populations is another fire before plants can reach viable reproductive maturity and replenish the soil seedbank. An Australia-wide analysis of fire history data from 1969 to 2020 and of the response traits of species affected by the 2019–2020 bushfires predicted that several hundred species are at risk of decline from subsequent fires (Gallagher et al. 2021).

Several life forms are at particular risk in the aftermath of the 2019–2020 bushfires. Obligate seeder woody plants will decline if frequent fires kill individuals and their seedbanks are depleted. Epiphytes such as

Dendrobium and *Plectorrhiza* are also vulnerable, because they lack a seedbank and are killed by fire (Godfree et al. 2021). Some species with the capacity to resprout might not persist if repeated fires create conditions outside their environmental tolerances.

Warmer and drier climatic conditions will drive more frequent and severe fires. These climatic conditions are also likely to result in woody plants producing fewer seeds and taking longer to reach reproductive maturity, as well as having lower seedling survival (Enright et al. 2015). The interaction of these processes is predicted to threaten the persistence of some species' populations (Enright et al. 2015).

For further information on threats to vegetation types and rainforests, refer to Sections 7.2 and 7.3.

Future directions

Insights gained from this project can assist fire planners and land managers to protect threatened plant species as they recover from the 2019–2020 bushfires. Further monitoring would fill knowledge gaps about the responses of threatened species to fire and their reproductive maturity periods, as these have not been confirmed for many species. The data from the recommended monitoring could then be included in DELWP's Vital Attributes database, to inform the timing of planned burning.

Threatened species' populations affected by the 2019–2020 fires should be protected from fire or other disturbances until all individuals have reached a life-stage that will allow survival or regeneration. Priority species are those that are fire-sensitive (obligate seeders with long reproductive maturity periods and short-lived seeds, or resprouters with short-lived seeds that are killed by severe fire) and which occur at sites where fire occurred less than around 10 years prior to the 2019–2020 bushfires. Spatial analysis of DELWP's fire history datasets is needed for species listed as threatened and those that are potentially at risk of decline.

Continuation of the deer control program, that started soon after the bushfires, is essential to protect threatened plants as they regenerate and become established.

Off-site conservation, involving seed collection, propagation, and replanting, may be needed for some endangered species.

Acknowledgements

This project was funded by the Victorian Government's Bushfire Biodiversity Response and Recovery program and the Australian Government Bushfire Recovery Package for Wildlife and Their Habitat.

We gratefully acknowledge the significant contributions to threatened plant locations and post-fire vegetation recovery by Gary Backhouse (https://bushorchids.weebly.com) and James Turner (Bairnsdale Field Naturalists).

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7.2 Vegetation types: Seven Ecological Vegetation Classes

Prepared by Annette Muir, Arn Tolsma and Judy Downe (ARI–DELWP)

Summary of key findings

Plant quadrat surveys were undertaken in seven Ecological Vegetation Classes (EVCs) in eastern Victoria to assess post-fire regeneration. Vegetation structure was greatly affected by high fire severity at most sites, and the rate of recovery varied by EVC.

At 9–10 months' post-fire, tree canopy cover in severely burnt forests remained at only 5–10%, and shrub cover was largely absent.

In contrast, the ground-layer vegetation generally showed strong recovery. The shrub layer in heathlands was recovering much faster than that in forests, reflecting its adaptions to more frequent fire. Resprouting species outnumbered reseeding species in all EVCs, as is typical of many Australian vegetation types.

Regeneration in all vegetation types was dominated by resprouter species.

Background

The 2019–2020 bushfires had the greatest impact on coastal and near-coastal bioregions of south-eastern Australia, which support large areas of eucalypt forests and heathlands (Godfree et al. 2021). Across these bushfire-affected areas, 62% of eucalypt-dominated vegetation and 14% of heath and shrublands were burnt (Gallagher et al. 2021).

In Victoria, over 1.5 million hectares were burnt, much of it at high severity (DELWP 2020a). Nine Ecological Vegetation Classes (EVCs) had greater than 50% of their modelled range within the fire extent (DELWP 2020a).

Although many of the species comprising this vegetation are fire adapted, the scale and severity of the bushfires will have varying levels of effect on the recovery of the vegetation communities. The aim of this project was therefore to assess the initial recovery in a range of vegetation types.

Methods

Locations surveyed

Survey sites were located within the extent of the 2019–2020 bushfires in eastern Victoria on public land (state forests, national parks, etc). The study area extended approximately north and east of Orbost, East Gippsland (Figure 86).

Survey methods

Floristic quadrats were assessed opportunistically by the ARI–DELWP while looking for threatened species' populations (see Section 7.1) and while assessing specific vegetation types, provided there were sufficient proportions of identifiable species at the site. These surveys were carried out at 26 of the threatened species' sites in seven different EVCs, in October and November 2020. The methods used in these surveys are outlined in Section 7.1. These sites were representative of commonly occurring EVCs, especially in the lower elevations of the fire-affected area. Nonetheless, EVC allocation was a 'best fit' only, due to the early recovery state of the vegetation, which made classification difficult. Between 21% and 84% of the total areas of these EVCs occurred within the extent of the 2019–2020 bushfires (DELWP 2020a, Table 48).

Warm Temperate Rainforest and Gallery Rainforest had 89% and 78%, respectively, of their areas impacted by the bushfires (DELWP 2020a). Accordingly, quadrat surveys and post-fire recovery assessments were also undertaken in rainforests, and the results are described separately in Section 7.3. Similarly, quadrat surveys were undertaken in Limestone Pomaderris Shrubland and are reported separately in Section 7.4.

Note that this report does not cover all bushfire-affected areas, so some vegetation types significantly affected by the 2019–2020 bushfires were not sampled. These included Damp Forest, the montane woodland and forests EVCs, and Sub-alpine Wet Heathland (DELWP 2020a).

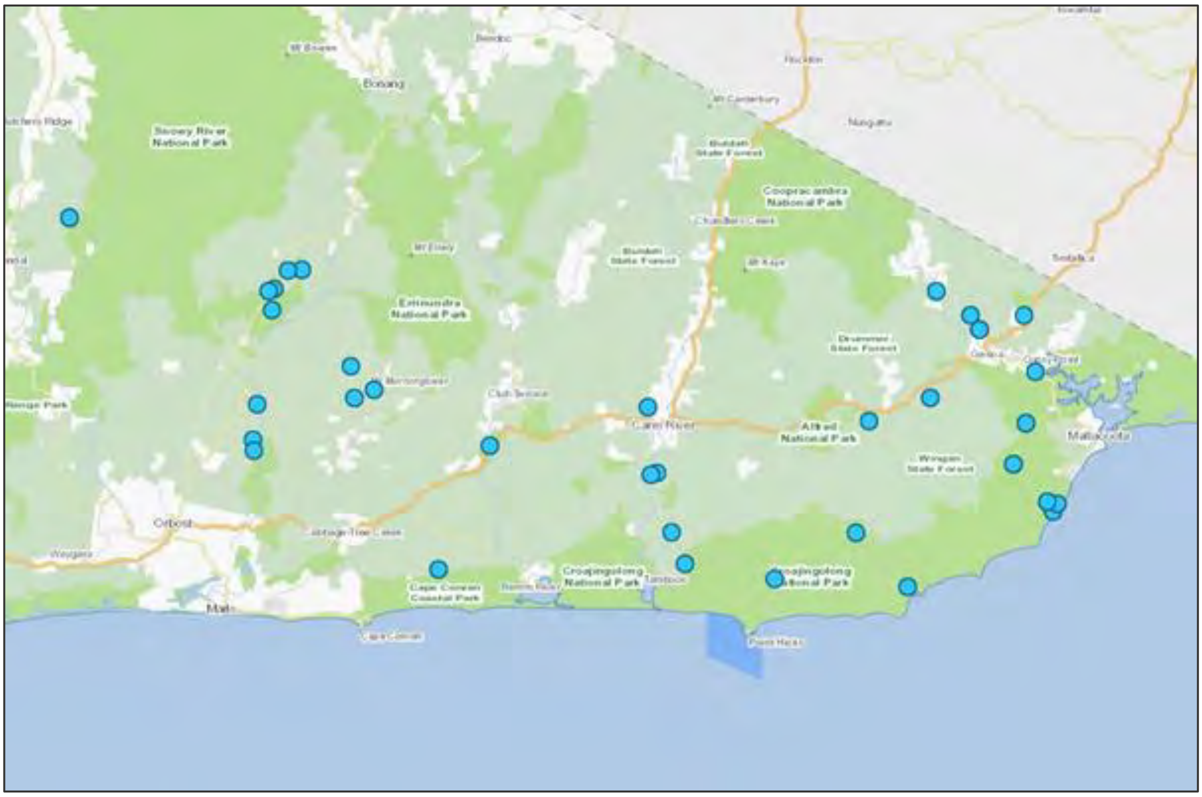

Figure 86. Locations of floristic quadrat surveys. All were within the 2019–2020 bushfires extent.

Table 48. Ecological Vegetation Classes surveyed, and percentage area within the bushfire extent [source: DELWP (2020) *Victoria's bushfire emergency: biodiversity response and recovery*, August 2020]

Ecological Vegetation Classes surveyed in this project	Total hectares within bushfire extent	Percentage of total EVC area within bushfire extent
Shrubby Dry Forest	294,303	37
Lowland Forest	216,438	40
Banksia Woodland	33,107	84
Sub-alpine Woodland	24,180	21
Riparian vegetation classes	12,720	43
Wet Heathland	8,970	31
Clay Heathland	1,869	58

Results

Fire response

Vegetation structure was greatly affected by the bushfires of 2019–2020, with large reductions in the biomass of the canopy, shrub and ground layers. Almost all vegetation targeted for sampling in October and November 2020 had been burnt at high severity (defined as >50% of the canopy consumed, or >80% of the canopy scorched). A few survey sites had experienced fire at moderate (20–80% scorched canopy) or low (>80% unburnt canopy) severities, reflecting local variations in intensity.

Tree canopy cover was mostly low, with only 5–10% foliage cover remaining at sites burnt at high severity. At sites burnt at low to moderate severity, the tree canopy cover ranged between 20 and 30%. At ground level, the cover of regenerating plants and ground parameters varied greatly from site to site, but ground parameters such as leaf and twig litter were much lower (0–40% cover) than in unburnt forest across all sites. The shrub layer in burnt forest was largely absent because regenerating species were still low in height. These are typical structural changes post-fire (Cheal 2010), and the cover of trees, shrubs and ground layer vegetation will increase over time, with the rate of recovery varying by vegetation type.

Ten months after the bushfires, the vegetation was growing vigorously in many areas. Such growth was due to an increase in the availability of soil nutrients, light and soil moisture (Cheal 2010). Most growth was in the understorey layer, and about two-thirds to three-quarters of species detected in the floristic surveys were resprouting (Table 49). This is typical across Australia, where overall the proportion of species with the capacity to resprout after fire is reported to be greater than 60% (Clarke et al. 2015).

The forests, woodlands and heathlands that were sampled were at a juvenile growth stage, with many plant species still being reproductively immature. In the mixed eucalypt forests, trees were covered in epicormic regrowth. Herbaceous species were abundant and regenerating more quickly than woody species, as expected. Herbaceous species were also flowering, whereas most shrubs had not yet reached this stage, except for some resprouting species.

Changes in floristic composition could not be measured, because either data from before the fires were not available or quadrat locations were not accurate enough. Nonetheless, the fires have provided an opportunity for some species to regenerate vigorously, while others will take longer to recover. Valuable data could be obtained from further monitoring, which should be considered.

Table 49. Ecological Vegetation Classes: representation of floristic quadrats surveyed, fire severity, and regeneration modes of plant species
(Rainforest vegetation and Pomaderris shrubland are covered in Sections 7.3 and 7.4)

Ecological Vegetation Classes surveyed in this project	Quadrats (*n*)	High fire severity (%)	Resprouters (%)	Seeders (%)
Shrubby Dry Forest	2	100	75	25
Lowland Forest	7	60	71	29
Banksia Woodland	4	50	69	31
Sub-alpine Woodland	4	100	70	30
Riparian Shrubland	3	100	64	36
Wet Heathland	4	100	68	32
Clay Heathland	2	100	75	25

Ecological Vegetation Classes

This section briefly describes the post-fire responses of each of the EVCs when they were surveyed at 9–10 months after the bushfires.

Shrubby Dry Forest – This vegetation type occurs on exposed ridge-lines and upper slopes, in high rainfall areas and on shallow infertile soils. It is characterised by an open forest to 25 m tall with a diversity of eucalypts, a well-developed medium to low shrub layer, and a sparse ground layer dominated by tussock-forming graminoids (DSE 2004).

At the time of the survey, Shrubby Dry Forest eucalypts were covered in epicormic regrowth, and there was dense eucalypt seedling germination at some sites. Tree canopy coverage was dependent on the fire severity experienced. Generally, less than a third of the ground surface was covered by regenerating shrub and herbaceous species, with the level depending on fire severity and terrain. Most of the regenerating understorey plants were resprouting (Figure 87).

Figure 87. Shrubby Dry Forest, north of Orbost, October 2020

Lowland Forest – This occurs on relatively fertile, moderately well-drained soils in areas of relatively high rainfall. It is a mixed eucalypt forest to 25 m tall, characterised by the diversity of life forms and species in the understorey, including a range of shrubs, grasses and herbs (DSE 2004).

At the time of the survey, the eucalypts were covered in epicormic regrowth, and there was dense seedling germination at some sites. The tree canopy coverage was dependent on the fire severity experienced. About a third of the ground surface was covered in regenerating shrub and herbaceous species, and most of these plants were resprouting (Figure 88).

Figure 88. Lowland Forest, north-east of Genoa, October 2020

<u>*Banksia Woodland*</u> – This vegetation type occurs on well-drained Quaternary and Tertiary sandy soils. It comprises an open scrub to open woodland to 10 m tall, with the overstorey dominated by Saw Banksia (*Banksia serrata*), sometimes with emergent eucalypts, and a shrub-rich understorey (DSE 2004).

Saw Banksias and eucalypts were regenerating both by resprouting from their trunks and by seedling germination. Regrowth of shrub and herbaceous species covered about a third of the ground and was dominated by resprouters (Figure 89). Anecdotal evidence suggests that a large proportion of Banksia Woodland in Victoria was already in poor condition prior to the fires, possibly due to long-term drought conditions, although the degree to which this would have affected recovery could not be determined by simple reconnaissance surveys. Given that 84% of this EVC was potentially burnt in 2019–2020, post-fire monitoring and fire protection might be critical steps to help secure the future of this vegetation type.

Figure 89. Banksia Woodland, Mallacoota, October 2020

Sub-alpine Woodland – This vegetation type occurs on a range of geologies and aspects, at elevations above around 1200 m (DSE 2004). It is normally a low, open woodland to 10 m tall dominated by Snow Gum (*Eucalyptus pauciflora*), with an understorey that can be variously grassy/herbaceous or densely shrubby (DSE 2004). However, at the study sites, it formed a low, Mallee-type scrub along a dry exposed ridge, with Snow Gum becoming codominant with Mallee Ash (*Eucalyptus kybeanensis*) or other eucalypt species.

Both Snow Gum and Mallee Ash were regenerating from lignotubers, and through tiny seedlings that were only around 2 cm tall at the time of the survey. As in other EVCs, the proportion of resprouters was high (70%), and seedlings that were present were small and barely identifiable. Indeed, fire severity had been high at the study sites, and the total foliage cover of understorey vegetation over the rocky ground was no more than a few percent.

Riparian Shrubland – This vegetation type occurs on rocky substrates along major streams, and on banks and channels of rocky creeks and in gorges. It consists of a diverse, medium to tall shrubland to 8 m tall, often forming dense thickets along the stream's edge, with irregularly scattered trees, sedges and rushes dominating the understorey, as well as an array of herbs and grasses, including many ephemeral species (DSE 2004).

Between 20 and 40% of the ground was covered by shrubs and herbaceous species resprouting or growing from seed. This cover varied depending on fire severity and the local site conditions, with drier rocky sites having sparser regrowth (Figure 90).

Figure 90. Riparian Shrubland, Genoa River, October 2020

Wet Heathland – Wet heathland occurs on flats or depressions that are infertile and subjected to prolonged waterlogging. It is a low, generally treeless heathland, with the understorey dominated by a range of sedges, grasses and shrubs, and Grass Tree (*Xanthorrhoea resinosa*) is often prominent (DSE 2004).

A high proportion of the ground was covered by regenerating plants. There was strong regrowth of resprouting rhizomatous sedges dominating the ground layer. Grass Trees were visually prominent because of mass flowering stimulated by fire. Crimson Bottlebrush (*Callistemon citrinus*) and Scented Paperbark (*Melaleuca squarrosa*) were vigorously resprouting, the former in vivid flower (Figure 91).

Figure 91. Wet Heathland, west of Bemm River, north-east of Genoa, October 2020

Clay Heathland – This occurs on sites with impeded drainage, often on duplex soils. It is dominated by heathy shrub species with or without a eucalypt overstorey, and the ground layer is dense and diverse with a variety of life forms (DSE 2004).

There was a strong growth of resprouting species, typically covering about 50% of the ground. Swamp She-oak (*Allocasuarina paludosa*) was the most common resprouting shrub. Lilies and herbaceous plants were also prominent, many in flower already (Figure 92).

Figure 92. Clay Heathland, Mallacoota, October 2020

Risks

Pre-existing risks (i.e. before the bushfires)

The forests, woodlands, shrublands and heathlands that were the focus of this project in Victoria had between 10 and 33% of their extent burnt in the 20 years prior to the 2019–2020 bushfires (Table 1, Table 50, DELWP 2020a). This has implications for obligate seeders with long reproductive maturity periods and short-lived seeds, and for resprouters that are killed by severe fire and have short-lived seeds. Such species are particularly sensitive to fire, to the extent that they drive the minimum Tolerable Fire Intervals for fire planning purposes in Victoria. Such minimum fire intervals are assigned to broad vegetation types (Table 50; Cheal 2010), to ensure that the most fire-sensitive plant species can grow to a stage where they can tolerate a subsequent fire. However, given previous fires, some sensitive plant species may already have declined, with a consequent impact on the composition and structure of vegetation communities at some locations.

Hotter, drier climatic conditions would also have affected the condition of the vegetation. Rainfall deciles in the 3 years before the East Gippsland bushfires were the lowest on record (BoM 2021), and drought and very high temperatures had been experienced across south-eastern Australia leading up to the bushfires (Godfree et al. 2021). Canopy dieback had been recorded across south-eastern Australian (Godfree et al. 2021), and vegetation in East Gippsland would have been under water and heat stress prior to the fires.

Sambar (*Cervus unicolor*) and other deer species have increased in recent years, and they have a significant impact on ecosystems, by rubbing and breaking woody plants, browsing and trampling, creating wallows, and interfering with regeneration (Menkhorst and Knight 2001; Peel et al. 2005; Davis et al. 2016). The Victorian Deer Control Strategy (DELWP 2020b) recognises the widespread and rapid increase in wild deer across the state since the last century, and the significant impacts deer have on the environment and biodiversity.

Table 50. Ecological Vegetation Classes and minimum Tolerable Fire Intervals
Sources: DELWP 2020a—fire history from DELWP datasets; Cheal 2010—Tolerable Fire Intervals defined for Ecological Fire Groups

Ecological Vegetation Class (EVCs)	Minimum Tolerable Fire Interval (high severity)	Minimum Tolerable Fire Interval (low severity)	Percentage of total EVC extent impacted by bushfires in 20 years prior to 2019–2020 bushfires
Shrubby Dry Forest	15 years	10 years	33
Lowland Forest	25 years	8 years	?
Banksia Woodland	12 years	8 years	14
Riparian Scrub	20 years	15 years	10
Sub-alpine Woodland	50 years	35 years	?
Wet Heathland	12 years	8 years	15
Clay Heathland	12 years	8 years	24

Additional risks driven by the 2019–2020 bushfires

The scale and intensity of the 2019–2020 bushfires has caused a temporary simplification of vegetation structure over a huge geographic area. This will have had an immediate effect on habitat structure and resource availability for animals (DELWP 2020a). As the vegetation grows back, the redevelopment of structural elements will depend on the severity of fire experienced in different areas. A study 2 years after the large 2009 bushfires in Victoria found that severely burnt forests had sparser tree canopy covers and denser covers of eucalypt saplings compared with unburnt areas, but there was heterogeneity in vegetation structure at the landscape scale (Bassett et al. 2017). High-severity fires may also cause simplified forest structures through increased mortality of trees of certain ages (Bennett et al. 2016). In eucalypt forests and heathlands that have evolved with frequent fire, floristic composition within a few years is not expected to be very different to that prior to the fires (Cheal 2010), although the relative biomass of species will be changed. However, species composition may be affected in areas where the fire intervals are too short, and lead to a decline in the abundance of some woody species (Bradstock et al. 1997; Enright et al. 2011). The seedlings and young plants regenerating in areas within the extent of the 2019–2020 bushfires are vulnerable if fire, or other disturbances such as timber harvesting, were to occur again in the next few years.

Climate change poses one of the greatest long-term threats to the extent and condition of many ecosystems globally, both through its effects on direct drivers of species occupancy and its interactions with other threats, particularly fire (Enright et al. 2015) (also see Section 7.3). Australia is already experiencing reductions in autumn and winter rainfall and increased mean temperatures (BoM and CSIRO 2018). This is likely to be particularly deleterious to a range of fire-sensitive species, especially woody obligate seeders, which could lead to simplification of the composition of plant communities. Banksia Woodland, anecdotally in poor condition prior to the fires, may be particularly susceptible to increased fire and drought.

In general, post-fire recovery at 10 months is as would be expected, given the severity of the fires. However, ongoing monitoring is recommended to enable existing and future threats to be addressed in a timely manner.

Acknowledgements

This project was funded by the Victorian Government's Bushfire Biodiversity Response and Recovery program and the Australian Government's Bushfire Recovery Package for Wildlife and Their Habitat.

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7.3 Rainforest surveys

Prepared by Arn Tolsma (ARI–DELWP)

Summary of bushfire impacts

Rainforests are remnants of the oldest extant vegetation in Australia and provide significant benefits to the natural environment, including plant and animal diversity, carbon storage, and water catchment values. However, they are sensitive to high-intensity fire, which is likely to occur more often in a warming, drying climate, with implications for their future distribution.

Spatial analysis showed that 6317 ha of rainforest was burnt at high severity during the 2019–2020 bushfires, representing approximately 18% of the total area of rainforest in Victoria. Some stands may now have burnt twice in recent decades. Therefore, the aim of this project was to determine the potential effects of the fires on different rainforest types in eastern Victoria, their recovery state and condition, and the major risks to rainforest in the post-fire period.

Summary of key findings

Comprehensive floristic surveys were undertaken in 13 rainforest sites.

Recovery of rainforest structure and species composition is strongly related to local fire severity.

The opening up of the canopy by fire has led to prolific germination of soil-stored seed. The understorey composition is currently very different to that of unburnt rainforest, and is dominated by short-lived species that are substantially less common in unburnt rainforest.

Recruitment of eucalypts into rainforest stands may lead to long-term changes in forest structure.

Observed threats to rainforest condition included deer activity, alteration of the canopy due to invasion by eucalypt species, weeds, and gully erosion. However, the greatest long-term threat to the remaining stands of rainforest is climate change, which may act directly through reduced rainfall, or indirectly through increases in the frequency and intensity of fire.

Background

Rainforests are threatened ecological communities that provide significant benefits to the natural environment, contributing to plant and animal diversity, carbon storage, and water catchment values (Lindenmayer et al. 2011; Riddington 2014). They are the remnants of the oldest extant vegetation type in Australia, which in the Cretaceous or early Tertiary dominated most of the continent (Busby 1992; Kershaw 1992). Following the break-up of the supercontinent Gondwana, the opening up of rainforest accelerated as rainfall decreased and became more variable, and about 2.7 million years ago, with a switch from a summer to a winter rainfall regime, rainforest became increasingly restricted to protected, moist areas (Kershaw 1992). Further decreases in rainforest extent within the last glacial–interglacial period appear to have corresponded with the arrival of aboriginal people and the development of more flammable vegetation (Kershaw 1992). BIOCLIM analysis has suggested that only around 1% of the Australian continent is now climatically suited to rainforest (Busby 1992), and this proportion is likely to be decreasing due to climate change.

Despite being called ‘rainforest’, rain is not the overarching driver of its distribution; rather, fire is the most potent factor that determines its distribution over a broad scale, especially in Victoria, while factors such as climate tend to operate at finer scales (Busby 1992; Cameron 1992). Climate change is predicted to increase fire frequency and severity, with implications for the future distribution of rainforest. Mature, closed rainforest can be reasonably resistant to low-intensity fire (Melick and Ashton 1991; Barker 1992; Busby and Brown 1994; Baker et al. 2012; Knox and Clarke 2012), but can rapidly revert to a more flammable, eucalypt-dominated forest type after being exposed to high-intensity fire (Chesterfield et al. 1990; Tolsma et al. 2019), and with a warmer climate the long-term future of rainforest is under threat.

The restricted distribution of rainforests and long-term threats are reflected in their conservation status. Eight types of rainforest community are officially listed as threatened under Victoria’s *Flora and Fauna Guarantee Act 1988* (FFG Act) (DELWP 2018), and another is listed as Critically Endangered under the Commonwealth’s *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) (DEWHA 2009) (Table 51). However, mapping of rainforest in Victoria tends to be at a broad classification level rather than a finer community level, and many listed communities, especially warm temperate types, are not individually mapped (Table 51). Cool Temperate Mixed Forest is difficult to reliably identify in aerial photographs (White et al. 2019) and is currently mapped as part of the generic Wet Forest (non-rainforest) unit. Conversely, Gallery Rainforest is mapped but not listed as a separate entity (Table 51). For practical purposes, given that broad-mapped units do not always align with the listed communities, this report will focus only on broad-mapped units for which the distribution is known.

A large proportion of the rainforest in eastern Victoria was potentially burnt at high severity in the fires of 2019–2020 (Table 51, Figure 93) (DELWP 2020), which is of great concern given the sensitivity of many rainforest species to fire and the strong influence of fire on rainforest distribution. Protection of burnt rainforest stands against post-fire threats may be critical if they are to persist in the landscape in the future. Therefore, the aim of this project was to investigate the potential effects of the 2019–2020 fires on rainforest stands in eastern Victoria, their recovery state and condition, and the major risks to rainforest in the post-fire recovery period.

Table 51. Types of rainforest in Victoria, their listed status, mapped area and proportion burnt at high severity in 2019–2020 (DELWP 2020)
*Data for Cool Temperate and Littoral Rainforest are from White et al. (2019) and fire modelling is as at 10 March 2020 (DELWP, unpubl. data).

Rainforest community	FFG status	EPBC status	Broad mapping unit	Total area mapped in Victoria (ha)	Area of this broad type burnt at high severity in 2019–2020 (ha)	Burnt area as percentage of all rainforest of this type in Victoria
Cool Temperate Rainforest	Listed		*Cool Temperate Rainforest	17,033	662	4%
Cool Temperate Mixed Forest	Listed		Part of Wet Forest (non-rainforest)	Not available	Not available	Not available
Dry Rainforest (Limestone)	Listed		Dry Rainforest	54	8	14%
Gallery Rainforest			Gallery Rainforest	348	146	42%
Littoral Rainforest and Coastal Vine Thickets of Eastern Australia		Critically Endangered	*Littoral Rainforest	48	2	4%
Strzeleckis Warm Temperate Rainforest	Listed		Warm Temperate Rainforest	16,663	5,499	33%
Warm Temperate Rainforest (Coastal East Gippsland)	Listed					
Warm Temperate Rainforest (Cool Temperate Overlap, Howe Range)	Listed					
Warm Temperate Rainforest (East Gippsland Alluvial Terraces)	Listed					
Warm Temperate Rainforest (Far East Gippsland)	Listed					
ALL RAINFOREST (excluding Cool Temperate Mixed)				**34,146**	**6,317**	**18%**

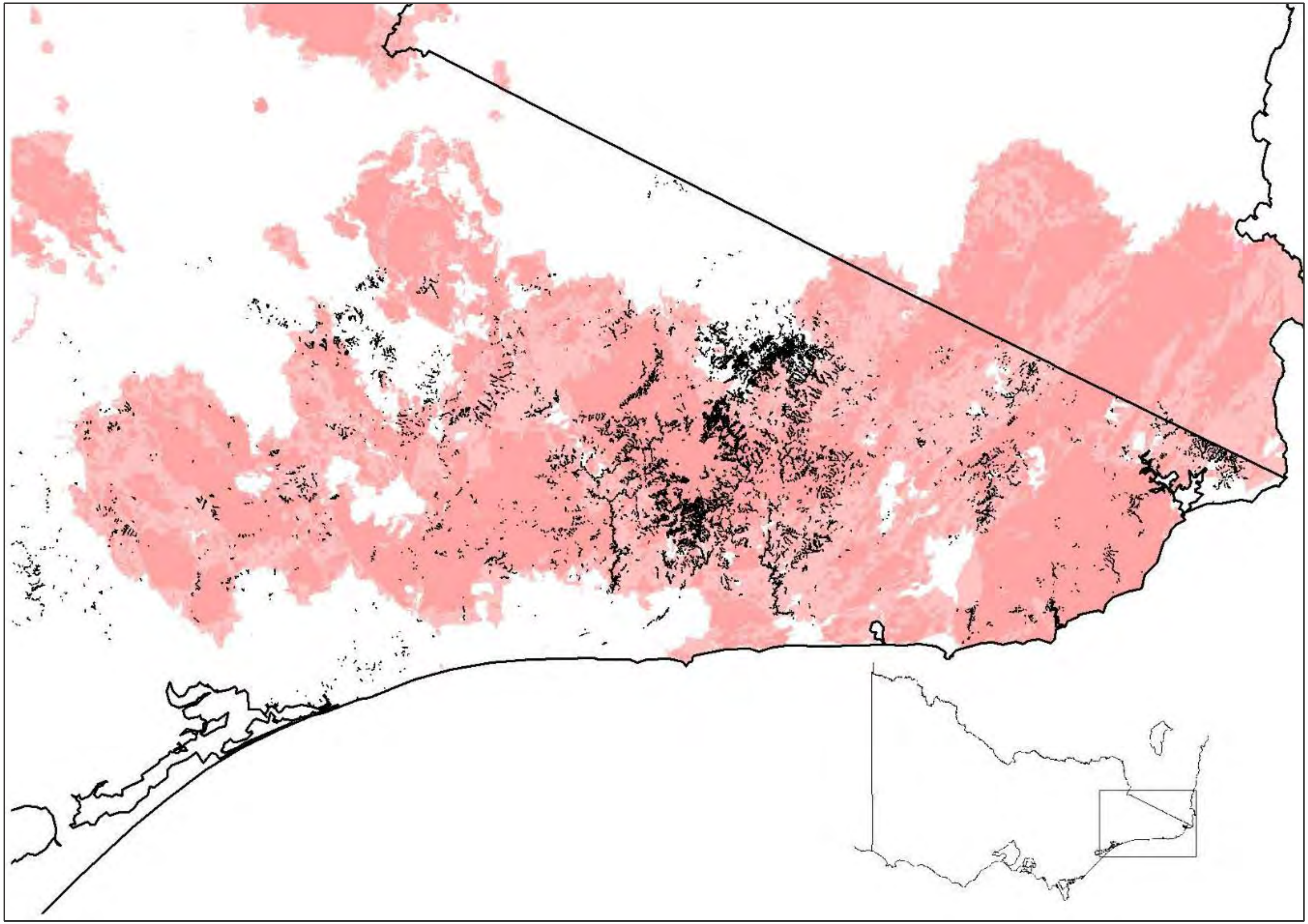

Figure 93. Rainforest in eastern Victoria (black patches) with respect to the 2019–2020 bushfire extent (pink areas). Darker pink shading signifies higher severity.

Methods

Locations surveyed

Comprehensive floristic surveys were undertaken in 13 burnt rainforest sites, located broadly between Orbost and Mallacoota (Figure 94). These included two surveys in Gallery Rainforest, three in Cool Temperate Rainforest and eight in Warm Temperate Rainforest, reflecting the proportionate occurrence of these main rainforest types in the fire area.

Figure 94. Rainforest sites surveyed in 2020 (red dots)

Survey methods

Mature, closed rainforest can be reasonably resistant to low-intensity fire (Melick and Ashton 1991; Barker 1992; Busby and Brown 1994; Baker et al. 2012; Knox and Clarke 2012). Thus, given that it was only possible to sample a small proportion of burnt rainforest stands, focus was placed on the areas predicted to have been burnt at high fire severity, under the assumption that these would be most impacted and at most risk. An existing high-resolution map of rainforest distribution (White et al. 2019) was overlain with fire-severity mapping (DELWP, unpubl. data, as of 10 March 2020) to extract the areas of rainforest identified as being burnt in the highest severity classes [crown scorched (Class 4) and crown burnt (Class 5)]. Patches larger than 10 ha were then extracted to identify important stands deemed to be of highest priority for assessment. Waypoints were generated for the approximate centres of sites that were reasonably accessible (<400 m from open tracks or roads), ensuring that these potential sites captured a cross-section of the broad rainforest mapping units within the fire area.

Field assessments of 13 priority sites were undertaken between October and December 2020 (Figure 94). Observers navigated their way to each site using a GPS and field maps. Observations were made of local fire severity, regeneration of both canopy and understorey species, and threats and potential risks to the rainforest stand, including establishment or encroachment of non-rainforest canopy species, browsing, other animal disturbance, erosion, and weed invasion. At each site, a floristic quadrat survey was conducted to characterise the vegetation at the site. An area of 20 m × 20 m (consistent with most VBA quadrats) was established in an area typical of the site. All vascular plant species rooted in or overhanging the quadrat, including canopy trees, were recorded, and their percentage overlapping cover (1%, 2%, then to nearest 5%)

was estimated. The cover of ground parameters such as bryophytes and bare ground was also recorded. Tree seedlings within a 4-m radius of the plot centre were identified and counted to ascertain the density of post-fire tree recruitment. The observers also estimated the distance from the plot centre to the nearest mature eucalypt that could have acted as a post-fire seed source.

All incidental and quadrat data were provided to the Victorian Biodiversity Atlas to supplement existing data and help refine habitat distribution models.

Results

A total of 6317 ha of rainforest was potentially burnt in the highest severity classes (crown scorched or crown burnt) during the 2019–2020 bushfires (Table 51, Figure 93), representing 18% of the total amount of rainforest in Victoria. Almost 90% of the rainforest burnt consisted of Warm Temperate Rainforest, with the area burnt (5499 ha) representing one-third of its total Victorian distribution. Gallery rainforest, virtually restricted to eastern Victoria, also had a high proportion burnt at high severity (42% of its total distribution). In contrast, only a small proportion (4%) of Cool Temperate Rainforest was burnt, as this type of rainforest has its highest representation in the Strzelecki Ranges, Otway Ranges and Central Highlands, rather than eastern Victoria.

Fire response

As expected, ferns were among the first forest plants to show signs of recovery after fire. In less than a year, fronds had regrown to mature size, and both Rough Tree-fern (*Cyathea australis*) and Soft Tree-fern (*Dicksonia antarctica*) visually dominated burnt slopes and rainforest gullies (Figure 95).

However, for most species, the rate and scale of rainforest vegetation recovery, both for canopy and understorey, were closely associated with the severity of the fire. When fire had been at moderate local severity, key rainforest canopy species such as Kanooka (*Tristaniopsis laurina*, in Gallery Rainforest), Lilly Pilly (*Syzygium smithii*, in Warm Temperate Rainforest) and Southern Sassafras (*Atherosperma moschatum*, in Cool Temperate Rainforest) were resprouting from epicormic buds on the trunks or branches, and regeneration of canopy cover was well underway (Figure 96a and c). In contrast, when fire had been at high local severity, resprouting in these canopy species was restricted to the very base of the trunk (Figure 96b and d) or was absent from some trees altogether. This suggests that mature trees were top-killed, and that re-establishment of rainforest canopy cover will depend on how long the resprouts or new seedlings take to grow to mature height. Tree architecture will also change for resprouting individuals, with single-stemmed trees becoming multistemmed trees.

The opening up of the canopy by fire led to prolific germination of short-lived fire-responsive species from soil-stored seed, so the understorey layer was usually dominated by native species that are substantially less common in unburnt rainforest, including Indian Weed (*Sigesbeckia orientalis*), Kangaroo Apple (*Solanum aviculare*) and Incense Plant (*Calomeria amaranthoides*) (Figure 97a to c). Most of these short-lived perennials will die back within a few years and be replaced by a diversity of longer-lived but slower-growing understorey and overstorey species. This is an early example of the successional changes that will occur in burnt stands for decades until mature rainforest canopy and ecological processes are restored.

Figure 95. Tree-ferns in burnt rainforest gully

Some long-lived species also germinated in large numbers after the fires from soil- or canopy-stored seed. Tree seedlings were common in the sites assessed, especially of wattle species such as Silver Wattle (*Acacia dealbata*) and Blackwood (*Acacia melanoxylon*), but also of *Eucalyptus* species. The number of *Acacia* seedlings regenerating from soil-stored seed averaged 5400 per hectare (range 0–20,000), while the number of *Eucalyptus* seedlings averaged 1000 per hectare (range 0–4000). The number of *Eucalyptus* seedlings within a 4-m radius of the plot centre was negatively associated with the distance to a mature, pre-fire seed source, with higher numbers of seedlings when the seed source was closer (Figure 98). Recruitment of eucalypts into rainforest stands that were previously relatively eucalypt-free is of great concern, as eucalypts can convert rainforest to a more flammable mixed sclerophyll forest (see next subsection on risks and threats).

(a)

(b)

(c)

(d)

Figure 96. Resprouting of rainforest canopy species following low- to moderate-severity fire (left; a and c) or high-severity fire (right; b and d). a and b = Lilly Pilly; c and d = Southern Sassafras

(a)
(b)
(c)

Figure 97. Temporary domination of understorey by short-lived fire-responsive species. a = Indian Weed; b = Kangaroo Apple; c = Incense Plant

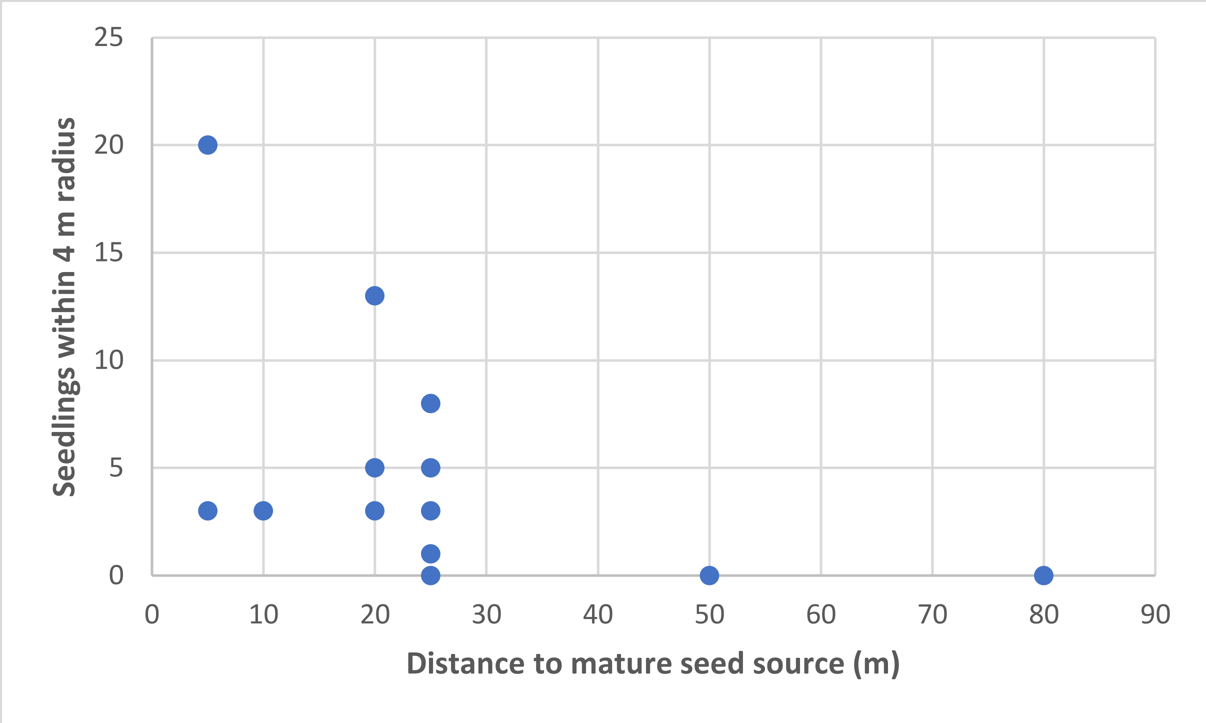

Figure 98. Number of eucalypt seedlings within a 4-m radius of the plot centre with respect to the distance to nearest mature (pre-fire) seed source

Risks

Pre-existing risks (i.e. before the bushfires)

The main pre-existing threat to rainforest condition, excluding climate change (see below), was activity by deer, especially Sambar Deer (*Cervus unicolor*). Sambar Deer were introduced into Victoria during the 1860s (Peel et al. 2005) and now have a large population throughout the mountain ranges of central to eastern Victoria (Parks Victoria 2002; Forsyth et al. 2009). Sambar Deer impact on native ecosystems, particularly rainforests and riparian zones, by rubbing and breaking shrubs and small trees, browsing and trampling, creating wallows, and interfering with post-fire regeneration (Menkhorst and Knight 2001; Peel et al. 2005; Davis et al. 2016). Consequently, "Reduction in biodiversity of native vegetation by Sambar (*Cervus unicolor*)" is listed as a threatening process under Victoria's FFG Act 1988 (DELWP 2016).

Large fires can have a major impact on deer populations. For example, Sambar Deer abundance in the Kinglake National Park (NP) was greatly reduced at 8 months after the 2009 fires (Forsyth et al. 2011, 2012), and although nearly all burnt habitat was reoccupied 16–24 months later, faecal pellet counts suggested that deer abundance was still much lower than in the unburnt habitat (Forsyth et al. 2011, 2012). Even in 2019, 10 years post-fire, rainforest survey plots in the nearby O'Shannassy Catchment had little obvious deer activity, except in areas where the understorey was relatively open and deer had easy access to defined streams (Tolsma et al. 2019).

Current surveys of rainforest in East Gippsland after the 2019–2020 fires also found only minor signs of deer activity. This may reflect mortality from fire, as well as the effectiveness of the aerial shooting program that was subsequently undertaken across eastern Victoria, with over 4300 deer culled across more than 200,000 ha (DELWP, unpubl. data). Nonetheless, as forest structure and habitat regain their suitability for these large browsing animals, populations are likely to increase again without ongoing control measures.

Additional risks driven by the 2019–2020 bushfires

<u>*Weeds*</u> – The opening up of the canopy has led to prolific germination of soil- and canopy-stored seed, including weed species. Fortunately, most weed species encountered in the 13 rainforest study sites in East Gippsland were ubiquitous, low-threat taxa such as Cat's-ear (*Hypochaeris radicata*) or Spear Thistle (*Cirsium vulgare*), which are of little concern. However, the high threat weed Blackberry (*Rubus fruticosus* spp. agg.) was present at 11 of the 13 sites, and Wandering Trad (*Tradescantia fluminensis*) occurred at two

sites. Blackberry was also considered a problem for threatened species and communities after the 2009 fires (Tolsma et al. 2012), as it can form a dense, impenetrable thicket (Richardson et al. 2007) and smother other vegetation. Some rainforest species may be unable to cope with the pressure of incursion by other species, introduced or not (Godfree et al. 2021).

Interestingly, high-threat weeds were not generally observed in sites assessed in drier vegetation types (see Section 7.1), suggesting that the edaphic conditions in rainforest make it particularly susceptible.

Pathogens – Myrtle Wilt, widespread in the Central Highlands and Otway Ranges, can have a severe impact on Myrtle Beech (*Nothofagus cunninghamii*) in Cool Temperate Rainforest (Packham and Kile 1992; Cameron and Turner 1996; Parks Victoria 2002). However, Myrtle Beech does not extend into the Cool Temperate Rainforests of East Gippsland, so Myrtle Wilt should not be a problem in the study area.

The root-rot fungus *Phytophthora cinnamomi* is able to attack many rainforest species, especially in disturbed forest (Busby and Brown 1994). Evidence of fungal attack was not observed in rainforest sites during the current surveys, but it remains a possibility given that it is present in the region, and that vast areas of rainforest have now been opened and disturbed.

Gully erosion – There was little obvious erosion at most of the sites assessed, suggesting that some protective covering of vegetation had been able to establish before any heavy rainfall occurred. One exception was a Gallery Rainforest site straddling a tributary of Martins Creek, where severe gully erosion (Figure 99) had led to partial damming of Martins Creek by stony debris. Gallery Rainforest is perhaps more susceptible to mass erosion because of its association with active streams.

Eucalypt invasion – Seedling recruitment by eucalypts can be high in severely burnt Warm Temperate Rainforest (Chesterfield et al. 1990) and Cool Temperate Rainforest (Worley 2012; Tolsma et al. 2019), and has the potential to drive long-lasting changes in overstorey composition and structure. Some stands of Warm Temperate Rainforest burnt at high severity in 1983 at Jones Creek, East Gippsland, have now transitioned to sclerophyll forest (Chesterfield et al. 1990). Similarly, nearly two-thirds of the Cool Temperate Rainforest in the O'Shannassy Catchment (Central Highlands, burnt at high severity in 2009) has been transformed more or less permanently into a different forest type dominated by sclerophyllous (and more fire-prone) eucalypt species rather than rainforest species (Tolsma et al. 2019).

Overstorey change is of most concern for smaller or linear rainforest patches, where edge effects are relatively high, as the rate of eucalypt seedling recruitment is known to be associated with distance from the rainforest edge (Cameron 1992; Tolsma et al. 2019). This was also observed in the current surveys, where the density of eucalypt seedlings was associated with the proximity to a mature (pre-fire) seed source. Successful growth of eucalypt seedlings after the 2019–2020 bushfires is likely to change the long-term overstorey structure of severely burnt rainforest stands in East Gippsland, especially small stands that may already be marginal. Barring another fire that kills the eucalypt saplings before they reach their viable reproductive maturity [for Ash species this is around 20 years (Flint and Fagg 2007)], the effect of eucalypt recruitment could last as long as the 300- to 400-year lifespan of the new tree cohort (Busby and Brown 1994; DNRE 1996; Flint and Fagg 2007).

Figure 99. Severe gully erosion in a narrow stand of Gallery Rainforest near Martins Creek

Given the predictions of increased fire frequency (see next section), further encroachment of eucalypts into already depleted rainforest appears almost inevitable, and it requires only one mature tree at the edge of the rainforest to act as a seed source. Eucalypts are predicted to increase with each successive fire in both Warm Temperate Rainforest (Chesterfield et al. 1990) and Cool Temperate Rainforest (Read 1992; Tolsma et al. 2019) until they eventually dominate, a feedback process known as a 'landscape trap' (Lindenmayer et al. 2011). Rainforests in regions such as north-eastern Victoria and parts of East Gippsland are likely to be more at risk than coastal areas such as the Otway Ranges or Wilsons Promontory NP, due to more pessimistic climate forecasts for those areas (Riddington 2014). Thus, while many primary rainforest species have some resistance to fire and could persist as components of mixed forest, the occurrence of 'pure' rainforest is likely to become increasingly restricted to stands in the wettest, most topographically protected parts of the landscape.

Climate change and increased fire – Climate change poses one of the greatest long-term threats to the extent and condition of many ecosystems globally, including rainforest, both through its effects on direct drivers of species occupancy and its interactions with other threats, particularly fire (Riddington 2014; Enright et al. 2015; Mariani et al. 2019; Godfree et al. 2021), and climate forecasts give little reason for optimism. Autumn and winter rainfall have reduced over south-eastern Australia, particularly in May to July, when rainfall has decreased by around 20% since 1970 (BoM and CSIRO 2018). Australia's mean temperature has increased by just over 1°C since 1910 with attendant increases in the frequency of extreme heat events and extreme fire weather and a lengthening of the fire season (BoM and CSIRO 2018). These changes are expected to continue, with predicted increases in the frequency of fire (Hennessy et al. 2005) and a reduction in climatically suitable areas for rainforest (Busby 1992; Riddington 2014).

Of the various rainforest types in Victoria, Cool Temperate Rainforest (including Cool Temperate Mixed Forest) is likely to be most affected by climate change, as rainfall by 2070 is predicted to fall below its climatic rainfall threshold, especially in areas away from the coast (Riddington 2014). Rainfall may also reduce below the climatic thresholds for key Cool Temperate Rainforest species such as Southern Sassafras, Myrtle Beech and Soft Tree-fern (Riddington 2014). Cool Temperate Rainforest depends greatly on its vegetation wetness and elevated humidity for fire protection (Riddington 2014), so it will also be increasingly subject to indirect climate change impacts through increased frequency of fire. Warm Temperate, Gallery and Dry Rainforests of eastern Victoria are likely to remain within the thresholds of their annual rainfall requirements (Riddington 2014), and impacts might be predominantly indirect through increased fire. Nonetheless, the Gallery Rainforest canopy species Kanooka has little physiological drought tolerance, either as an adult or seedling, helping explain its restricted distribution (Melick 1990), and such species may exhibit range contraction from a drier climate, even in the absence of fire.

Even if fires do not enter the core areas of rainforest, all fires in their vicinity have the potential to damage or destroy the rainforest buffers and margins, drying the forest and increasing the risk of subsequent fires penetrating further into the stand (Chesterfield et al. 1990; Cameron 1992; Read 1992). This can set up a self-perpetuating cycle of sclerophyll expansion and rainforest attrition, and place severe limitations on the ability of rainforests to expand again to occupy their climatically and edaphically determined niches (Chesterfield et al. 1990; Cameron 1992), and indeed the ability of rainforests to persist in anywhere near their current (already depleted) extent. Ongoing monitoring of eucalypt invasion may be a critical part of future rainforest management.

Acknowledgements

This project was funded by the Victorian Government's Bushfire Biodiversity Response and Recovery program and the Australian Government's Bushfire Recovery Package for Wildlife and Their Habitat.

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7.4 Limestone Pomaderris Shrubland

Prepared by Judy Downe (ARI–DELWP)

Summary of bushfire impacts

Silurian Limestone Pomaderris Shrubland community exists at only one site, at Marble Gully, in the Mount Tambo Nature Conservation Reserve (NCR), Tambo Valley, East Gippsland. This community was burnt by a high-severity bushfire in 2003, after not having been burnt in the previous 100 years, and there were fears that it might have been burnt again in 2019–2020. It was therefore opportune to repeat quadrat surveys undertaken previously in 2004, 2006 and mid-2019, to determine the resilience of this community to both fire and long-term drought.

Our surveys found that the 2019–2020 bushfires, fortunately, did not impact the Marble Gully Silurian Limestone Pomaderris Shrubland, with the nearest fire boundary approximately 500 m to the south.

Silurian Limestone Pomaderris Shrubland appears to be relatively resistant to a single fire, as most species recorded during broadscale surveys in 1993 were still present in the 2004, 2006 and 2020 surveys.

The community had previously been severely impacted by long-term drought, with substantial dieback of perennial shrubs and tussocks. However, most plants in 2020 showed signs of recovery in the form of new shoots, both basal and aerial. Growth is slow on these dry, rocky slopes, but it is anticipated that the vegetation structure will re-establish successfully provided the community is not subject to further severe disturbance in the coming years.

The serious environmental weed Horehound (*Marrubium vulgare*) was present at Marble Gully, but in smaller numbers than in previous years, suggesting that herbicide spraying has been largely effective. Similarly, Blackberry (*Rubus fruticosus* spp. agg.) was not found in 2020 despite being previously present, also indicating that past herbicide treatment had been successful.

The survey in 2020 indicated that the main impacts on vegetation condition have been caused by drought (mostly affecting the shrub and graminoid species) and deer (which have predominantly browsed on some tree and shrub species). Less deer activity was observed in 2020 compared with the level of activity observed in the 2019 surveys; however, this should be monitored, as deer were observed close to Marble Gully and may return quickly if alternative food sources decline.

Summary of key findings

The impact of long-term drought was still apparent in 2020, but most species have produced new shoots, both aerial and basal (resprouts), and are recovering.

Seedling regeneration was occurring for most species, suggesting that the community is self-replicating and has largely recovered from the 2003 fire.

Most species are reproductive (currently flowering or fruiting), suggesting the community may now have some regeneration capacity in the event of a future fire.

Browsing by deer in 2020 was minimal, possibly due to the high availability of food following good autumn rainfall, or post-fire control actions, but it may increase as deer populations grow again.

Weed competition was minimal, with Horehound being the only high-threat weed observed (but in low numbers).

Browsing by European Rabbits (*Oryctolagus cuniculus*) or European Brown Hares (*Lepus europaeus*) was minimal.

Silurian Limestone Pomaderris Shrubland appears to be relatively resilient to fire.

Background

Silurian Limestone Pomaderris Shrubland community occupies an area of 40 ha at Marble Gully in the Mount Tambo NCR, near Omeo, East Gippsland (Figure 100), where it occurs on steep exposed north-east to north-west facing slopes (DSE 1998).

It is listed as endangered under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and threatened under Victoria's *Flora and Fauna Guarantee Act 1988* (FFG Act) as it contains 11 threatened plant species, and three significant plant species with disjunct geographical distributions (Peel 1993) (Table 52). One species, *Olearia astroloba* (Marble Daisy-bush), is listed as vulnerable under both national and state legislation. Following the 2003 bushfire, post-fire recovery was considered good, with all dominant character species, including eight threatened species and two disjunct species, regenerating. Only three rare species (*Asplenium trichomanes* subsp. *quadrivalens, Desmodium varians* and *Pimelea pauciflora*) plus one disjunct species (*Isoetopsis graminifolia*) were not relocated (Downe and Coates 2004). In the 2006 survey, one threatened species (*Vittadenia tenuissima*) and one disjunct species (*Ptilotus spathulatus*) were not found (Downe 2007). The structure of the community was highly modified but, as most species were regenerating, it was anticipated that the vegetation structure would re-establish (Downe 2007). In 2019, identification of a species of spear-grass (*Austrostipa* sp.) could not be confirmed due to the timing of the survey (Downe 2019).

However, the survey carried out in mid-2019 indicated that there were substantial impacts on the vegetation condition from drought and browsing by deer. The drought mostly affected the shrub and graminoid species, and browsing was predominantly on tree and shrub species (Downe 2019). Given the condition of this community, there was concern that the 2019–2020 bushfires, which burnt close to Marble Gully, may have caused additional stresses on it. Field surveys were therefore undertaken to determine whether the 2019–2020 bushfires had impacted on the community, and to gauge its ability to recover in the face of multiple stressors.

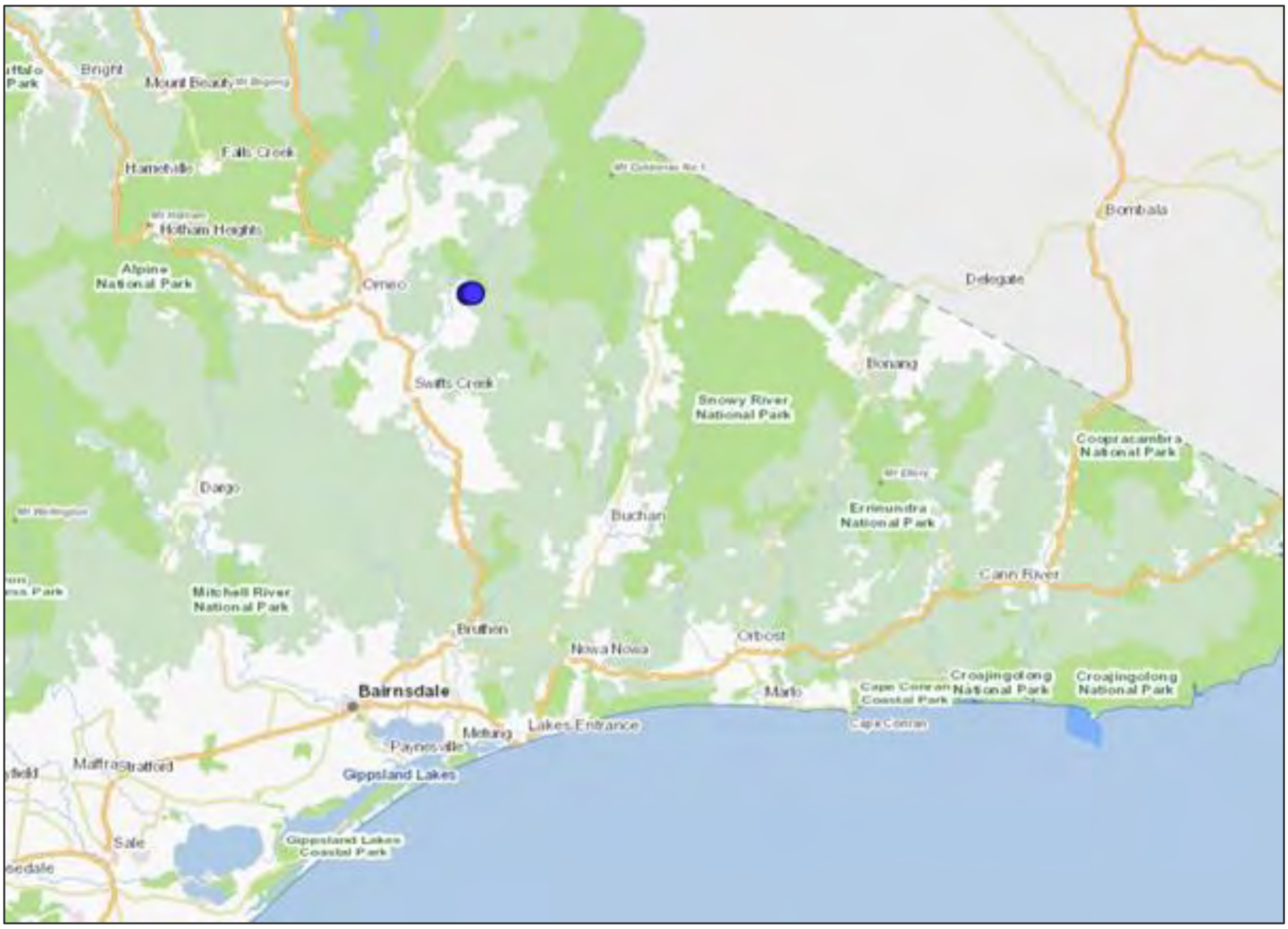

Figure 100. Location of Marble Gully, Tambo Valley, East Gippsland, Victoria

Table 52. Significant species recorded in the Silurian Limestone Pomaderris Shrubland community at Marble Gully by Peel (1993) and the survey years where present. Surveys were undertaken in 1993, 2004, 2007, 2019 and 2020.

Species	Common name	Conservation status	Survey year recorded*
Olearia astroloba	Marble Daisy-bush	Vulnerable (EPBC), vulnerable (FFG)	All
Ozothamnus adnatus	Winged Everlasting	Vulnerable (FFG)	All
Arthropodium sp. 1	Tall Vanilla-lily	Rare (FFG)	All
Asplenium trichomanes subsp. *quadrivalens*	Common Spleenwort	Rare (FFG)	1993
Desmodium varians	Slender Tick-trefoil	Rare (FFG)	1993
Pimelea flava subsp. *dichotoma*	Diosma Rice-flower	Rare (FFG)	All
Pimelea pauciflora	Poison Rice-flower	Rare (FFG)	1993
Pomaderris oraria subsp. *calcicola*	Limestone Pomaderris	Rare (FFG)	All
Pultenaea densifolia	Dense Bush-pea	Rare (FFG)	All
Senna aciphylla	Sprawling Cassia	Rare (FFG)	All
Vittadenia tenuissima	Delicate New Holland Daisy	Rare (FFG)	1993, 2004
Austrostipa scabra subsp. *falcata*	Rough Spear-grass	Disjunct	1993, 2004, 2007, potentially 2019—unconfirmed, as immature
Isoetopsis graminifolia	Grass Cushion	Disjunct	1993
Ptilotus spathulatus	Pussy Tails	Disjunct	1993, 2004

*1993 (Peel), 2004 (Coates and Downe), 2007 (Downe), 2019 (Downe), 2020 (Downe and Tolsma).

Methods

Locations surveyed

The quadrats were located on Hill 1 and Hill 2, above Marble Gully Track in the Mount Tambo NCR (Figure 101).

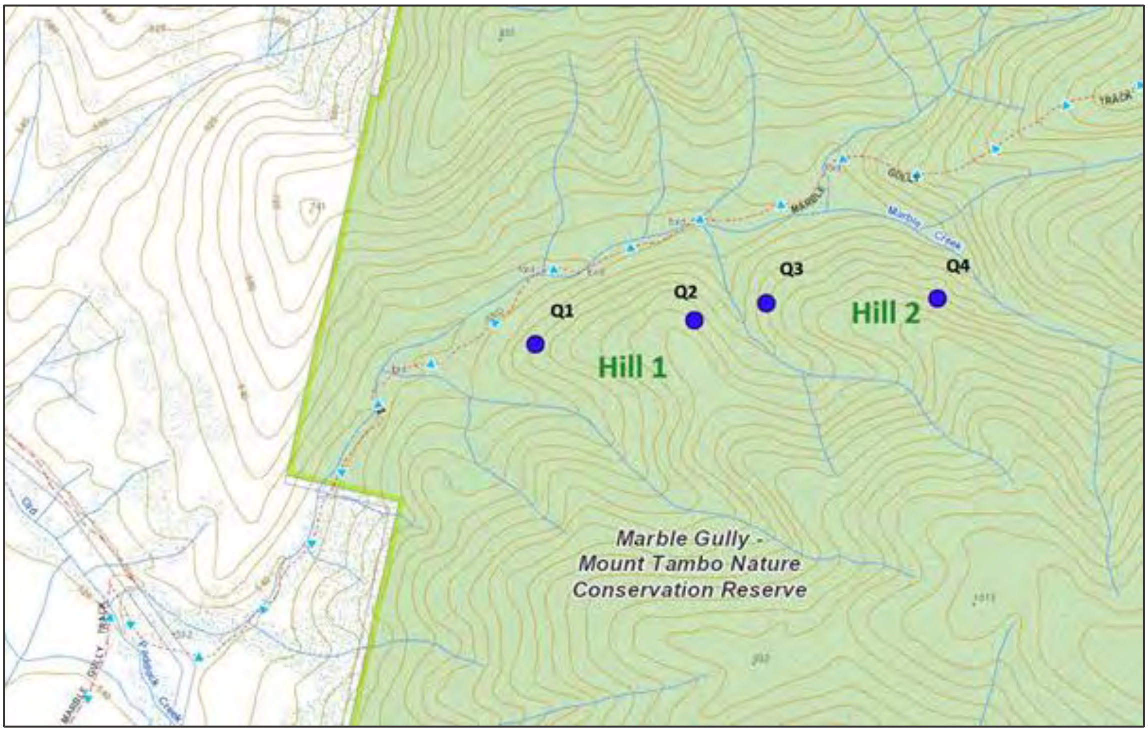

Figure 101. Location of quadrat sites at Marble Gully, Mount Tambo Nature Conservation Reserve

Survey methods

Permanent sites were established for the original post-fire study in 2004, based on the location of previous species records. Early surveys used multiple small quadrats, but later surveys used a single, large quadrat. At each site, a 30 m × 30 m quadrat was established, and delineated using measuring tapes and flagging tape. All vascular plants rooted within or overhanging the quadrat were identified and recorded, and a visual estimate was made of their percentage projected foliage cover. Additional data were recorded for plant size, regeneration mode, numbers of each plant, and evidence of browsing and drought impacts.

Results

The threatened species and key species recorded in 2019 and 2020, their mode of regeneration, change in cover (since 2019) and threatening processes observed are shown in Table 54 and Table 54.

Since the previous survey in 2019, the cover of most species has shown little change. An increase in cover was recorded for only two species (*Pomaderris oraria* subsp. *calcicola* and *Allocasuarina verticillata*). The effect of above-average rainfall at Marble Gully in January, April, July and October 2020 (Bureau of Meteorology http://www.bom.gov.au/climate/data) was apparent, with new growth present on most species, both woody and herbaceous. In some species [e.g. *Banksia marginata* (Silver Banksia)], new growth was observed on the tips of branches (Figure 102a), and many species produced new shoots from the base (such as *Olearia astroloba*, *Pomaderris oraria* subsp. *calcicola*, *Ozothamnus adnatus*, *Allocasuarina verticillata* and *Eucalyptus* species).

Some species were also observed regenerating from seed. *Pimelea flava* subsp. *dichotoma* (an obligate seeder) was the most prolific, with several cohorts, and plants only 25 cm tall had flowers (Figure 102b). *Bursaria spinosa* subsp. *lasiophylla* and *Exocarpus cupressiformis* produced several seedlings, and single seedlings were found for *Pomaderris oraria* subsp. *oraria, Ozothamnus adnatus, Pultenaea densifolia, Banksia marginata* and *Senna aciphylla.*

Table 53. Threatened species (2019 and 2020 surveys)—mode of regeneration, change in cover since 2019, and threats observed

Threatened species (2019 and 2020 surveys)	Regeneration in 2020	Cover in 2020 compared with 2019	Threats in 2020
Olearia astroloba	Shooting, flowering	No change	Still drought impacted, minor browsing
Ozothamnus adnatus	Shooting, flowering, seedlings	No change	
Arthropodium sp. 1	Flowering (buds)	No change	Browsed
Pimelea flava subsp. *dichotoma*	Flowering, seedlings	Minor increase	
Pomaderris oraria subsp. *calcicola*	Shooting, flowering, seedlings	Increase	Insect damage
Pultenaea densifolia	Shooting, flowering, seedlings	No change	
Senna aciphylla	Shooting, seedlings	No change	

Table 54. Key species—mode of regeneration, change in cover since 2019, and threats observed

Key species	Regeneration in 2020	Cover in 2020 compared with 2019	Threats in 2020
Allocasuarina verticillata	Shooting, flowering	Increase in all plots	Still drought impacted, minor browsing Some browsing (plot 1) observed
Banksia marginata	Shooting flowering, one seedling	Slight increase	
Bursaria spinosa subsp. *lasiophylla*	Flowering (buds), seedlings in 3 plots (range 2–15 cm tall)	Slight increase in one plot	Some browsing (plot 4) observed
Dodonaea viscosa	Shooting, fruiting	In 2 plots, new records	
Eucalyptus globulus var. *globulus*	Shoots to 1.5 m tall; single sapling (4–5 m tall)	Slight increase (present in only one plot)	
Eucalyptus nortonii	Shoots to 40 cm tall, single juvenile (80 cm tall)	No change in cover	
Exocarpus cupressiformis	Shooting, seedlings	Slight increase	Browsed
Poa sieberiana var. *sieberiana*	New shoots, many dead stems, flowering	Increase in cover in one plot, unchanged in 3 plots	Still drought impacted
Themeda triandra	New shoots, many dead stems, flowering	Increase in cover in 2 plots, unchanged in 2 plots	Still drought impacted

(a)

(b)

Figure 102. (a) *Banksia marginata* (Quadrat 2) with new shoots. (b) *Pimelea flava* subsp. *dichotoma* (Quadrat 2) seedling

This community seems to be naturally depauperate in herbaceous species. Herbs and geophytes were poorly represented in 2019, and it was assumed that this was due to the timing of the August survey being too early for most annual herbs and geophytes to emerge. However, the current survey was carried out in November, and the diversity of herbs and geophytes was still low. Of note, the rare lily *Arthropodium* sp. 1 and *Bulbine glauca* have been consistently recorded at Marble Gully, and several orchid species (*Caladenia* sp. and *Diuris sulphurea*) were also found. All these species were flowering.

Risks

Pre-existing risks (i.e. before the bushfires)

This community has been subject to degradation by introduced herbivores such as deer, hares or rabbits, by climate change—specifically, reduced precipitation, bushfires, and competition with introduced weed species.

Additional risks driven by the 2019–2020 bushfires

Browsing – The presence of deer was apparent at all sites—scats, browsing and tracks were present. The browsing damage was less than that observed in 2019, but fresh scats indicated that deer were still active. Deer were observed in nearby pasture, and it is assumed that browsing damage is currently reduced in the community due to the plentiful supply of food elsewhere following the autumn rainfall in the area. Post-fire deer control may also have helped reduce deer numbers.

Browsing is presently not posing a severe threat to the threatened and key species in this community. If, however, all plants of a cohort were severely browsed or killed by browsing, this would impact on the population. The risk due to browsing may increase as deer numbers increase, or as drought leads to reduced supply of suitable unburnt fodder in the surrounding area.

In 2019, severe browsing was noted on *Allocasuarina verticillata, Bursaria spinosa* subsp. *lasiophylla* and *Banksia marginata*, and moderate browsing on the threatened species *Olearia astroloba, Pomaderris oraria* subsp*. calcicola, Pimelea flava* subsp*. dichotoma, Ozothamnus adnatus, Pultenaea densifolia* and *Senna aciphylla*, and the common species *Exocarpus cupressiformis* and *Correa reflexa* var. *reflexa.* In the 2020 survey, the impacts of browsing were still evident, but new (unbrowsed) growth was observed on most of these species. Minor browsing was noted on the threatened species *Olearia astroloba,* and *Arthropodium* sp. 1, as well as *Allocasuarina verticillata* and *Bursaria spinosa* subsp*. lasiophylla.*

(a) (b)

Figure 103. (a) New aerial tips on *Allocasuarina verticillata* (Quadrat 4)—the impact of prior browsing is evident on the left side of the branch. (b) New resprouts on *Olearia astroloba* (Quadrat 4)—dead branches indicate the impact of browsing

Drought – The impact of drought was still obvious, despite new growth on most plants. Some plants remain in poor condition due to dieback (e.g. *Olearia astroloba* Figure 103b). *Pomaderris oraria* subsp. *oraria* appeared to be the most resilient shrub species with respect to drought. Drought effects were patchy, with shrubs in some areas very impacted, whereas in other areas (often close by) plants were in reasonable condition.

The graminoid species were also reshooting, but many populations were in poor condition with large areas of dieback, including *Dianella revoluta* (Figure 104.a), *Themeda triandra* (Figure 104.b), *Poa sieberiana* var. *sieberiana*, *Austrostipa blackii* and *Lomandra longifolia* var. *longifolia*.

Climate change resulting in drought and more frequent and intense fires is expected to severely impact this plant community.

Weeds – Generally, weeds are not a threat to this community. The risk of infestation with invasive weeds is low but possible, as Horehound has been growing in this community for many years, despite spraying between 2004 and 2006.

The small populations of Horehound observed in 2006 and 2019 on the lower slopes of Hill 1 were still present, despite spraying between 2004 and 2006. The small untreated populations on Hill 2 (above the gully between Hills 2 and 3—north of Quadrat 2) also remain viable. Plants had visibly died back in 2019 following the drought conditions, but new shoots were observed in 2020. This infestation does not appear to be spreading, but it is recommended that the plants are removed while the populations are small. Blackberry was not recorded in either the 2019 or 2020 surveys.

Ubiquitous low-threat weeds such as Cat's-ear (*Hypochaeris radicata*) and Sow Thistle (*Sonchus oleraceus*) were scattered over the area, and annual weed species such as Australian Carrot (*Daucus glochidiatus*), Pimpernel (*Lysimachia arvensis*) and Hairy Pink (*Petrorhagia dubia*) were beginning to germinate. These are of little concern.

(a) (b)

Figure 104. (a) *Dianella revoluta* (Quadrat 3) with several new leaves. (b) *Themeda triandra* (Quadrat 3) with new shoots present on right side of clump

Erosion – Erosion was not observed. The risk of erosion is minimal but possible if climate change results in severe rain events, and potentially could occur following heavy rain, as many deer tracks are present on the steep, loose rocky slopes.

Future directions

Priority actions identified for consideration within DELWP's decision-support tools are as follows:

Deer control

Monitoring of deer impacts

Herbicide treatment of all Horehound populations in the surrounding area.

Acknowledgements

This project was funded by the Victorian Government's Bushfire Biodiversity Response and Recovery program and the Australian Government's Bushfire Recovery Package for Wildlife and Their Habitat.

Thanks to Fraser and Penny for allowing access through their property to the Silurian Limestone Pomaderris Shrubland at Marble Gully.

Surveys were conducted by Judy Downe and Arn Tolsma (both ARI).

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