EYES ON RECOVERY

A large-scale collaborative camera survey initiative tracking the recovery of Australian wildlife after the 2019-2020 bushfires

Case Study Reports
2024

WWF AUSTRALIA

WWF-Australia

WWF is an independent conservation organization, with over 30 million followers and a global network active in nearly 100 countries. Our mission is to stop the degradation of the planet's natural environment and to build a future in which people live in harmony with nature, by conserving the world's biological diversity, ensuring that the use of renewable natural resources is sustainable, and promoting the reduction of pollution and wasteful consumption.

Acknowledgements

Eyes on Recovery surveys were conducted on the land of the Gugu-Badhun, Agwamin, Yuggera, Bundjalung, Gumbainggir, Biripi, Geawegal, Wonnarua, Dharug, Eora, Kuring-gai, Yuin, Ngarigo, Bidwell, Wiradjuri, Jaitmatang, Ngarigo and Kurnai peoples. We acknowledge the Traditional Custodians of these lands and their continuing connection to land, water and culture. We pay our respects to their Elders – past, present and emerging.

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Cover photographs: Collection of images captured by Eyes on Recovery wildlife cameras

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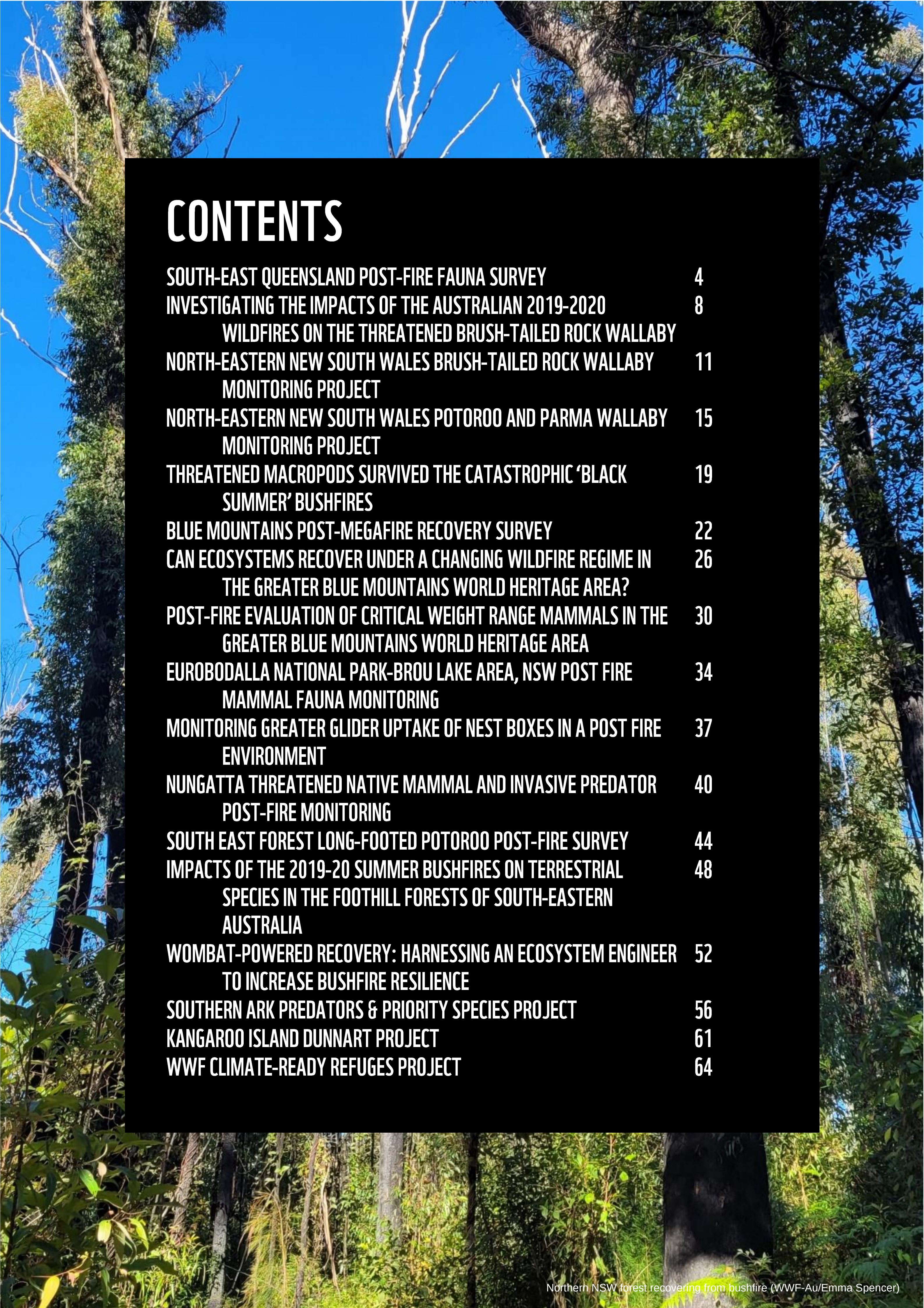

Northern NSW forest recovering from bushfire (WWF-Au/Emma Spencer)

SOUTH-EAST QUEENSLAND POST-FIRE FAUNA SURVEY

Location: South-east Queensland, Australia

Project Partners: Natalya Maitz and Diana Fisher from the University of Queensland

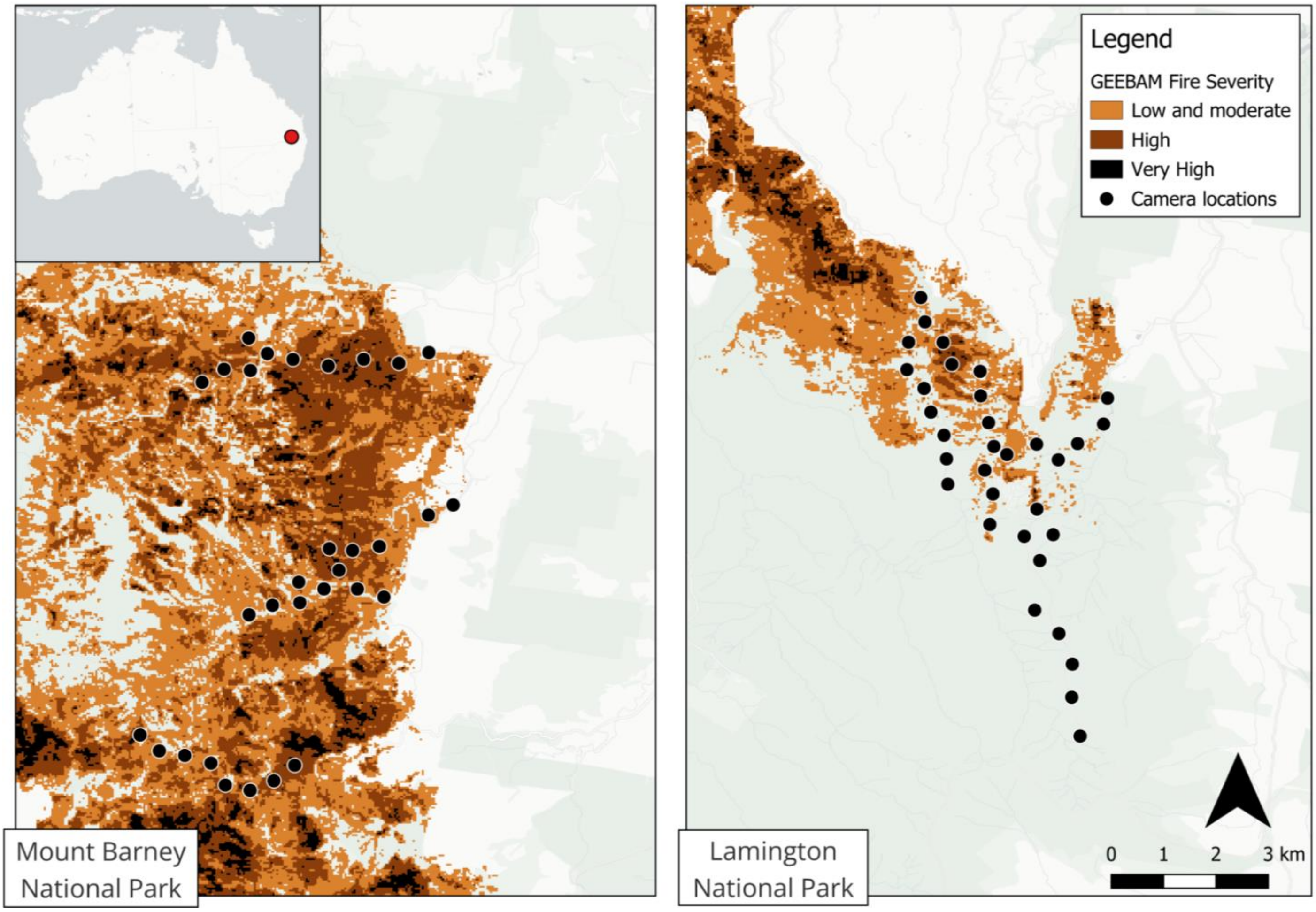

Figure 1. Camera deployment across fire-impacted regions of Mount Barney and Lamington National Park in south-east Queensland, overlaid on the 2019/20 wildfire severity Google Earth Engine Burnt Area Map data.

PROJECT OVERVIEW AND AIMS

The Gondwana Rainforests World Heritage Area is comprised of 40 national parks and reserves in south-east Queensland and northern NSW with remnants of the ancient rainforests that covered Australia in cooler and wetter times. During the 2019-2020 bushfire season, fires affected approximately 53% of this World Heritage Area[1]. In south-east Queensland, the reserves that were most heavily impacted by fire were Mount Barney National Park, Lamington National Park, and Main Range National Park.

This project aimed to: (1) assess post-fire presence and activity of key priority species such as long-nosed potoroo (*Potorous tridactylus*), spotted-tailed quoll (*Dasyurus maculatus*), and Albert's lyrebird (*Menura alberti*), (2) understand the presence and activity of feral animals, such as red foxes (*Vulpes vulpes*), cats (*Felis catus*), and pigs (*Sus scrofa*), to guide an adaptive management response from QPWS, and (3) establish baseline data for threatened species in unburnt habitats.

Cameras were deployed within Lamington National Park and Mount Barney National Park (**Figure 1**), in areas selected to complement other QPWS monitoring activities. Approximately 10% of the area of Lamington National Park was burnt during the 2019-20 bushfire season, including significant areas of subtropical and dry rainforests[1]. Approximately 78% of the World Heritage area of Mount Barney National Park was burnt during the 2019-20 season[1].

[1] Australian Government Department of Agriculture, Water and the Environment. 2020. Gondwana Rainforests of Australia State of Conservation Update – April 2020. Commonwealth of Australia, Canberra.

METHODS

This fauna monitoring survey encompassed 64 sites across Mount Barney and Lamington National Parks, in south-east Queensland. These sites included habitat within and outside of the fire extent (**Figure 2**), and in areas of varying fire severity (i.e., low/moderate: areas where tree canopy was mostly untouched by fire, high/very high: areas where tree canopy was mostly or entirely burnt by fire).

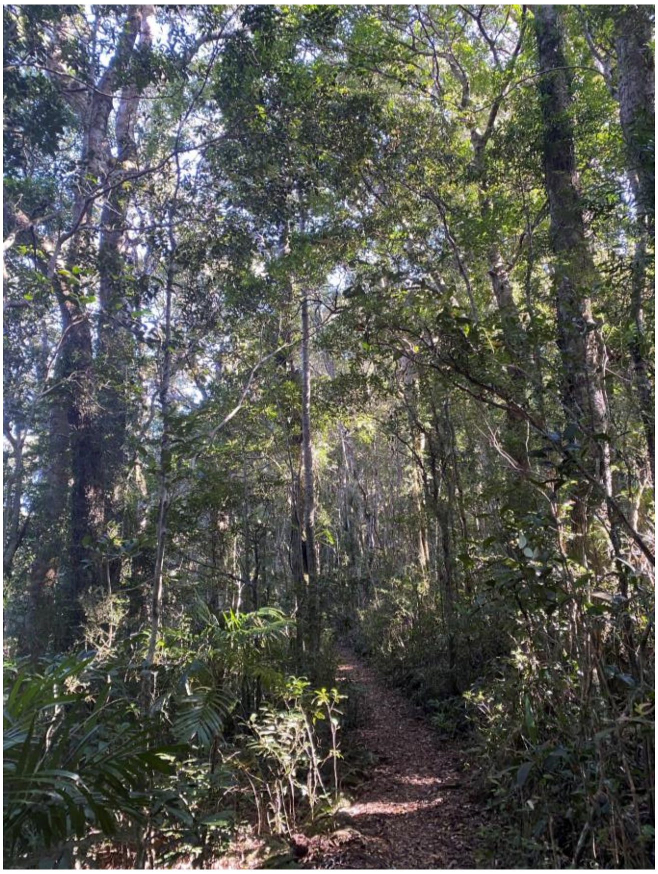

Figure 2. Typical habitat where monitoring cameras were deployed in Lamington National Park.

One monitoring camera (Swift Enduro; Outdoor cameras) was deployed at each site, positioned about 0.5 m off the ground and set to take pictures continuously if wildlife entered the camera frame (**Figure 3**). Data was analysed separately for each National Park. At Mount Barney, 31 cameras were deployed for a total of about 12 months between the 23rd of July 2021 to the 26th of July 2022. All cameras were deployed in burnt habitat (low/moderate: 25 cameras, high/very high: 6 cameras). In Lamington, 33 cameras were deployed over about 13 months between 23rd of August 2021 to 8th of October 2022. We only considered burnt versus unburnt locations in Lamington as most cameras in burnt locations were set up in habitat affected by low/moderate intensity burns (unburnt: 13 cameras, low/moderate: 19 cameras, high/very high: 1 camera).

Camera images were uploaded to the online image processing platform Wildlife Insights, where they were identified and sorted to species where possible. For images of animals that could not be identified to species, the closest taxonomic grouping was used, e.g., "Aves", "Macropod", "Possum species" "Unidentified Small Mammal <500g" etc., or "Unknown".

Once all images were classified, species detection events (or species group where applicable) were calculated by grouping all images of a species taken by a single camera within 30 minutes of each other into single events. These detection events were then summed for each camera. To account for differences in camera monitoring effort (some cameras stopped functioning due to low battery of full memory cards), "encounter rates" for each species were calculated. This was achieved by dividing the total number of species detection events at a camera by the total number of days the camera was active, and then multiplying this number by 100 to make rarer species more visible. This encounter rate was then averaged over all cameras within each national park and fire category.

Figure 3. Checking a wildlife monitoring camera next to a stream in Mount Barney National Park.

KEY FINDINGS

A total of 281,157 camera images were captured over the monitoring survey period, including 55,538 containing pictures of animal species. At least 54 species were detected by cameras, including 32 species of birds, 20 mammal species and one reptile species. The most commonly encountered species were Australian brush turkeys (*Alectura lathami*), swamp wallabies (*Wallabia bicolor*), long-nosed potoroos (*Potorous tridactylus*) and red-necked wallabies (*Notamacropus rufogriseus*) (**Figure 4**).

Across the survey, cameras detected activity of identified key priority species including long-nosed potoroos, northern brown bandicoots (*Isoodon macrourus*), and Albert's lyrebird (*Menura alberti*) (**Table 1**). In Mount Barney National Park, long-nosed potoroos were detected at 9 sites, while northern brown bandicoots were detected at 15 sites and Albert's lyrebirds were detected at only 1 site. In Lamington National Park, long-nosed potoroos and northern brown bandicoots were detected at 3 sites each and Albert's lyrebirds were detected at 1 site. At Mount Barney, long-nosed potoroos were encountered more frequently in low/moderate burnt sites than high/very high burnt sites, while northern brown bandicoots were encountered at similar rates across fire categories and Albert's lyrebirds were only encountered in low/moderate burnt sites (**Figure 4**). In Lamington, northern brown bandicoots were also encountered similarly across fire categories, while Albert's lyrebirds were encountered only in unburnt sites (**Figure 4**).

Cameras also captured images of brush-tailed rock wallabies at 3 sites in Mount Barney National Park including one high/extreme and two low/moderate burnt sites (**Table 1; Figure 4**). Koalas were recorded at 10 sites in both Lamington and Mount Barney National Park. They were encountered more frequently at low/moderate burnt habitats compared to high/very high burnt habitats in Mount Barney National Park but were only detected at burnt sites in Lamington National Park (**Table 1; Figure 4**). The cameras did not capture images of any spotted-tail quolls.

Table 1: Number (and percent) of camera sites where key priority species identified by national park (NP).

	QLD State Listing	Location	
		Mount Barney NP	Lamington NP
Long-nosed potoroo	v	9 (29%)	3 (9%)
Northern bandicoot	lc	15 (48%)	3 (9%)
Albert's lyrebird	nt	1 (3%)	1 (3%)
Brush-tailed rock wallabies	v	3 (10%)	0
Koala	e	10 (32%)	10 (30%)
Spotted-tailed Quoll	v	0	0
v = Vulnerable, e= Endangered, lc= Least Concern, nt= near threatened			

Feral/domestic cats (*Felis catus*) and red foxes (*Vulpes vulpes*) were detected across both Lamington (cat: 10 sites, fox: 3 sites) and Mount Barney National Park (cat: 8 sites, fox: 4 sites). At both national parks, they were encountered at similar rates across different fire categories (**Figure 4**). No deer or pigs were detected across either national park, but European hare (*Lepus europaeus*) were detected at Mount Barney National Park, only in the low/moderate burnt habitat (**Figure 4**).

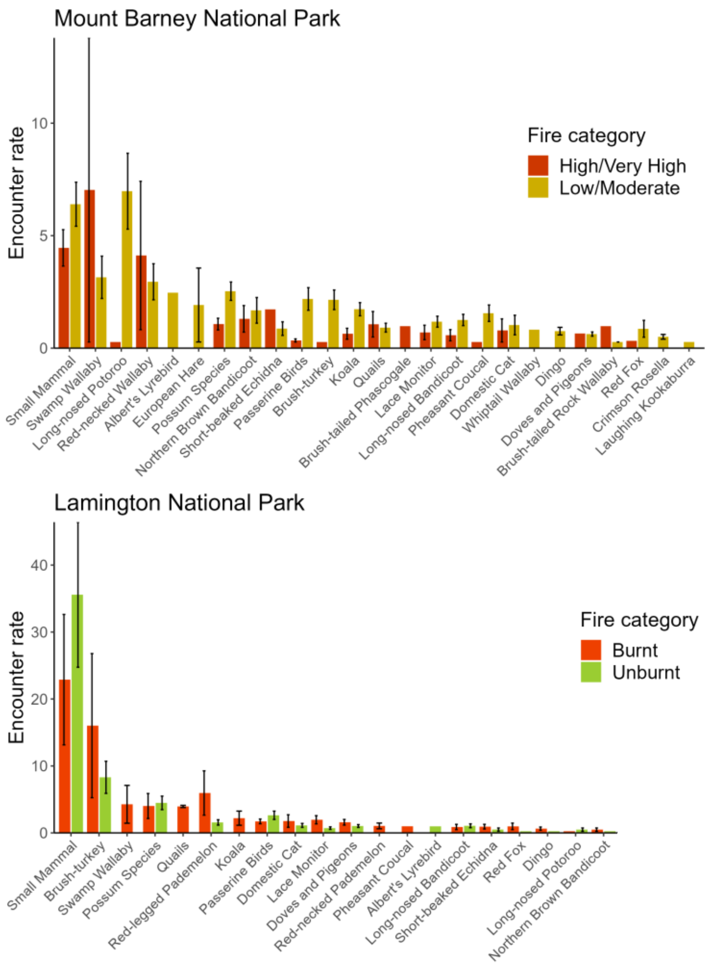

Figure 4. Encounter rate for key species at Mount Barney National Park across habitat burnt by low/mod and high/very high severity fires (top), and Lamington National Park for unburnt and burnt habitats (bottom).

MANAGEMENT OUTCOMES

The results of this study have contributed to understanding trends of species presence across Lamington and Mount Barney National Park. This includes threatened or priority species, particularly the long-nosed potoroo and Albert's lyrebird, but also invasive species like feral cats and red foxes. There is some indication that both the long-nosed potoroo and Albert's lyrebird may be fire-impacted, as both species appeared in higher numbers in habitat that was either unburnt (in Lamington National Park) or burnt by lower severity fire (in Mount Barney National Park). As records were low for these species, especially for the lyrebird, it is important that further investigation is carried out, or otherwise that this data is consolidated and considered with other datasets collected in the region post 2019/20 fires (e.g., collected as part of the

Queensland Government Gondwana Species assessment[2]).

The results of this study also contributed to understanding the distribution and activity of invasive species in these national parks, especially deer, feral cats, red foxes and feral pigs in Mount Barney National Park and feral cats within Lamington National parks. This information contributed to management activities, including strategic pest control to benefit native wildlife. In general, these species were encountered relatively infrequently across this survey, with only red foxes, feral cats and hares detected. Further, no feral pigs or deer were recorded, indicating perhaps that early post-fire pest management efforts may have been successful.

INVESTIGATING THE IMPACTS OF THE AUSTRALIAN 2019-2020 WILDFIRES ON THE THREATENED BRUSH-TAILED ROCK WALLABY

Location: South-east Queensland, Australia

Project Partners: Natalya Maitz and Diana Fisher from the University of Queensland and Jenny Molyneux from the Queensland Government Department of Environment, Science and Innovation

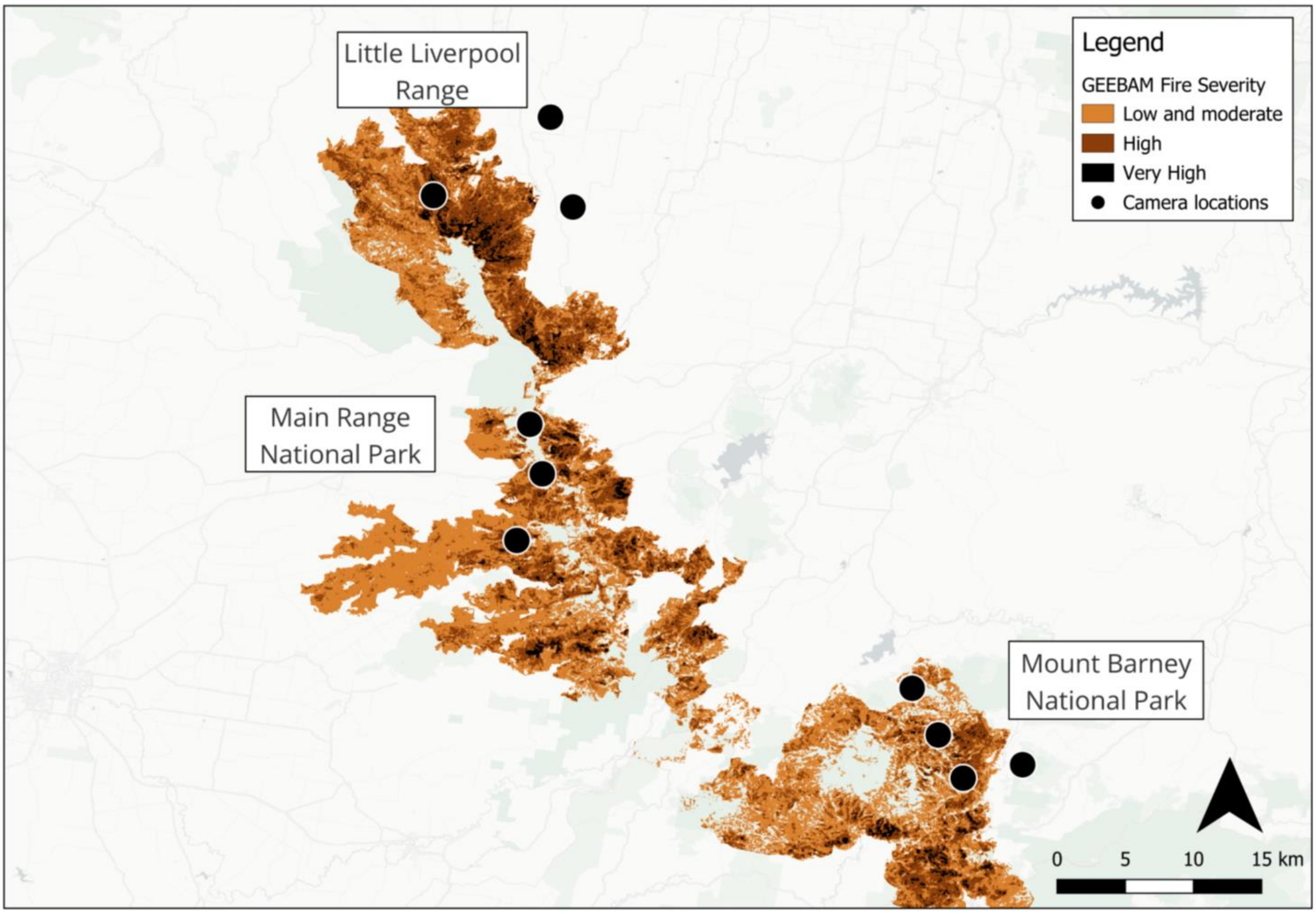

Figure 1. Locations of 10 brush-tailed rock wallaby monitoring sites deployed across south-eastern Queensland, overlaid on the 2019/20 wildfire severity Google Earth Engine Burnt Area Map data.

PROJECT OVERVIEW AND AIMS

During the 2019-2020 wildfires, approximately 38% of brush-tailed rock wallaby (*Petrogale penicillata*) habitat was burned[1]. Already in decline prior to the fires, the brush-tailed rock wallaby has undergone a substantial contraction in range, primarily due to invasive predators and habitat loss. As part of a PhD thesis at The University of Queensland, this project is investigating the impact of these fires on the species as studies in this area are limited. For this project, a landscape level camera trap survey is being conducted throughout south-east Queensland, a region that forms part of the national stronghold for the species. Unfortunately, much of the core brush-tail rock wallaby habitat in this area was severely burned during the wildfires, including the National Parks of Mount Barney, Main Range, and Crows Nest, along with many of the surrounding private properties (**Figure 1**).

The primary aim of this project is to investigate the impact of the wildfires on brush-tailed rock wallaby habitat use, with a focus on better understanding the potential interactions between wildfires and other

[1] Ward et al. 2020. Impact of 2019–2020 mega-fires on Australian fauna habitat. Nature Ecology & Evolution 4(10): 1321-1326.

existing threats, such as invasive predators like the red fox (*Vulpes vulpes*) or competition with other herbivores. To achieve this, we have deployed additional cameras at each site to gather information on the activities of predators and other co-occurring species that reside alongside these rocky habitats (**Figure 2**). Understanding how different threatening processes influence each other is crucial for informing conservation actions. For instance, wildfires lead to a loss in vegetation which may result in certain species becoming more prone to predation by reducing available hiding places. Information generated from this survey will be beneficial for helping prioritize future management actions to protect this iconic but nationally vulnerable species.

METHODS

Our landscape-scale survey encompasses 40 sites across south-east Queensland, covering areas both within and outside the burn footprint (**Figure 1**). We considered whether the surrounding habitat was intact or degraded, as neighbouring habitat conditions may influence the impacts of the wildfires and interactions with other threatening processes. At each site, we deployed 8 cameras, for a total of 320 cameras over the duration of the study (**Figure 3**). We relocated cameras to new sites after seven weeks in the field for broad coverage. The project, which commenced in August 2022, will be continuing until November 2023. As data collection was still ongoing at the time, this report outlines initial results from 10 sites (80 cameras), including 3 unburned sites and 7 burned sites.

Figure 2. Typical brush-tailed rock wallaby habitat.

Brush-tailed rock wallaby detection events were calculated by grouping all images of this species that were taken on a single camera and within 30 minutes of each other into single events. These detection events were then totalled across each camera. To account for differences in camera monitoring effort, "encounter rates" for this species were calculated, by dividing the total number of detection events for brush-tailed rock wallabies at a camera by the total number of days that the camera was active and then multiplying that number by 100. This final value was then averaged over all cameras and fire severities. Average encounter rates for predator species detected across different fire severities were also calculated. In this case, dingo (*Canis Dingo*), red fox and feral cat (*Felis catus*) detection events were all combined to calculate encounter rates for this species group.

Alongside the camera deployments, we opportunistically collected predator scats throughout brush-tailed rock wallaby habitat. These scats will be analysed to provide better insight into the predation rates of brush-tailed rock wallabies and ideally complement camera trap findings.

Figure 3. Setting up monitoring cameras.

KEY FINDINGS

Based on our ongoing camera trap surveys, it is encouraging to find that brush-tailed rock wallabies have managed to persist in Queensland despite the devastating 2019-2020 wildfires. Initial findings (including a total of 10 sites) reveal the presence of the species at nine of ten sites that were monitored, including six out of seven sites that were affected by the wildfires (**Figure 4**). Interestingly, we also observed a higher average encounter rate of brush-tailed rock wallabies in areas that experienced more severe burns, in comparison to less impacted regions (**Figure 5**). However, given the small sample size and associated uncertainties, definitive conclusions on the impacts of fire severity cannot yet be made.

It is also worth noting that predator (red fox, feral cat and dingo) activity appears to be elevated in these severely burned areas too, which could pose a challenge to the wallabies, especially during initial post-fire stages when food sources are scarce. Across the 10 sites, dingoes were detected at 90% of sites, and were only absent at one burnt location. Red foxes were identified at 40% of sites and were found at more sites in unburned (3 of 3 sites) compared to burned areas (1 of 7 sites). Feral cats, on the other hand, were detected at 70% of sites (6 of 7 burnt sites and 1 of 3 unburnt sites). Invasive herbivores including European hares (*Lepus europaeus*) and feral pigs (*Sus scrofa*) were also detected across the survey sites.

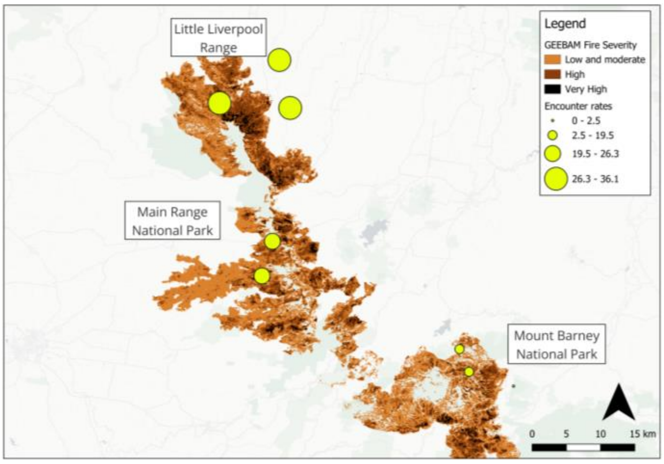

Figure 4. Map showing locations showing where brush-tailed rock wallabies were encountered on camera images most commonly (larger circles indicates greater encounter rates).

To ensure the long-term survival of the brush-tailed rock wallaby, it may be beneficial to intensify predator control measures in severely burned regions, especially in the early post-fire stages. While these findings are preliminary and subject to uncertainties, we anticipate refining our results as we continue to incorporate additional camera trap data.

MANAGEMENT OUTCOMES

Findings from this project will provide valuable information for conservation planning and management. In the short term, we are working closely with collaborative partners to address immediate threats to the species. For example, in areas where we have noticed increased predator activity that also happen to coincide with brush-tailed rock wallaby colonies, we have communicated our findings in real-time with property managers to enable swift predator control.

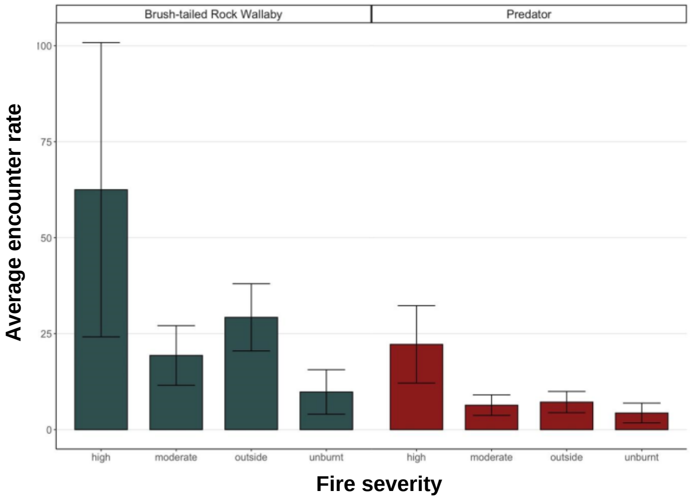

Figure 5. Average encounter rate (per 100 trap nights) for brush-tailed rock wallabies (blue) and predators (red) across different fire severities and in unburnt patches within the fire extent and outside of the fire extent at ten sites in southeast Queensland.

In the long-term, the project will provide crucial baseline information on the locations of key brush-tail rock wallaby colonies and the relative activities of predators in these areas, which will be essential for planning future management actions. Additionally, the project will help us better understand the interactions wildfires may have with other threatening processes, which can further help inform management recommendations for future fire events. The combination of these immediate and gradual outcomes will contribute towards improving efforts to prevent further population decline and conserve the brush-tail rock wallaby.

NORTH-EASTERN NEW SOUTH WALES BRUSH-TAILED ROCK WALLABY MONITORING PROJECT

Location: Northern New South Wales, Australia

Project Partners: Tim Scanlon, Dell Gorring, Caroline Blackmore from NSW National Parks and Wildlife Service

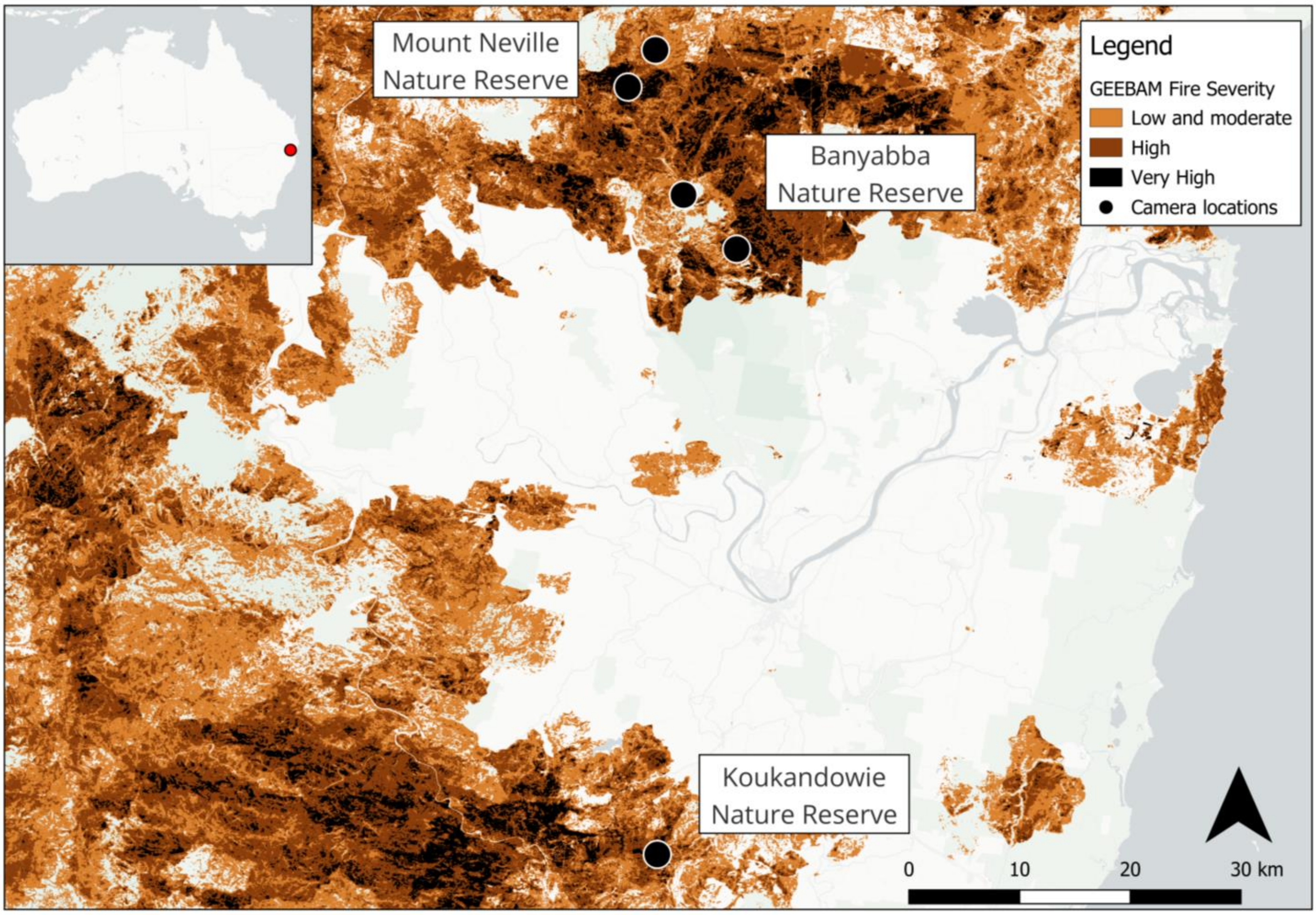

Figure 1. Locations of 5 brush-tailed rock wallaby monitoring sites deployed across 3 Nature Reserves in Northern NSW, overlaid on the 2019/20 wildfire severity Google Earth Engine Burnt Area Map data.

PROJECT OVERVIEW AND AIMS

The brush-tailed rock wallaby (*Petrogale penicillata*) is listed as endangered under NSW legislation, in decline due to threats such as introduced predators, competition with introduced herbivores, and habitat loss, degradation and fragmentation[1]. The species has largely been constrained to isolated colonies in complex, rocky habitats along the Great Diving Range. Due to this isolation and fragmentation, brush-tailed rock wallabies are at risk of inbreeding, but they also face increased vulnerability to large-scale disturbance events such as bushfires.

The 2019-2020 Australian bushfires burnt more than 80% of brush-tailed rock wallaby habitat in New South Wales (NSW)[2]. These fires directly impacted this species, as some may have perished in the smoke or flames, but it also destroyed important habitat and therefore sources of food and shelter from predators. For example, in northern NSW individuals were identified in poor condition with little to no natural food available in the vicinity of colonies and any surviving vegetation was also drought-impacted[3]. Further,

[1] Menkhorst & Hynes. 2010. National Recovery Plan for the Brush-tailed Rockwallaby *Petrogale penicillata*. Department of Sustainability and Environment, East Melbourne.
[2] DPIE. 2020. Wildlife and Conservation Bushfire Recovery: Immediate Response January 2020. Department of Planning, Industry and Environment: Sydney, NSW.
[3] Mo et al. 2021. Corporate support for threatened species recovery efforts: three case studies from the 2019–20 Australian bushfire season. Australian Zoologist 41(2): 186–193.

invasive species, including both herbivores and predators often flourish in post-fire landscapes, where burnt, more open habitat provides more opportunities for dispersal and discovery of potential prey.

Monitoring resident rock wallaby colonies and invasive species in these areas is important to assessing species recovery and key threats. This project aimed to establish camera monitoring surveys across reserves impacted by the 2019-20 bushfires to: (1) determine the presence and recovery of brush-tailed rock wallabies, and (2) opportunistically survey for a range of fauna species, including invasive predators and herbivores that may threaten brush-tailed rock wallaby colonies.

This project specifically focused on reserves in north-eastern NSW. Prior to the 2019-20 bushfires, the brush-tailed rock wallaby colonies of this region were poorly understood. A NPWS camera trap documented the first record of a brush-tailed rock wallaby in Banyabba Nature Reserve (NR) in 2015, and Koukandowie NR was known to support brush-tailed rock wallabies, with occasional reports since 1998, but the number, location and extent of colonies was unknown. Heavy wildfire impacts to these reserves made it critical to locate colonies and commence recovery monitoring. Information generated from this survey will be beneficial for helping prioritise future management actions to protect this iconic but vulnerable species.

METHODS

Forty camera sites were selected for brush-tailed rock wallabies across 3 reserves: Banyabba NR, Mount Neville NR and Koukandowie NR. The project focused on reserves that were most impacted by the 2019-20 wildfires, were most likely to support brush-tailed rock wallabies and were not currently the focus of other brush-tailed rock wallaby camera monitoring programs by the New South Wales National Parks and Wildlife Service (NPWS).

Two locations in Banyabba NR (Banyabba south: 10 cameras, Banyabba north: 10 cameras) were chosen as focus sites to confirm the presence of brush-tailed rock wallabies at suitable habitat within the reserve. Banyabba north sites were in an area of predominantly low/moderate fire severity, while the Banyabba south sites were in an area of high and very high fire severity (**Figure 1**). Mount Neville NR (10 cameras) was chosen as this location had similar habitat type and burn history to Banyabba NR, with no previous records of brush-tailed rock wallabies. These cameras were split into two locations, Mount Neville north (5 cameras; in low/moderate burnt habitat) and south (5 cameras; in high and very high burnt habitat). Koukandowie NR sites (10 cameras) were located in an area of predominately low/moderate and high fire severity (**Figure 1**).

The preferred habitat of brush-tailed rock wallabies includes rock ledges and caves, especially where there are cliffs below and above to reduce predation (**Figure 2**). Scat searches were made in suitable habitat, and traps were established in locations with suitable habitat and fresh scat but also relatively close to access trails to reduce time during camera maintenance. Cameras were attached to trees, tomato stakes or star pickets, avoiding blue sky and glare wherever possible, and positioned approximately 50cm above the ground. Cameras were angled towards potential brush-tailed rock wallaby runways wherever possible. Cameras were deployed at different times, ranging from November 2020 (in Banyabba NR south) to September 2021 (in Mount Neville). Data collection is ongoing across all sites; however, this report includes analyses of camera images up to November 2022.

Figure 2. Example of preferred habitat for the brush-tailed rock wallaby

Camera images were uploaded to the online image processing platform Wildlife Insights, where they were identified and sorted to species where possible. For images of animals that could not be identified to species, the closest taxonomic grouping was used e.g., “Macropod”, “Possum species” “Unidentified Small Mammal <500g” etc., or “Unknown”.

Once all images were classified, detection events were isolated by grouping all images of a species or group of species that were taken on a single camera and within 30 minutes of each other. These detection events were then totalled across each camera. To account for differences in camera monitoring effort (some cameras stopped functioning due to low battery or full memory cards), “encounter rates” for each species or species group were calculated by dividing the total number of detection events for each species/species group at a camera by the total number of days that camera was active and then multiplying that number by 100. This final value was then averaged over all cameras within each NR.

KEY FINDINGS

Brush-tailed rock wallaby presence was confirmed in all three reserves, although they were sighted at Mount Neville south but not Mount Neville north (**Figure 2**). This was the first detection of the species in Mount Neville NR, and the first confirmation of populations in two separate areas of suitable habitat in Banyabba NR.

More detailed analysis showed that Banyabba NR north sites had a higher brush-tailed rock wallaby encounter rate than the Banyabba NR south sites (**Figure 2**). The overall brush-tailed rock wallaby encounter rate in Koukandowie NR was lower than both Banyabba NR sites (**Figure 2**). Mount Neville had the lowest encounter rates overall for this species, with individuals only identified in the southern site (**Figure 2**).

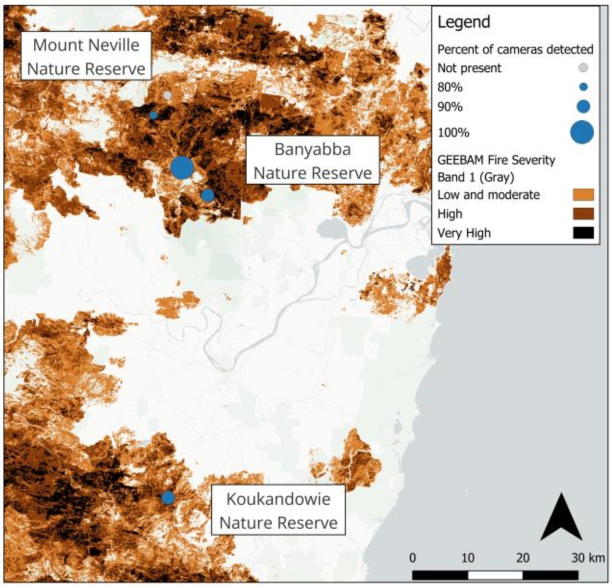

Figure 2. Spatial distributions of brush-tailed rock wallaby detections across all sites. Size of circles increases with the percentage of cameras at a site that detected a brush-tailed rock wallaby.

Across the three reserves, at least 37 other species were detected on cameras. Some species were only detected in locations impacted by low/moderate severity fires (e.g. feral goats *Capra aegagrus*, brush-tailed phascogales *Phascogale tapoatafa*, common wallaroos *Macropus robustus*, tawny frogmouths *Podargus strigoides*, dingoes *Canis dingo*, whiptail wallabies *Macropus parryi*) while others were only detected in areas affected by high/very high severity fires (e.g. northern brown bandicoots *Isoodon macrourus*, red-necked wallabies *Notamacropus rufogriseus*, feral cats *Felis catus*, long-nosed bandicoots *Perameles nasuta*, cane toads *Rhinella marina*, swamp wallabies *Wallabia bicolor*, kookaburras *Dacelo sp.*). This included another priority species, the koala (*Phascolarctos cinereus*), which is listed as endangered under the Environment Protection and Biodiversity Conservation Act 1999. This species was encountered at Banyabba Nature Reserve and Mount Neville Nature Reserve, although it was only detected in the Banyabba and Mount Neville North sites, where the fire severity was lower (i.e. low/moderate burn). Note that correlations between species presence and fire severity should be interpreted cautiously due to the small number of sites and variation in pre-fire species distributions.

Across the survey, 4 invasive species including red foxes (*Vulpes vulpes*), cane toads, feral cats and goats. Red foxes were the most commonly sighted invasive vertebrate species on cameras (**Figures 4, 5**) and were recorded across all nature reserves. Interestingly, foxes were recorded at three of the four cameras at Mount Neville North (where brush-tailed rock wallabies were absent) but were not recorded at Mount Neville South (where brush-tailed rock wallabies were present) indicating that there may be predator interactions taking place. Feral cats were detected at 40% of sites at Banyabba North and two of the five cameras at Mount Neville south but were not detected elsewhere (**Figures 4, 5**). Cane toads were encountered on two separate occasions at Banyabba North, and feral goats were encountered at 30% of sites at Banyabba South (**Figures 4, 5**).

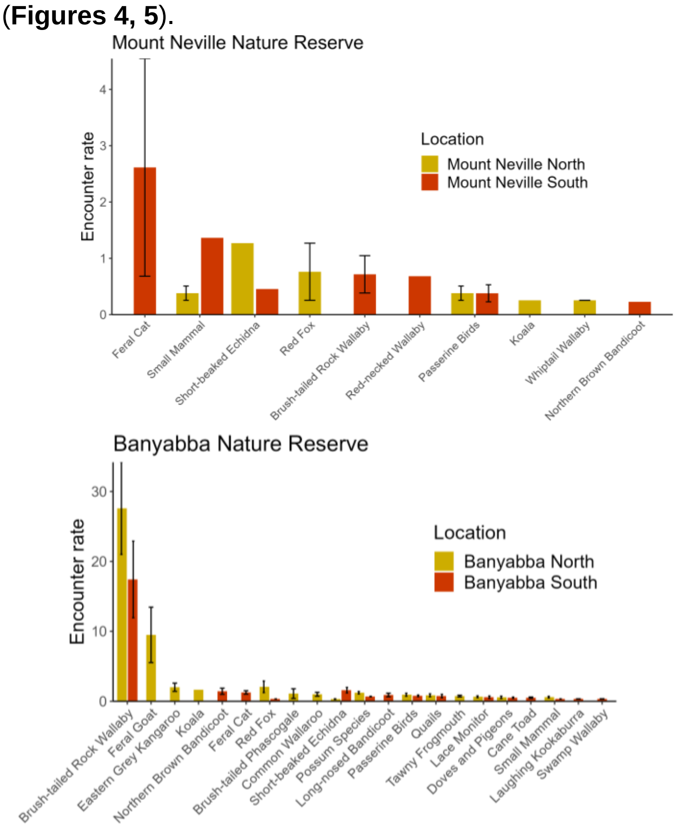

Figure 4. Average encounter rate of brush-tailed rock wallaby and predator detections across Mount Neville and Banyabba NR.

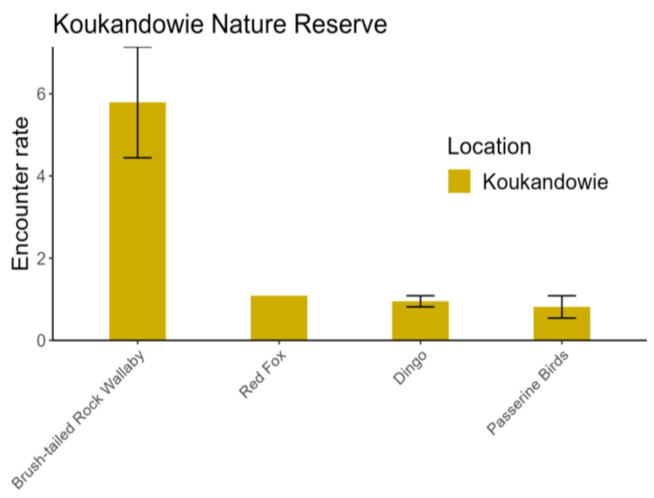

Figure 5. Average encounter rate of brush-tailed rock wallaby and predator detections across Koukandowie NR.

MANAGEMENT OUTCOMES

The discovery of the threatened brush-tailed rock wallaby in Mt Neville NR and confirmation of more than one breeding population in Banyabba NR will have several implications for management. The brush-tailed rock wallabies in these locations can now be protected during NPWS fire hazard reduction, wildfire suppression, and road maintenance operations. Breeding will be monitored to detect increasing threats to populations that might not be immediately evident where adults persist.

The cameras also detected pest predators at the brush-tailed rock wallaby colonies. Further investigation of the impact of red foxes at Mount Neville Nature Reserve in particular could be warranted, as no brush-tailed rock wallabies were detected at this location, while red foxes were regularly detected. The findings of this project will be shared with species Accountable Officers for consideration in the NSW-wide management of this species under the Saving our Species program[4].

[4] NSW Government Department of Environment and Heritage. 2024. Saving our Species program. Available from: https://www.environment.nsw.gov.au/topics/animals-and-plants/threatened-species/saving-our-species-program.

NORTH-EASTERN NEW SOUTH WALES POTOROO AND PARMA WALLABY MONITORING PROJECT

Location: Northern New South Wales, Australia

Project Partners: Tim Scanlon, Dell Gorring, Grant Wilcock, Josh Armitage, Geoffrey James, Scott Filmer, Peter Ellem, Mark Fletcher, Matt Wiseman and Caroline Blackmore from NSW National Parks and Wildlife Service

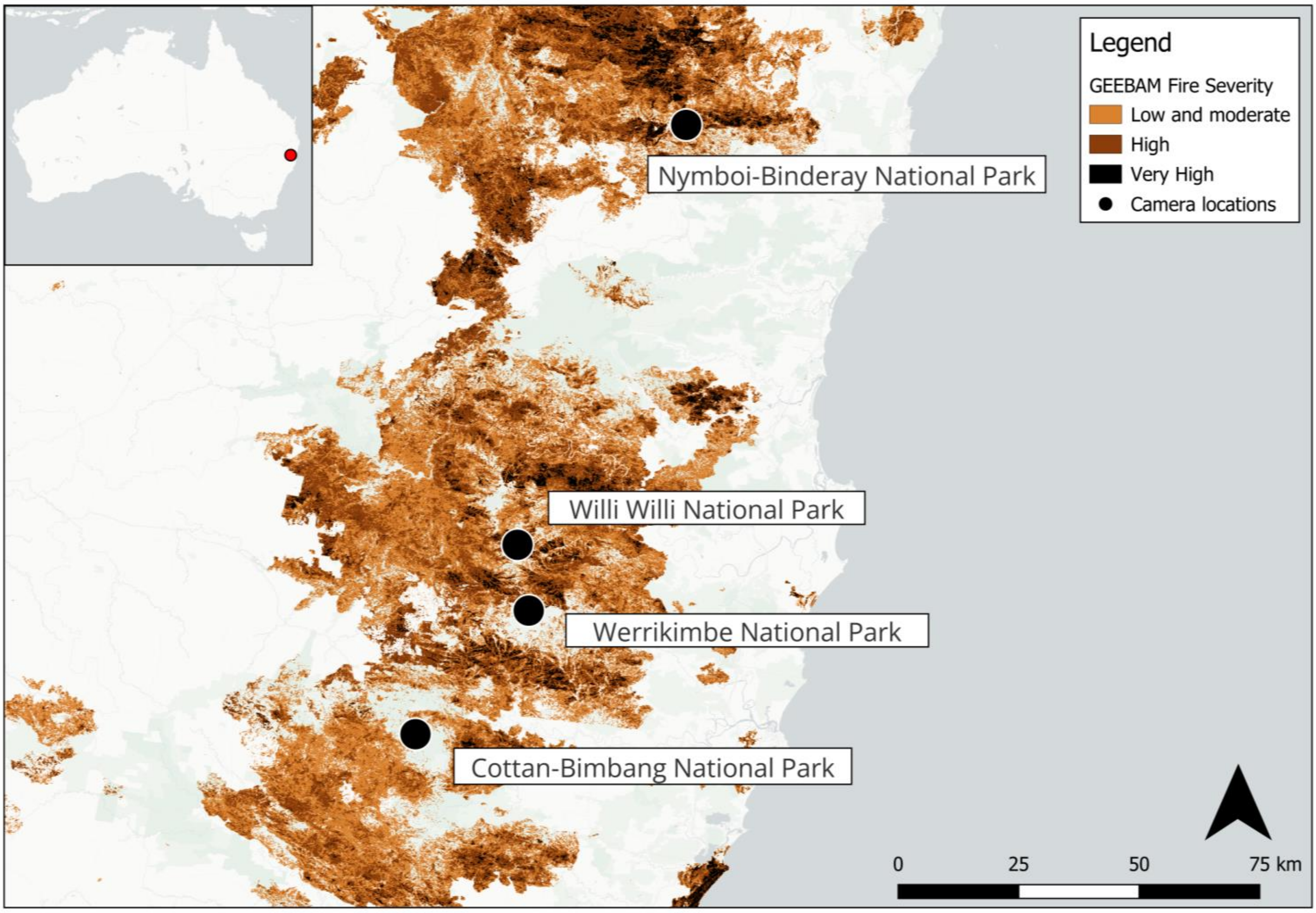

Figure 1. Locations of the four camera survey locations in Northern NSW, overlaid on the 2019/20 wildfire severity Google Earth Engine Burnt Area Map data.

PROJECT OVERVIEW AND AIMS

Australia's 2019–20 mega-fires were unprecedented in extent and burnt 10 million hectares across south-eastern Australia[1]. The mega-fires are considered Australia's largest wildlife disaster, resulting in the death or displacement of almost 3 billion animals, including threatened fauna[2]. The extent of habitat burnt may have further increased the number of threatened wildlife by 14%. The lack of long-term survey information necessitated the establishment of rapid on-ground post-fire assessments to aid in post-fire recovery planning for affected wildlife. We describe the results of such assessments across several reserves in the NSW National Parks and Wildlife (NPWS) North Coast Branch after the mega-fires swept through.

In NSW, there were 293 threatened animal species or populations with records within the fire ground[3]. This project focuses on two of these threatened species present on NPWS estate in the North Coast Branch: the long-nosed potoroo (*Potorous tridactylus*) and the parma wallaby (*Notamacropus parma*). Both the long-nosed potoroo and parma wallaby are currently listed as vulnerable. The long-nosed potoroo had 97% of all

[1] Wintle et al. 2020. After the megafires: What next for Australian wildlife? Trends in Ecology & Evolution, 35(9), 753–757.
[2] Van Eeden et al. 2020. Impacts of the unprecedented 2019–2020 Bushfires on Australian animals. Report Prepared for WWF-Australia.
[3] DPIE. 2020. Wildlife and Conservation Bushfire Recovery: Immediate Response January 2020. Department of Planning, Industry and Environment: Sydney, NSW.

records located within the fire extent, while 10% of all parma wallaby records were within the fire extent.

The specific aims of this project were to: (1) monitor the presence of the threatened long-nosed potoroo and parma wallaby, and (2) monitor the presence of other fauna species in fire-impacted reserves following the 2019-2020 bushfires.

METHODS

A total of 52 camera sites were selected for monitoring surveys across 4 reserves in the study region: Cottan-Bimbang National Park (NP; 12 cameras), Nymboi-Binderay NP (20 cameras), Werrikimbe NP (10 cameras) and Willi Willi NP (10 cameras; **Figure 1**). These reserves were chosen as they all (i) were heavily impacted by the 2019-20 bushfires, (ii) had little to no current camera coverage, and (iii) were identified as having habitat suitable for the target threatened species.

Each reserve was impacted differently by the 2019-20 wildfires, with Willi Willi and Nymboi-Binderay NPs having the highest percentage of land burnt by the fires and Cottan-Bimbang NP the lowest (**Table 1**). Camera sites in Nymboi-Binderay, Werrikimbe and Willi Willi NPs were generally positioned in habitat burnt by low/moderate, high, and extreme burns (**Figure 2**), while cameras in Cottan-Bimbang NP had one camera placed in unburnt habitat with others distributed in habitat impacted by low/moderate severity burns (**Table 1**).

Table 1. Area burnt in each National Park and positioning of cameras across habitat affected by different fire severities.

National Park	Area Burnt (ha)	% Burnt	Camera site fire severity
Cottan-Bimbang	10391.9	70.8%	Low/mod=9 Unburnt = 1
Werrikimbe	15344.2	80.1%	Low/mod=6 High=3 Extreme=1
Nymboi-Binderay	12080.7	90.8%	Low/mod=12 High=7 Extreme=1
Willi Willi	30322.5	93.0%	Low/mod=7 High=3

Within the chosen reserves, camera sites were selected to match the preferred habitat of both parma wallabies and long-nosed potoroos. For example, the optimum habitat for parma wallabies is wet or dry sclerophyll forest with a thick, shrubby understorey and grassy patches and occasionally rainforest habitat[4]. Long-nosed potoroos habitat preferences include coastal heaths and wet and dry sclerophyll forests, and dense canopy and shrub cover[5].

Figure 2. Habitat burnt with very high severity fire in Nimboi-Binderay National Park.

Swift Enduro cameras were used to survey wildlife except in Cottan-Bimbang NP where Reconyx Ultrafire WP9 cameras were used (**Figure 3**). Cameras were positioned approximately 50m from trails to ensure that they were accessible, and that camera servicing could be maintained over long periods of time. At each site, cameras were placed along a transect and were located approximately 500m apart. Lures of peanut butter and rolled oats were used, as they have been found to be successful in attracting parma wallaby and long-nosed potoroo to camera traps. Lures were made using either PVC pipes with end caps, or drain cowls with end caps, and secured to star pickets using nuts and bolts.

Figure 3. Checking a camera in Nymboi-Binderay National Park.

Cameras were deployed beginning in March 2021, with specific deployment periods differing for each reserve. Camera monitoring is ongoing in some locations, and this report includes data up until 31 July 2022.

[4] Maynes. 2008. Parma wallaby *Macropus parma*, in Van Dyck & Strahan (Eds) The Mammals of Australia. Reed New Holland. Chatswood, New South Wales. pp. 200–50.

[5] Norton et al. 2010. Habitat associations of the long-nosed potoroo (*Potorous tridactylus*) at multiple spatial scales. Australian Journal of Zoology 58, 303-16.

Camera images were uploaded to the online image processing platform Wildlife Insights, where they were identified and sorted to species where possible. For images of animals that could not be identified to species, the closest taxonomic grouping was used e.g. “Aves”, “Macropod” etc., or “Unknown”. For the purpose of clarity, some less common species were grouped for the purposes of visualisation (e.g. “Possum species”, “Passerine Birds”, “Doves and Pigeons”, “Small Mammal”; which included small mammal species <500g).

Once all images were classified, detection events were isolated by grouping all images of a species or species group that were taken on a single camera and within 30 minutes of each other into single events. These detection events were then totalled across each camera. To account for differences in camera monitoring effort (some cameras stopped functioning due to low battery of full memory cards), “encounter rates” for each species or species group were calculated by dividing the total number of detection events for each species/species group at a camera by the total number of days that camera was active and then multiplying that number by 100. This final value was then averaged over all cameras within each reserve.

KEY FINDINGS

Across all cameras, at least 50 species were detected across almost 40,000 images of wildlife. Across the four reserves, the greatest number of species were recorded at Cottan-Bimbang NP (at least 35 species), then Weirrikimbe and Nimboi-Binderay NPs (both at least 31 species each), and lastly Willi Willi NP (at least 23 species). The most commonly detected species included superb lyrebirds (*Menura novaehollandiae*), Northern brown bandicoots (*Isoodon macrourus*), brush-turkeys (*Alectura lathami*) and swamp wallabies (*Wallabia bicolor*).

In terms of priority species, Cottan-Bimbang NP recorded the highest average encounter rate for parma wallabies, with the other three reserves recording lower but similar average encounter rates for this species (**Figure 4**). On the other hand, the average encounter rate for long-nosed potoroos was similar across reserves, except in Willi Willi NP where they were not detected (**Figure 4**).

Koalas (*Phascolarctos cinereus*) and spotted-tailed quolls (*Dasyurus maculatus*), which are both listed as endangered on the *Environment Protection and Biodiversity Conservation (EPBC) Act 1999*, were also recorded in the survey. Koalas were encountered slightly more in Cottan Bimbang NP compared to other reserves but were not detected in Willi Willi NP, and spotted-tailed quolls were detected at similar levels in three reserves but were not detected in Nymboi-Binderay NP (**Figure 4**).

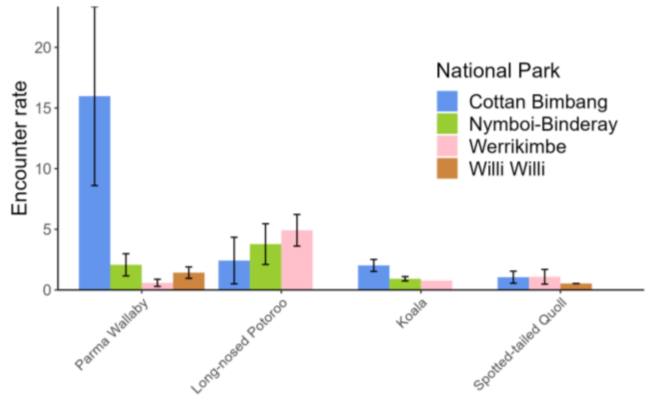

Figure 4. Average encounter rate for priority species recorded across the four study reserves

In general, native species were encountered most frequently in Cottan Bimbang NP, while species were encountered at a similar rate across Willi Willi, Werrikimbe and Nymboi-Binderay NPs (**Figures 4, 5**). This was perhaps unsurprising, as Cottan Bimbang NP had the least burnt area of the four reserves, with cameras set in only low/moderately burnt habitat or unburnt habitat. Some common native species were not observed in all reserves; for example northern brown bandicoots (*Isoodon macrourus*) did not appear in Willi Willi NP and red-necked wallabies (*Notamacropus rufogriseus*), red-necked pademelons (*Thylogale thetis*) and eastern grey kangaroos (*Macropus giganteus*) were not detected in Willi Willi or Nymboi-Binderay NPs (**Figure 5**).

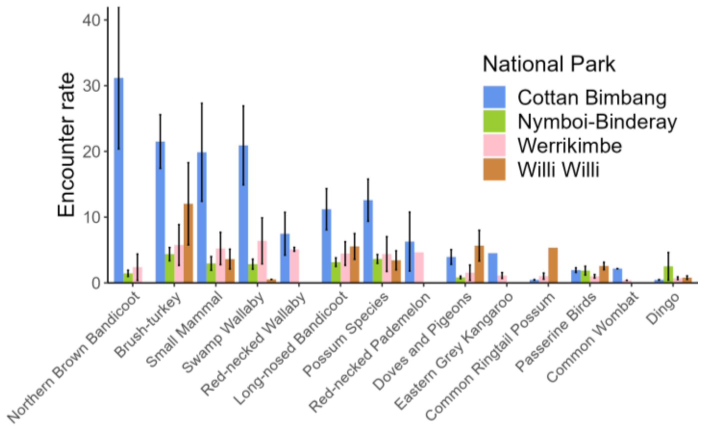

Figure 5. Average encounter rate for commonly encountered native species recorded across the four study reserves.

Of feral mammalian species, feral cats (*Felis catus*) were most frequently encountered, especially in Cottan Bimbang NP (**Figure 6**). On the other hand, feral pigs (*Sus scrofa*) were not recorded in Nymboi-Binderay NP, red foxes (*Vulpes vulpes*) were only seen in Werrikimbe and Willi Willi NP and cattle (*Bos taurus*) were recorded in Nymboi-Binderay and Willi Willi NP (**Figure 6**).

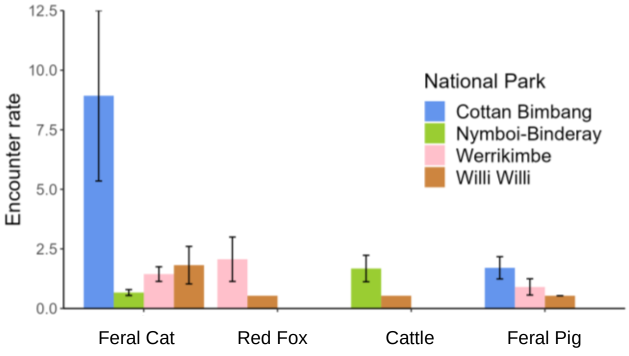

Figure 6. Average encounter rate for feral animal species recorded across the four study reserves.

MANAGEMENT OUTCOMES

Project records have been uploaded into BioNet, the repository for biodiversity data managed by the NSW Department of Planning and Environment. Inclusion in BioNet allows the location and habitat requirements of these species to be incorporated into fire management planning and environmental assessments, leading to better protection during NSW NPWS hazard reduction, wildfire suppression, and asset maintenance operations.

Results have also been used to inform an update on the State of Conservation of the Gondwana Rainforests of Australia World Heritage Area, as the parma wallaby contributes to the Outstanding Universal Value of the World Heritage property. NSW NPWS will continue to monitor presence and breeding of these species to detect changes in populations and identify threats.

The cameras also detected pest predators. NSW NPWS will use this information to monitor the effectiveness of and refine pest control programs to protect these threatened species. The findings of this project will be shared with species experts and threatened species officers for consideration in the NSW-wide management of this species under the Assets of Intergenerational Significance and Saving our Species programs.

THREATENED MACROPODS SURVIVED THE CATASTROPHIC 'BLACK SUMMER' BUSHFIRES

Location: Hunter Central Coast New South Wales, Australia

Project Partners: Kieran Marshall and Ben Karlson from NSW National Parks and Wildlife Service

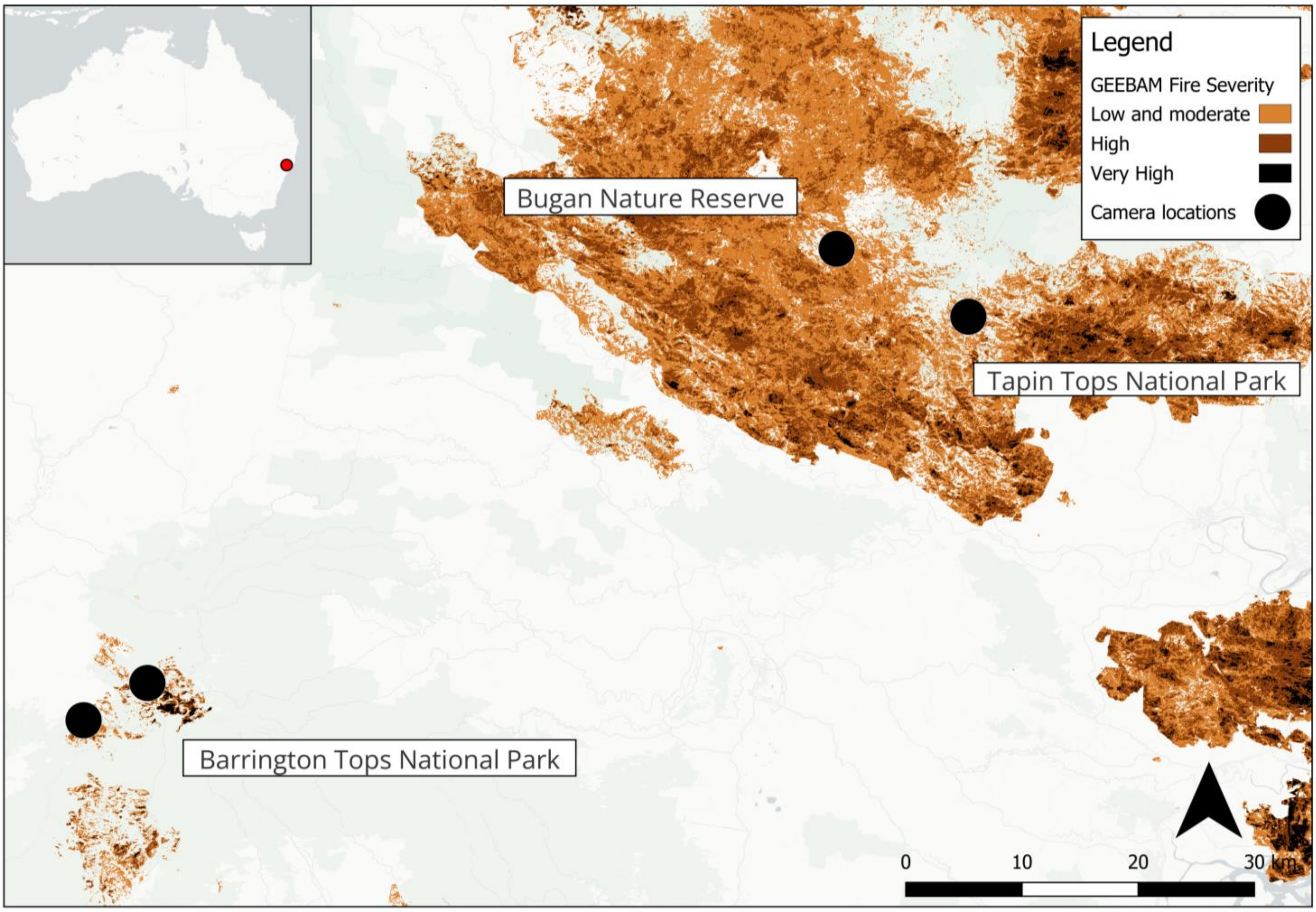

Figure 1. Locations of four study sites, across three National Parks in the Hunter Central Coast region, overlaid on the 2019/20 wildfire severity Google Earth Engine Burnt Area Map data.

PROJECT OVERVIEW AND AIMS

Following the 2019-2021 bushfires more than 2.7 million hectares, equal to 38% of the NSW national park estate, were burnt. With support from WWF-Australia and the Federal bushfire recovery grants, a camera monitoring project was developed to facilitate strategic on-ground support for the most impacted native species and ecological communities across the Hunter Central Coast Branch.

Post-fire surveys for threatened animals are an essential component of assessing the impact of fires on threatened species and to help direct recovery efforts, such as post-fire pest control. One hundred remote cameras were installed and maintained from January 2022 to June 2023 in fire affected areas in Barrington Tops National Park, Tapin Tops National Park and Bugan Nature Reserve.

The focus of this study was key weight range mammal occupancy within burnt patches of rainforest – wet sclerophyll interfaces, compared with unburnt patches. Specifically, this study targeted parma wallabies (*Notamacropus parma*), red-legged pademelons (*Thylogale stigmatica*), rufous bettongs (*Aepyprymnus rufescens*), spotted tail quolls (*Dasyurus maculatus*) and long nosed potoroos (*Potorous tridactylus*), which are all listed as either vulnerable or threatened under NSW state legislation. This study addressed the questions: (1) Has the distribution and occupancy of key weight range mammals changed from before and after the 2019/2020 black summer fires? (2) To what extent are feral species occupying post fire recovery sites? (3) How to develop a baseline data set of threatened and feral animals from which to measure the effectiveness of management practices?

METHODS

This project ran from January 2021 to June 2023 and drew upon data from a total of one hundred Reconxy Hyperfire 2 cameras deployed across four study areas. These study areas incorporated parts of Barrington Tops National Park (2 study areas), Tapin Tops National Park (1 study area) and Bugan Nature Reserve (1 study area) (**Figure 1**).

Cameras were deployed using methodology adapted from McHugh et al. (2019)[1] based on average home ranges of long-nosed potoroos and parma wallabies. Sites were stratified by fire intensity according to Fire Extent and Severity Mapping (FESM) and on-ground verification, as well as vegetation community type (**Figure 2**). These surveys were conducted in conjunction with spotlighting surveys for greater gliders and yellow bellied gliders, thermal imagery analysis for hard-hooved pests, call playback surveys for large forest owls, and passive audio surveys targeting koalas.

Figure 2. Setting up wildlife cameras in fire-impacted habitat (NPWS HCCB).

Survey work is ongoing, and this report incorporates data up until March 2023. Additional key findings addressing the study's key questions will be available once a full analysis of the project's data is completed.

KEY FINDINGS

As part of this project over 536,000 photos have been processed to date, with around 370,000 including images of wildlife. At least 78 animal species were identified in camera images, with swamp wallabies (*Wallabia bicolor*), red-necked wallabies (*Notamacropus rufogriseus*), long-nosed bandicoots (*Perameles nasuta*) and red-necked pademelons (*Thylogale thetis*) the most frequently detected native species.

Across the fire-impacted survey locations, nine species of threatened mammalian fauna were identified, including NSW State Listed endangered greater gliders (*Petauroides volans*) and koalas (*Phascolarctos cinereus*), and vulnerable flame robins (*Petroica phoenicea*), long-nosed potoroos (*Potorous tridactylus*), parma wallabies (*Notamacropus parma*), red-legged pademelons (*Thylogale stigmatica*), spotted-tailed quolls (*Dasyurus maculatus*), yellow-bellied gliders (*Petaurus australis*) and brush-tailed phascogales (*Phascogale tapoatafa*) (**Table 1**).

Table 1: Threatened Species identified by national park (NP) or nature reserve (NR).

	NSW State Listing	Location		
		Barrington Tops NP	Tapin Tops NP	Bugan NR
Flame robin	v	x		
Greater glider	e	x		
Koala	e	x	x	x
Long-nosed potoroo	v	x	x	x
Parma wallaby	v		x	x
Red-legged pademelon	v	x	x	x
Spotted-tailed Quoll	v	x		x
Yellow-bellied glider	v	x		
Brush-tailed phascogale	v	x		
v = Vulnerable, e= Endangered				

Phascogales, greater gliders, yellow-bellied glider and flame robins were only detected at one or two camera sites, with all detections occurring in the Barrington Tops National Park. Long-nosed potoroos were detected across all national parks (at 24 camera sites), as were red-legged pademelons and koalas (**Figure 3**) (both 18 sites). Spotted-tailed quolls were detected at 23 sites, in Barrington Tops National Park and Bugan Nature Reserve and parma wallabies were detected at 11 camera sites, in Tapin Tops National Park and Bugan Nature Reserve.

Figure 3. Koala with joey, Tapin Tops National Park (NPWS HCCB).

[1] McHugh et al. 2019. Habitat and introduced predators influence the occupancy of small threatened macropods in subtropical Australia. Ecology and Evolution 9:6300-6317.

Invasive predators and hard hooved herbivores were also present within the post-fire landscape, especially feral cats (*Felis catus*; detected at 49 camera sites), feral pigs (*Sus scrofa*; 46 sites), deer (including red deer; *Cervus elaphus*, and sambar; *Rusa unicolor*, 16 sites), rabbits/hare (*Oryctolagus cuniculus* and *Lepus europaeus*; 14 sites) and red foxes (*Vulpes vulpes*; 13 sites).

MANAGEMENT OUTCOMES

One of the main findings of this project was the presence of feral predators within the habitat of key weight range mammals and the presence of significant number of pigs and deer within burnt landscapes including several Endangered Ecological Communities.

As a result, a set of complementary on-ground and aerial pest programs were implemented in direct response to data collected from this study. The range of techniques implemented targeted the protection of vulnerable post-fire ecological communities and threatened species habitat.

In order to inform our understanding of effective pest management practices within post-fire recovery areas, the rolling baseline data set established under this program will continue to be maintained as current and future pest management is implemented.

BLUE MOUNTAINS POST-MEGAFIRE RECOVERY SURVEY

Location: Blue Mountains New South Wales, Australia

Project Partners: Aaron Greenville, Pascale Pinn, Chris Dickman and Glenda Wardle from the University of Sydney

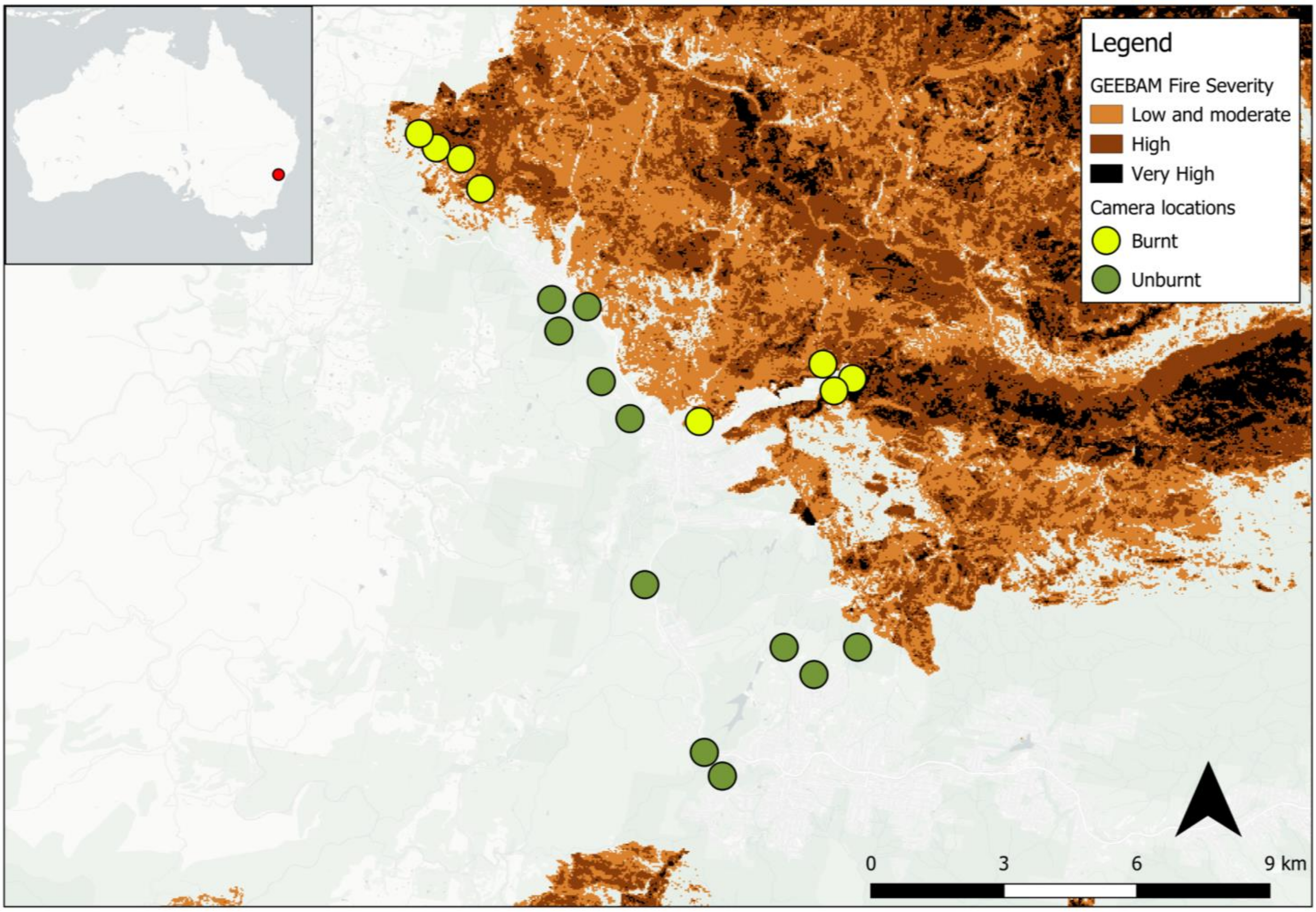

Figure 1. Location of study sites across Blue Mountains City Council reserves in the Blue Mountains, NSW, overlaid on the 2019/20 wildfire severity Google Earth Engine Burnt Area Map data.

PROJECT OVERVIEW AND AIMS

Australia's 2019/20 mega-fires were unprecedented, with 24 million hectares burnt across south east Australia[1]. The wildfires across Australia resulted in the death or displacement of almost 3 billion animals, and the extent of habitat burnt may increase the number of threatened fauna by 14%[2,3]. The mega-fires are considered Australia's largest wildlife disaster[2]. In the fire extent of the Greater Blue Mountains World Heritage Area, 71% burnt, including 34% that recorded a combined high and extreme fire severity[4,5]. As a result of the wildfires, the conservation outlook for the Blue Mountains World Heritage Area was downgraded to 'Significant Concern' by the IUCN[4].

Invasive predators, such as red foxes and feral cats, pose a significant extinction risk to wildlife after fire events[6,7], using the newly-opened forest floor habitat as an open hunting arena. To aid post-fire recovery of native species, threat abatement programs are therefore essential. Such programs can include trapping, shooting, fumigation of den sites and baiting, and need information on predator numbers and locations as well as native prey species that are most at risk. This project aims to inform vertebrate control

[1] Wintle et al. 2020. After the megafires: What next for Australian wildlife? Trends in Ecology & Evolution 35: 753-757.
[2] Van Eeden et al. 2020. Impacts of the unprecedented 2019–2020 bushfires on Australian animals. Report Prepared for WWF-Australia.
[3] Ward et al. 2020. Impact of 2019–2020 mega-fires on Australian fauna habitat. Nature Ecology & Evolution. 4:1321–1326.
[4] Osipova et al. 2020. Greater Blue Mountains Area:2020 Conservation Outlook Assessment. Pp. 90 in IUCN World Heritage Outlook 3: A conservation assessment of all natural World Heritage sites. edited by IUCN: Gland, Switzerland.
[5] Smith 2021. Impact of the 2019-20 Fires on the Greater Blue Mountains World Heritage Area - v2 (report to Blue Mountains Conservation Society). Blaxland, NSW.
[6] McGregor et al. 2017. Habitat preference for fire scars by feral cats in Cape York Peninsula, Australia. Wildlife Research 43: 623-633.
[7] McGregor et al. 2016. Extraterritorial hunting expeditions to intense fire scars by feral cats. Scientific Reports 6: 22559.

programs administered by the Blue Mountains City Council (BMCC) and contribute to postfire recovery of native species. Our specific aims are to: (1) Determine spatial trends in relative abundance of vertebrate fauna presence and the relative abundance of these animals across burnt and unburnt Council reserves, and (2) Reveal the interaction between vegetation and fire two years after the megafires.

METHODS

This survey used 19 of 22 camera sites established during a one-year rapid post-fire survey of this region that was undertaken in 2020[8] (**Figure 1**). Eleven of the sites used were not burnt during the 2019/20 fires, while eight were burnt by fires of medium to high intensity (**Figure 2**). Data used in this summary was collected by camera traps over approximately 4 months (approx. 01/04/2022 – 28/08/2022).

Figure 2. Example of vegetation differences at burnt and unburnt sites in the BMCC reserves. Left image shows regrowth at a burnt site: dense understorey primarily consisting of basal resprouting by Eucalyptus species, plus epicormic growth on trees in the background. Right image shows dense mid-storey at an unburnt site.

In April 2022, one Swift Enduro (Outdoor Cameras Australia, Toowoomba, QLD, Australia) camera trap was deployed at each of the 19 sites. These were attached to the same tree (> 20 cm diameter to prevent movement) and beneath the camera traps from the previous survey (Buckeye X7D Wireless model; Buckeye Cam Wireless, Athens, OH, USA) to allow for future comparison of results as different camera models may differ in their ability to successfully detect wildlife (**Figure 3**). The Swift cameras were secured to the trees using a tie-down strap and a Python Cable Lock (The Lock People, San Diego, CA, USA). Swift cameras were situated approximately 80 cm above the ground and aimed to capture a field of view similar to that of the camera from the previous survey. Camera traps were set to the highest sensitivity rating and were programmed to take five consecutive photos whenever movement was sensed. To reduce false triggers, vegetation within the field of view was trimmed (where reasonable).

Species were identified from the images taken from cameras using the Wildlife Insights Platform. Wildlife Insights employs artificial intelligence (AI) to assist with species identification. All AI species identifications were verified by an ecologist, and an ecologist identified any species the AI could not. Tagging was performed to species level, wherever possible, and a count of how many of each species were in each image was also tagged. In cases where species level identification was not possible, animals were tagged to a general group level, such as "Macropodidae" or "Aves". Blurry or poor-quality images in which species or groups could not be identified were tagged as "Unknown", and any images where no animal could be identified were tagged as "Blank". Note that only 1 photo of the same species from the same camera will be included if they occur within 5 minutes of each other to prevent counting the same individual repeatedly.

Figure 3. Camera set up with Buckeye camera positioned above Swift Enduro camera.

Species richness was defined as the number of species present at each site, inclusive of both native and non-native species. Species activity measures were calculated as relative abundance indices (RAI) based on independent images captured of each species, at each camera site. We used RAIs to account for differences in the number of days that each camera was active. To calculate RAIs, we used the following equation:

"Relative Abundance Index (RAI)" = ("Total number of independent images" ×100)/"Camera-days"

where the "total number of independent images" included the sum of all independent image (i.e. those

[8] Spencer et al. 2022. One year on: rapid assessment of fauna and red fox diet after the 2019–20 mega-fires in the Blue Mountains, New South Wales. Australian Zoologist 42, 304-325.

taken more than 5 min after any consecutive image) and where "camera-days" included the number of days that each camera was active. We calculated the mean RAI per fire treatment.

In addition to camera surveys, we also conducted vegetation surveys in July 2022. A point-intercept survey method was used to measure vegetation structure as it relates to habitat attributes for wildlife, such as shelter. At each site, three 20 m transects were selected, with the camera traps as the fixed starting point. Transects were 10 m apart, and parallel to each other, creating a 20 x 20 m plot. Vegetation structure was recorded every second metre along each transect (from 0-20m, inclusive), for a total of 33 measurements per site.

KEY FINDINGS

The camera trap survey accumulated a total of 2,789 active camera trap days from the 1st of April until the 28th of August 2022. During this time, the Swift Enduro cameras captured a total of 51,846 images, including 21,812 images of animals and 2,272 'independent images' of animals. All cameras remained functional throughout the survey period; however, due to fieldwork logistics the active camera trap days varied from 145–149 days per camera.

There were 34 vertebrate species identified, including 16 mammals and 18 birds. The most commonly detected species were swamp wallabies, followed by the small mammal (< 500g) grouping, and Eastern grey kangaroos. Small mammals (< 500g) included bush rats (*Rattus fuscipes*), Antechinus spp. (dusky antechinus, *Antechinus mimetes* and brown antechinus, *Antechinus stuartii*), and other unidentifiable small mammals which appeared to weigh less than 500 grams. Overall species richness differed significantly between burnt (mean ± standard error: 6.0 ± 0.7) and unburnt sites (8.6 ± 1.2). The unburnt Fairy Bower site had the highest species richness (17 species), whereas the burnt Mt York (1) site had the lowest (3 species) (**Figure 4**).

Introduced species

The red fox (169 independent images) and three other invasive species were identified: the feral cat (8 independent images), European rabbit (*Oryctolagus cuniculus*) (4 independent images) and feral goat (*Capra hircus*) (4 independent images). Red foxes were mostly found at unburnt sites (23 images), predominantly at Bonne Doone Reserve 1 (15 images), and followed by Medlow Bath Station St Reserve (4 images). Other fox sightings were at Pulpit Rock Reserve 1 (3 images), Bonne Doone Reserve 2 (2 images), Fairy Bower (2 images), Lockyer's Track 1 (1 image), Rock Hill Reserve (1 image) and the Rhododendron Garden (1 image). Domestic cats (*Felis catus*) were only spotted twice; once at Bonne Doone Reserve 2 and once at Fairy Bower, both of which are unburnt sites (**Figure 5**). Feral goats (*Capra hircus*) were found twice at a burnt site (Lockyer's Track 2). A single domestic dog (*Canis lupus familiaris*) was spotted at Lockyer's Track 1.

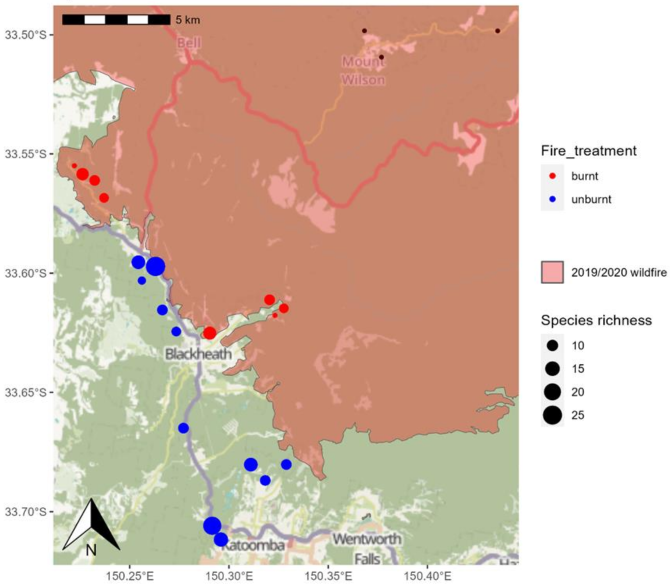

Figure 4. Species richness across sites at the Blue Mountains City Council reserves.

Commonwealth priority species

Superb lyrebirds (*M. novaehollandiae*) were the sixth most common species recorded (64 independent images). The superb lyrebird was identified across nine unburnt (mean Relative Activity Index (RAI): 2.7) and four burnt sites (mean RAI: 1.7). No statistical difference in activity was found at burnt and unburnt sites. They were most commonly found at Lockyer's Track 1 (burnt site), with the rest found at Fairy Bower, Bonne Doone Reserve 1, and Medlow Bath Station Street Reserve. Unfortunately, no rockwarblers (*Origma solitaria*) were identified.

We also found that the response of most species was linked to vegetation structure. Many species, especially small mammals, preferred habitats with dense plant cover, likely as it provides them shelter and helps them to avoid predators like red foxes and feral cats. Further, the move to wet conditions from successive years of La Nina has accelerated the regrowth of understorey vegetation across the fire ground, which may also be assisting in species recovery post-fire.

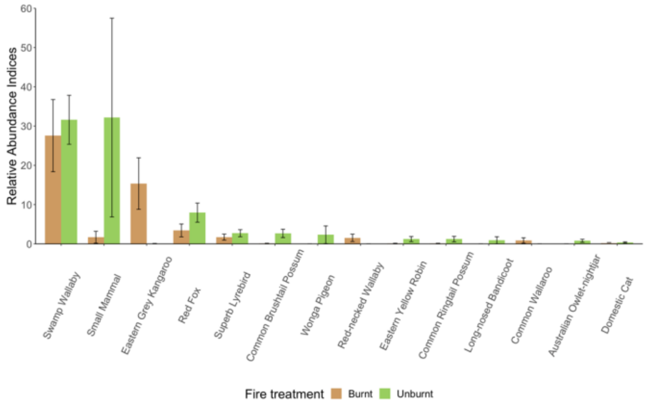

Figure 5. Average relative abundance indices (± standard error) for the 14 most common species or species groups, across burnt and unburnt sites in the Blue Mountains City Council reserves, NSW[9].

MANAGEMENT OUTCOMES

These results (and the ongoing camera monitoring at these sites) will help to inform more effective management decisions in the Blue Mountains, and similar fire-prone ecosystems. Such knowledge is essential for the preservation of biodiversity, especially as the frequency and severity of wildfires is expected to continue increasing with climate change impacts predicted to worsen.

While this survey showed that vertebrate fauna assemblages differed between fire treatments, vegetation and substrate cover were more important in determining abundance of the four most common species. Comparing results from this survey to the initial survey conducted in 2020[8], it is also clear that species are responding positively to vegetation regrowth from successive La Nina years. This suggests that for areas that burnt in the 2019-20 fires, careful consideration is required before introducing fire to locations where the tree canopy cover was lost, as the understorey regrowth from the rains may be aiding in species recovery.

As this study is part of a continuous and long-term collaborative project with the Blue Mountains City Council, the results are being regularly shared with council land managers. As such, they are helping to inform reserve management practices, providing regular assessment of the success of feral animal control activities and habitat restoration works including weed management.

[9] Pinn 2022. Assessing post-megafire recovery of flora and fauna in the Blue Mountains. Honours thesis, University of Sydney, Sydney.

CAN ECOSYSTEMS RECOVER UNDER A CHANGING WILDFIRE REGIME IN THE GREATER BLUE MOUNTAINS WORLD HERITAGE AREA?

Location: Blue Mountains New South Wales, Australia

Project Partners: Aaron Greenville, Chris Dickman and Glenda Wardle from the University of Sydney

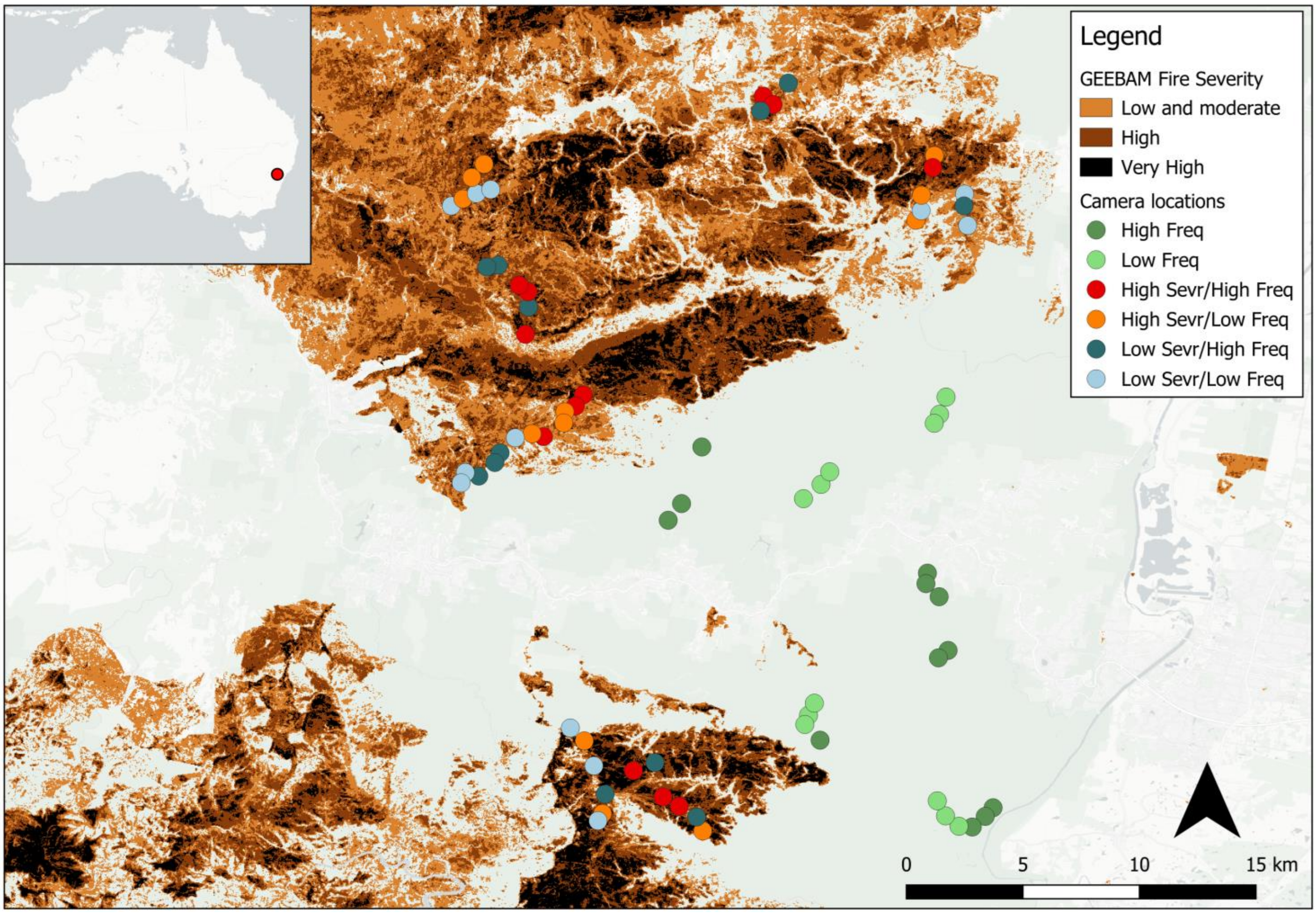

Figure 1. Location of study sites across National Parks and Wildlife Service reserves in the Blue Mountains, NSW, overlaid on the 2019/20 wildfire severity Google Earth Engine Burnt Area Map data. Camera locations are coloured by whether they are positioned in habitat impacted by high/low frequency fires, and by low/high severity burns during the 2019-20 fires.

PROJECT OVERVIEW AND AIMS

The unprecedented pace of global environmental change in our new geological epoch—the Anthropocene—is coupled with increases in disturbance events, such as extreme wildfires[1]. Australia's 2019/20 wildfire season was unprecedented[2,3], but just how ecosystems respond to dramatic disturbances is highly uncertain[4]. Nor do we understand the complex responses of ecosystems to increases in fire frequency and severity because of climate change. The 2019–20 mega-fires burnt 71% of the Greater Blue Mountains World Heritage Area (697,564 ha), with 34% of the region recording either high or extreme fire severity[5,6]. The first fire—Gospers Mountain Fire—started in late October 2019 and was also the last fire to be extinguished after a major rainfall event in February 2020. The thresholds for optimal return-time of fire were exceeded, placing the region's

[1] Jolly et al. 2015. Climate-induced variations in global wildfire danger from 1979 to 2013. Nature Communications 6: 7537.
[2] Boer et al. 2020. Unprecedented burn area of Australian mega forest fires. Nature Climate Change 10: 171-172.
[3] Nolan et al. 2020. Causes and consequences of eastern Australia's 2019-20 season of mega-fires. Global Change Biology 26: 1039-1041.
[4] Greenville et al. 2018. Biodiversity responds to increasing climatic extremes in a biome-specific manner. Science of the Total Environment 634: 382-393.
[5] Osipova et al. 2020. Greater Blue Mountains Area:2020 Conservation Outlook Assessment. Pp. 90 in IUCN World Heritage Outlook 3: A conservation assessment of all natural World Heritage sites. edited by IUCN: Gland, Switzerland.
[6] Smith 2021. Impact of the 2019-20 Fires on the Greater Blue Mountains World Heritage Area - v2 (report to Blue Mountains Conservation Society). Blaxland, NSW.

vegetation into a vulnerable ecological state[7]. As a result of the extensive nature and severity of the wildfires, the conservation outlook for the Blue Mountains World Heritage Area was downgraded to 'Significant Concern' by the IUCN[6].

To aid post-fire recovery of native species, we must understand the complexity of the interactions among threats from increased fire frequency and severity. This project aims to investigate how the fire severity and past fire frequency affect the trajectory of change in species composition and abundances from the 2019/20 mega-fires in the greater Blue Mountains and thus provide new insights into how communities may respond under changing wildfire regimes.

METHODS

Survey plots were established in the Greater Blue Mountains World Heritage Area to quantify changes in species loss, gain, and composition after the 2019-20 megafires. There were 72 study sites set up as part of the project (**Figure 1**). The sampling design was hierarchical, with four '2019/20 burnt' sites and four '2019/20 unburnt' sites selected, matched for vegetation type and interspersed spatially. Within each of the burnt sites, there were two treatment levels for fire frequency: low (< 3 wildfires since 1960s) and high (>5 fires since 1960s), and a further two levels for fire severity: high-extreme and low-moderate (**Figure 2**).

Figure 2. Regrowth in a habitat impacted by a high severity fire.

Each combination of fire frequency and severity was replicated three times (i.e. 4 burnt sites × 2 fire frequencies × 2 fire severities × 3 replicates). Within each of the unburnt sites (control), there were also two treatment levels per fire frequency (low and high, as above) that were replicated three times (i.e. 4 unburnt sites × 2 fire frequencies × 3 replicates).

At each camera station, a bait of peanut butter and oats was used to lure animals to the cameras and get animals to pause at the station for identification (**Figure 3**). Of the 72 cameras, 12 at Kings Tableland require processing and are not included in this report.

Figure 3. Setting up camera and lure station in burnt habitat in the Blue Mountains.

We calculated Relative Abundance Indices (RAI) as a measure of species activity and used N-mixture modelling to estimate the abundance of the most commonly detected species at each camera trap[8]. N-mixture modelling is an extension of occupancy modelling and adjusts estimates of abundance based on the detection probability of each animal. It assumes that the activity at each camera trap (count of images) is proportional to the number of animals available to be detected at each site[8]. The count of images were pooled for each week, after removing images of the same animal that were taken within 5 minutes of each other to avoid counting the same animal more than once per event. We also incorporated potential changes in detection probability due to longitude, week of survey and camera effort.

KEY FINDINGS

The camera trap survey accumulated a total of 717,760 (total as of May 2023) and a total of 15,865 active camera trap days from the 8/12/2021 04/11/2022 (included in this report). A total of 119,103 images of animals, with 44 species detected.

The species composition between fire severity and frequency differed two years after the wildfires. Small mammal abundance was lower at burnt sites with low severity fires compared to unburnt sites, but rapid regeneration of ground and shrub cover at high severity

[7] Nolan et al. 2021. Limits to post-fire vegetation recovery under climate change. Plant, Cell & Environment 44: 3471-3489.

[8] Royle 2004. N-Mixture models for estimating population size from spatially replicated counts. 60(1): 108-115.

sites may be aiding in recovery (**Figures 4, 5**). The Swamp Wallaby (*Wallabia bicolor*) was the most common species identified and occurred in higher abundances at burnt sites, regardless of severity and frequency compared to unburnt low fire frequency sites (**Figure 4**). There was no difference between unburnt high frequency sites and the burnt sites.

The second most common sighting was a Commonwealth priority species, the Superb Lyrebird (*Menura novaehollandiae*). The superb lyrebird was common across all fire treatments, except had lower abundance in unburnt sites with past high fire frequency (**Figures 4, 5**). This suggests that the species is recovering in the short-term and is more influenced by past fire frequency than the recent wildfires. However, rapid re-generation of vegetation after the consecutive wet periods since the 2019/20 wildfires has probably aided the superb lyrebird response.

Long-nosed bandicoots (*Perameles nasuta*) showed a strong response to the past fire frequency compared to the 2019/20 wildfires. The abundance of long-nosed bandicoots was lower at sites that experienced past high fire frequency compared to other treatments (**Figure 4**). In contrast, brush-tailed possums had higher abundances at unburnt sites compared to all burnt treatments (**Figure 4**). Lastly, the common wombat showed no response to fire treatment (**Figure 4**), suggesting it had recovered from the wildfires or was not impacted due to its ability to escape fire by using burrows.

MANAGEMENT OUTCOMES

Across the Blue Mountains region there are few areas that remain unburnt after the 2019-20 mega-fires and the results of this study indicate that this unburnt habitat is providing an important refuge for some species. Land managers in the Blue Mountains should therefore practice caution when determining where they conduct future hazard reduction burns. Further, as hazard reduction burns also influence the fire frequency history of different locations and the results of this study also indicate that fire frequency is an important driver for the activity or abundance of some species, longer-term fire history should also be an important consideration for future management burns too. For example, an unburnt site with a high fire frequency may not act as a refuge for some species.

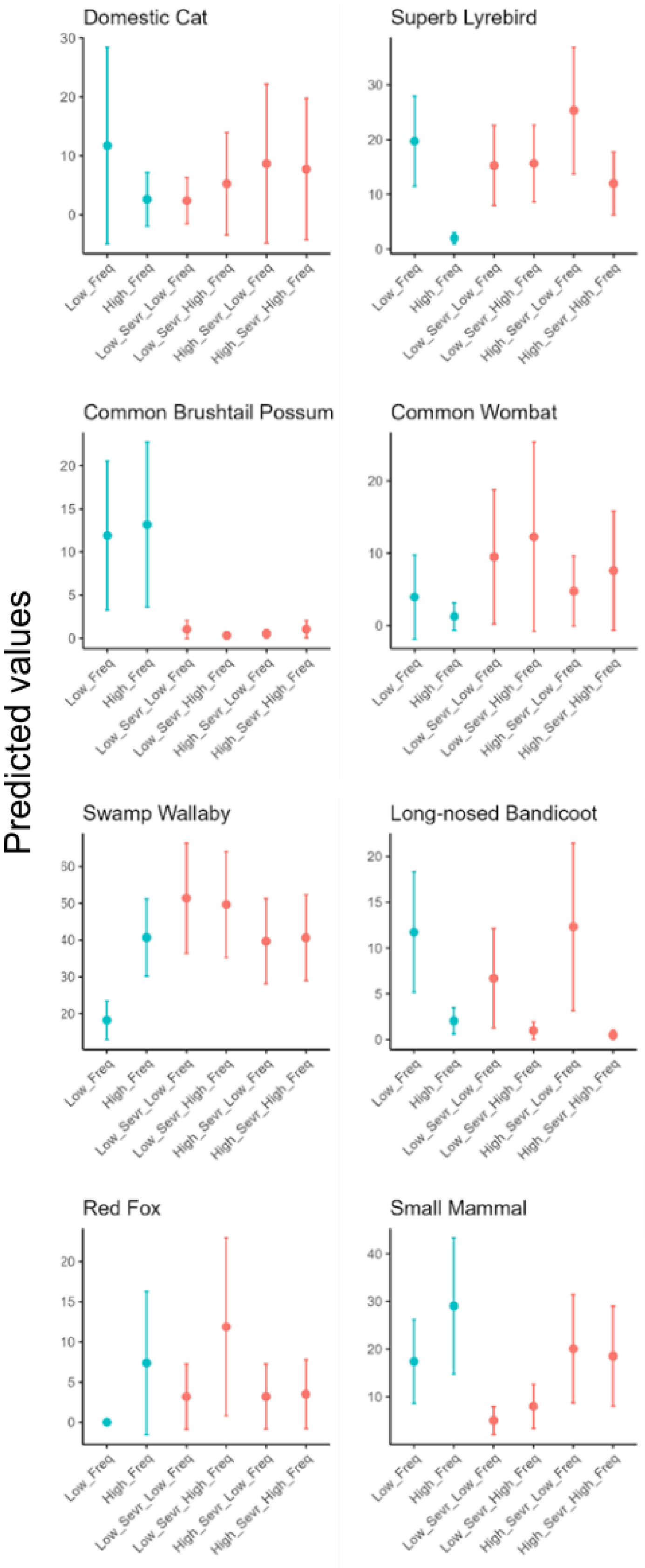

Figure 4. Predicted abundance of selected species across habitats with different fire severity and frequency histories in the Blue Mountains, NSW

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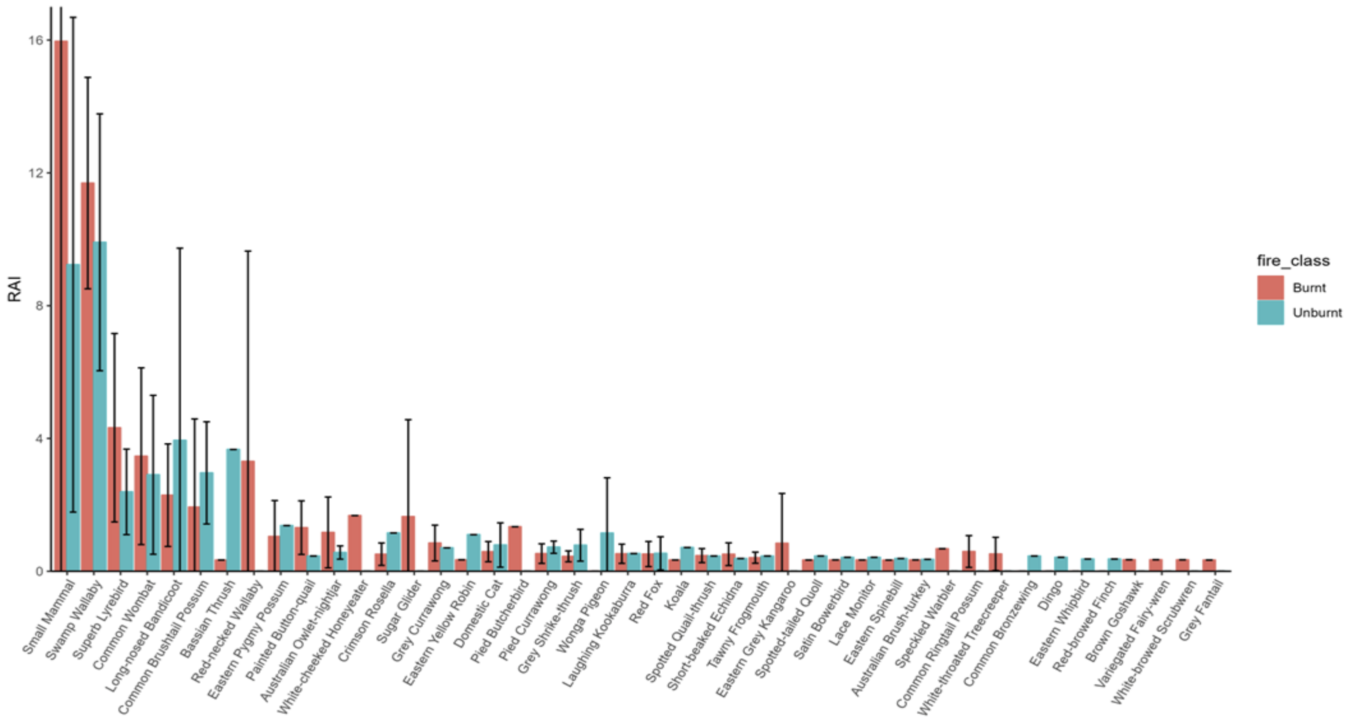

Figure 5. Mean relative abundance indices (RAI) (± 95% confidence intervals) for species detected across the Blue Mountains National Park and Blue Mountains City Council Reserves. Data from a total of 60 cameras were used.

POST-FIRE EVALUATION OF CRITICAL WEIGHT RANGE MAMMALS IN THE GREATER BLUE MOUNTAINS WORLD HERITAGE AREA

Location: Blue Mountains New South Wales, Australia

Project Partners: Victorian Inman and Kellie Leigh from Science for Wildlife

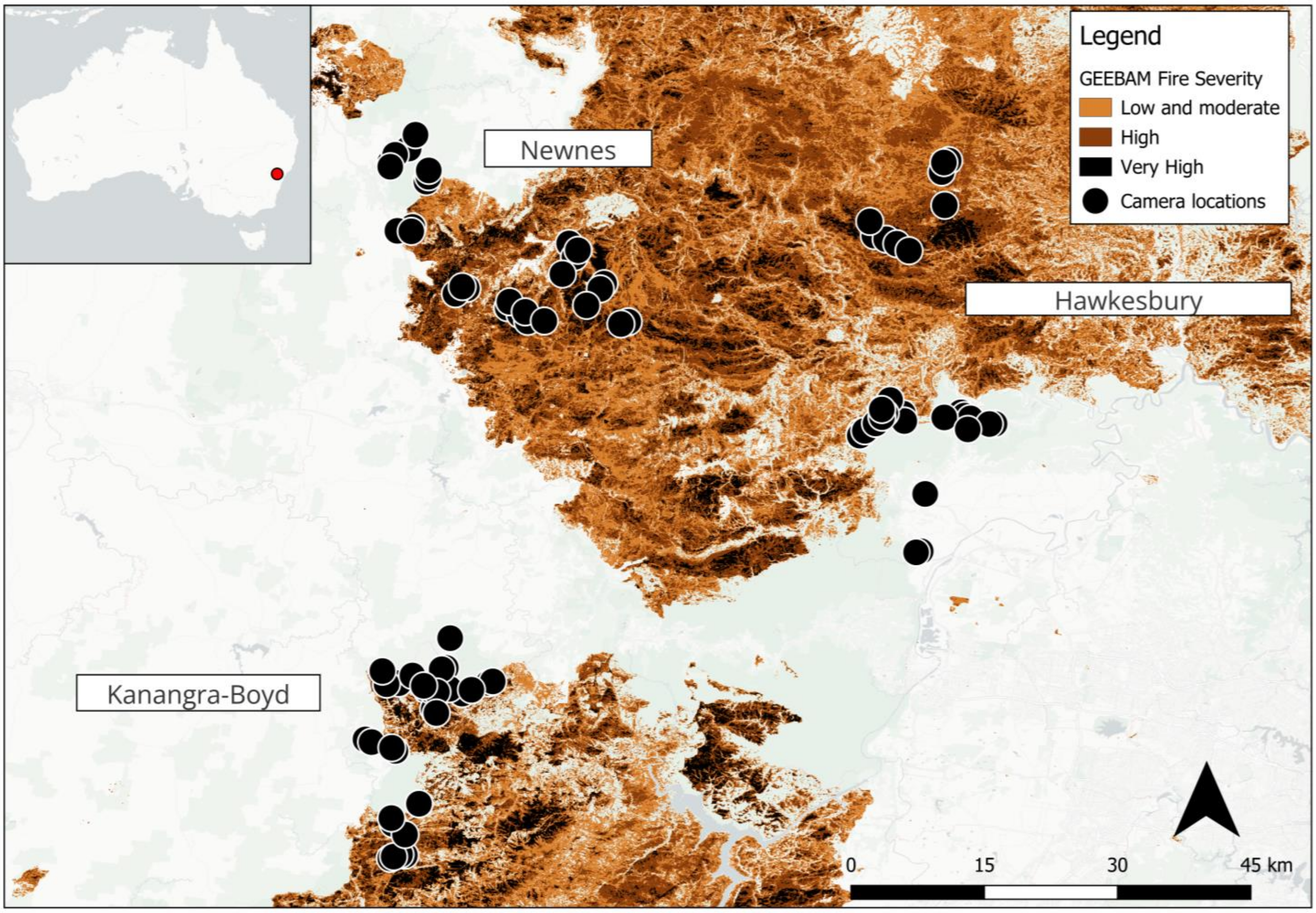

Figure 1. Locations of 90 cameras deployed across three study sites in the Greater Blue Mountains World Heritage Area, overlaid on the 2019/20 wildfire severity Google Earth Engine Burnt Area Map data.

PROJECT OVERVIEW AND AIMS

This report describes a collaborative research and monitoring project implemented in the Greater Blue Mountains World Heritage Area (GBMWHA) following the 2019-20 Australian bushfires. The project aimed to provide information on critical weight range (CWR) mammals population recovery and long-term management under climate change and altered fire regimes. Specifically, it applied a landscape-scale camera trap design, using 90 cameras to:

i) Inform the characterisation of fire refugia and long-term fire management for CWR mammals. These species face threats from invasive predators and the impacts of fire are likely to be additive. Critical weight range mammal survey data (i.e., species diversity and abundance) was collected and evaluated against environmental data including a range of parameters for habitat type and structure and fire intensity, to assess the determining factors behind post-fire biodiversity across sites. By building this critical knowledge base, management can be targeted towards priority areas that are likely to provide refugia for different species during and after fire.

ii) Collect baseline data to facilitate future understanding around how ecosystems recover or change under altered fire regimes, including looking across different fire intensities to quantify changes in species compositions, and determining the loss of ecosystem function due to introduced predators.

This project aligns with recommendations by Commonwealth and State governments that identify the need for post-fire surveys to better understand impacts on biodiversity and selected species, and for characterising climate refugia[1,2]. It is worth noting that most recovery plans and conservation advice had not been updated since the bushfires at the time of writing this report. Further, due to the extent and severity of the 2019-20 bushfires in the GBMWHA, even common species could be threatened at the population level. The impacts of biodiversity loss and changing ecosystem function are of great concern generally, and this is supported by extensive scientific literature that outlines the potential issues of biodiversity loss and ecosystem function under climate change[3,4,5]. Baseline data post-fire, across fire intensities, is also essential information from which management plans can be formulated and priorities identified.

METHODS

Ninety camera traps were deployed across three sites: 'Newnes' (which included the Newnes Plateau and Capertee and Wolgan Valleys), 'Hawkesbury' (which included SE Wollemi National Park and Kurrajong), and 'Kanangra' (which included Kanangra-Boyd National Park) between 6 – 22 October 2021 (**Figure 1**).

Fieldwork was conducted by two contracting ecologists in conjunction with 16 trained volunteers from the Blue Mountains community. Cameras were placed at minimum 500m from one another, stratified over fire severity (unburnt, low severity [no canopy scorch], moderate severity [20-90% canopy scorch], high/extreme severity [>90% canopy scorch]). Cameras were set on a tree 50 – 60 cm off the ground, with a lure of peanut butter and oats placed in a capped PVC pipe set 20 – 25 cm off the ground, 250 cm from the camera. Cameras were set to take five photos in rapid succession if triggered. Cameras were deployed over a period of approximately 3 months, between October 2021 and March 2022.

Fire severity and the habitat group were recorded for every camera site. In addition, each camera site (within a 10m x 10m plot, centred on the camera) was also surveyed for the following variables associated with potential food and shelter resources, which may contribute to small mammal occurrence (i) the estimated percentage area of bare soil, rock, leaf litter, ground vegetation, non-flowering shrubs, flowering shrubs, tree seedlings, or trees, (ii) the number of hollows and logs, (iii) the depth of the leaf litter, (iv) the top three most dominant species for shrubs and trees, (v) and shrub and tree phenology (i.e. the percentage of the dominant shrub and tree species that were flowering, budding, or fruiting) and the amount of new growth.

Camera trap images were classified to species level (where possible) on the Wildlife Insights platform by three expert contributors. We calculated species richness and abundance for: all mammals; native mammals; critical weight range (CWR) native mammals (35-5500g); feral/invasive non-predator mammals (e.g., rabbit); and feral/invasive predator mammals (e.g., fox). Animals classified as 'unidentified small mammal' or 'Rattus sp.' (i.e., an unidentified rat species) were not included as CRW mammals as these could be either native or feral species.

Species richness was calculated as the total number of species present at a given location. For abundance, all images capturing the same species taken within ten minutes of one another were considered as one 'event' and abundances for each camera were then calculated as the sum of all events. Abundances were corrected for the number of days the cameras were deployed, aligning it to the camera that was out for the longest period (142 days) by dividing 142 by the number of days the camera was deployed and then multiplying by the abundance.

KEY FINDINGS

Fire severity had significant impacts on CWR mammals. Our results indicate that unburnt areas appear to act as post-fire refugia for native mammals. Species richness and abundance of CWR mammals was significantly higher in unburnt areas at some sites, with similar non-significant trends at others (see extended report[6] and **Figures 2, 3**). Further, CWR mammal abundance sometimes had a negative relationship with fire severity, being highest in unburnt areas, and decreasing from low fire severity to moderate fire severity, and to high/extreme fire severity areas in certain sites (e.g., Newnes; **Figure 2**). Other studies have also shown that

[1] OEH (2018). NSW Koala Strategy. Sydney, Australia. Available from: www.environment.nsw.gov.au/koalas.
[2] Department of Agriculture Water and Environment 2020. Greater Blue Mountains Area State of Conservation Update-April 2020. Canberra, Australia.
[3] Fox 2006. Using the Price equation to partition the effects of biodiversity loss on ecosystem function. Ecology 87:.2687-2696.
[4] Doherty et al. 2015. Multiple threats, or multiplying the threats? Interactions between invasive predators and other ecological disturbances. Biological Conservation190: 60-68.
[5] Greenville et al. 2018. Biodiversity responds to increasing climatic extremes in a biome-specific manner. Science of the Total Environment 634: 382-393.
[6] Science for Wildlife 2021. Post-fire evaluation of critical weight range mammals and koalas in the Greater Blue Mountains World Heritage Area. Science for Wildlife, Sydney, NSW.

CWR mammals are known to be impacted by fire, particularly at higher severities, with mortality risk in high fire severity areas over 20 times higher than in unburnt areas[7].

CWR abundance was significantly lower in low fire severity areas compared to unburnt areas in Hawkesbury and Newnes, even though ground fires are often considered to have minimal, or even positive impacts on fauna[7,8]. These surveys were conducted more than 18 months after the 2019/2020 Black Summer Bushfires, and yet even in low fire severity areas, CWR mammal abundance appeared not to have fully recovered. This is consistent with other research that showed that even 3-4 years post-fire, some species had not returned to pre-fire levels[9].

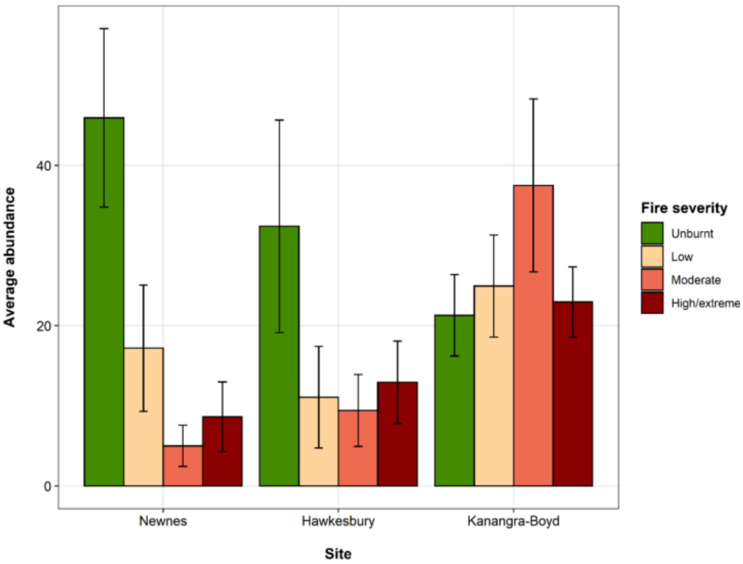

Figure 2. Average CWR mammal abundance in each location based on fire severity.

The negative relationship between CWR abundance and fire severity may be explained by the abundance of feral cats and foxes, which increased with increasing fire severity, being almost double in high/extreme fire severity areas compared to unburnt areas (see extended report[6]). Species richness of feral non-predators did not vary much by fire severity, being highest in unburnt areas and lowest in low fire severity areas (**Figure 3**), but abundance was highest in moderate fire severity areas (see extended report[6]). Our results support other studies on feral animal abundance and activity following fires, which have established two patterns; predatory animals taking advantage of the lack of cover for prey species[7,10] and herbivorous animals taking advantage of resprouting[11]. Following the fires, the NSW government prioritised increased post-fire aerial baiting and shooting with the aim of controlling feral animals to mitigate these threats[12].

In addition to the impacts on ground mammals, tree coverage declined with increasing fire severity, reducing habitat for arboreal CWR mammals (see extended report[6]). Shrub coverage, which we would have predicted to provide more habitat for terrestrial CWR, increased with increasing fire severity. However, most of the shrubs in moderate and high/extreme fire severity areas were new regrowth since the fire, and therefore are unlikely to provide as much food (flowers, seeds, fruits) or structural complexity for shelter compared to more mature, developed, shrubs in unburnt areas. We did not differentiate coverage based on plant maturity, so this is an area for further study.

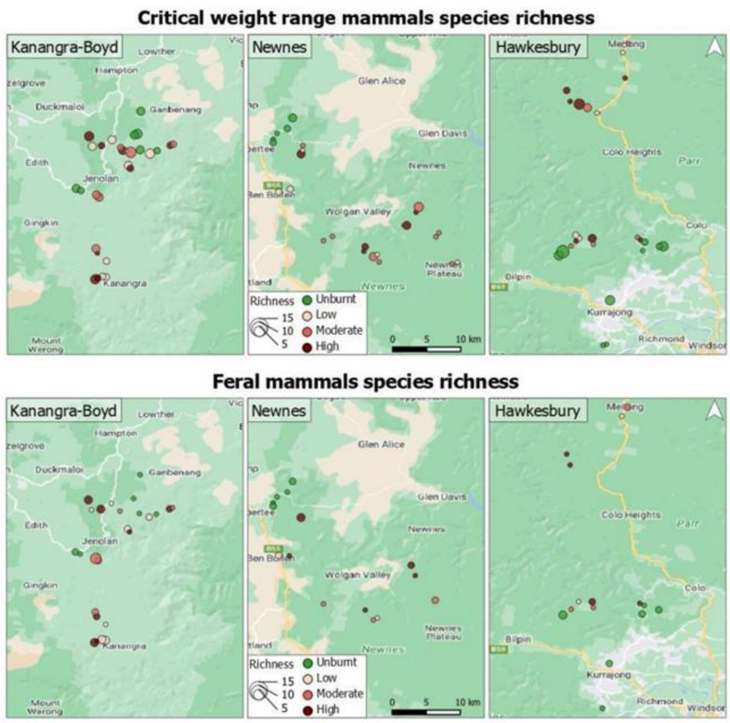

Figure 3. Species richness distribution maps in Kanangra, Newnes and Hawkesbury sites

There were clear differences in mammal populations between sites, with Kanangra having the highest native mammal and CWR richness and abundance, and the lowest abundance of feral predators (see extended report[6] and **Figures 2, 3**). This may be due to the expansive feral predator control program implemented in this area[13]. Although, feral herbivore abundance was also highest in Kanangra.

[7] Leahy et al. 2015. Amplified predation after fire suppresses rodent populations in Australia's tropical savannas. Wildlife Research 42: 705–716.
[8] Radford et al. 2020. Prescribed burning benefits threatened mammals in northern Australia. Biodiversity and Conservation 29: 2985–3007.
[9] Lindenmayer et al. 2008. Contrasting mammal responses to vegetation type and fire. Wildlife Research 35: 395–408.
[10] McGregor et al. 2015. Feral cats are better killers in open habitats, revealed by animal-borne video. PLoS ONE 10: 1–12.
[11] Reid et al. 2020. Distribution and abundance of large herbivores in a northern Australian tropical savanna: A multi-scale approach. Austral Ecology 45: 529–547.
[12] NSW Department of Planning Industry and Environment. 2021. NSW Wildlife and Conservation Bushfire Recovery - Medium-term response plan. Parramatta, Australia.
[13] OEH. 2012. Regional Pest Management Strategy 2012-17: Blue Mountains Region. Sydney, Australia.

MANAGEMENT OUTCOMES

Aside from site differences, fire impacts in this region appeared to be the dominant factor influencing mammal populations. To protect these populations, particularly the vulnerable CWR mammals, priority should be given to ensure unburnt areas of vegetation remain throughout the GBMWHA, as these unburnt areas clearly act as refugia. Prescribed burning, including in asset protection zones, is often considered low impact given they involve low-heat ground fires. However even low fire severity areas had significantly lower CWR abundance than unburnt areas. Further, we recommend the continuation of widespread efforts to reduce feral mammal numbers, to reduce predation of CWR mammals and allow post-fire recovery of the native flora required by CWR mammals.

EUROBODALLA NATIONAL PARK-BROU LAKE AREA, NSW POST FIRE MAMMAL FAUNA MONITORING*

Location: Southern New South Wales, Australia

Project Partners: Southern Cross Environmental/ NSW National Parks and Wildlife Service

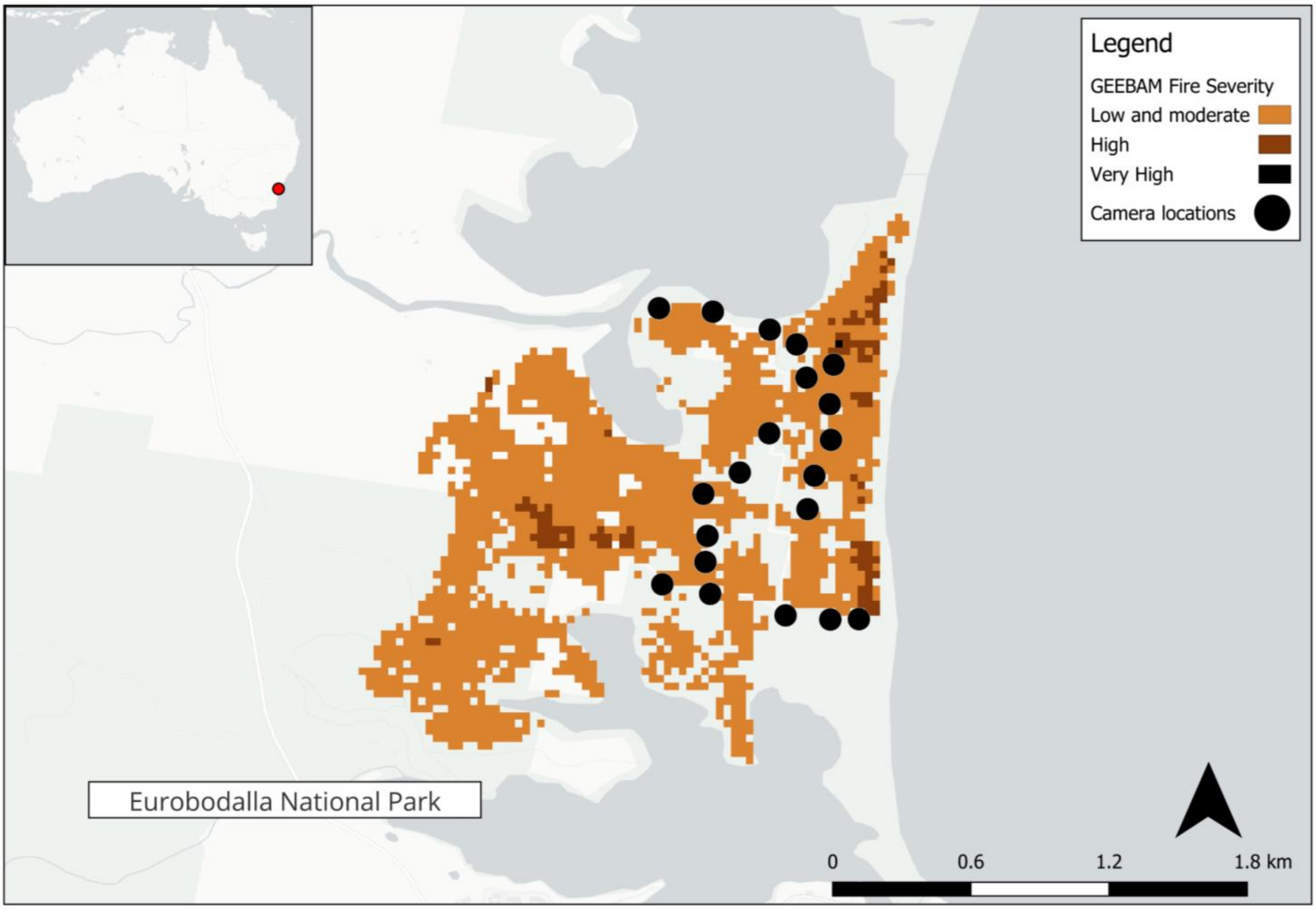

Figure 1. Camera set up at the study area, in Eurobodalla National Park, overlaid on the 2019/20 wildfire severity Google Earth Engine Burnt Area Map data.

PROJECT OVERVIEW AND AIMS

Eurobodalla National Park has an area of 2220 ha, and is located approximately 300 km southwest of Sydney, spanning an area between Moruya Heads and Tilba Tilba (south of Narooma). The National Park was gazetted on 22 December 1995, and is a series of sixteen non-contiguous areas. Eurobodalla National Park is considered important because it incorporates approximately 30kms of coastal land, including the intertidal zone along much of this area that is important habitat for migratory and resident shorebirds. Within the sixteen areas of Eurobodalla National Park, twelve endangered vegetation communities are identified, and 324 vertebrate fauna, 52 of which are considered endangered or vulnerable. This is approximately 39% of the total endangered or vulnerable species of the Eurobodalla coastal region.

Brou Lake forms part of the Eurobodalla National Park and incorporates an area of approximately 280ha, situated 20kms north of Narooma. This section of the National Park incorporates the high-water mark of the beach, the intertidal zone of the lake and the lake bed.

* Report summarised from: Southern Cross Environmental. 2022. Eurobodalla National Park – Brou Lake Area, NSW Post Fire Mammal Fauna Monitoring – Feb-April 2022.

Eurobodalla National Park also forms part of the Ulladulla to Merimbula Important Bird Area, identified as such by BirdLife International because of its importance for Swift Parrots. For this reason, much of the study conducted in the Eurobodalla National Park, especially in the Brou Lake area, has focussed on avian species, in particular migratory and listed shorebirds such as the Little Tern and Hooded Plover.

This survey was tasked to gain information on the contemporary distribution of arboreal species present in the Brou Lake area since the devastating 2019-20 Badja Forest fire that burnt through the park. This fire burnt areas of the park in severity from moderate to high according to the 2019/20 wildfire severity Google Earth Engine Burnt Area Map (GEEBAM) mapping (**Figure 1**). Fire intensity has been shown to negatively affect arboreal species, and areas of low intensity can become refugia for some species[1]. Estimating changes in population density of arboreal species for this area is difficult, with no pre-2020 baseline data of species presence or population sizes within the site. Scientific data for the Brou Lake area was last collected in 1996-97 as a census of species after the Park's gazettal. However, the low numbers of species detected in total for this report indicate that both the fire, and potentially other management issues within the National Park are affecting the arboreal fauna assemblage at Brou Lake.

METHODS

Remote motion-activated wildlife cameras (Enduro Swift) were used to detect fauna (and primarily, ground-dwelling terrestrial mammal species), present within the reserve (**Figure 2**). For this survey, no lures were used to attract wildlife to the cameras. The exclusion of lures therefore allowed for opportunistic recordings of fauna only (i.e., animals that happened to move past the camera as opposed to animals deliberately lured to the camera).

The placement of cameras was all at ground-level, generally at 30-50cm high, and were aimed at capturing terrestrial fauna groups that are mainly ground-dwelling, or that may use different habitat types at ground level (for example, possums, which regularly come to ground to move across the landscape). The general areas targeted for deployment included sites where there were large fallen logs/trees, drainage lines, higher vegetation cover and/or where a fauna trail was evident in the undergrowth, providing potential habitat for smaller terrestrial mammal species. Camera placements were generally aimed to include different vegetation types, however, the topography and vegetation types over the Brou Lake site do not dramatically vary and consequently, there is no notable distinction in placement at various elevations or stratification of survey sites based on vegetation type.

For this study, a total of 20 cameras were deployed across the National Park over the three-month survey period. Each camera was set to record night-time activity with a 30-minute pre and post sunset start/finish time. Based on this, the overall combined number of individual camera trap nights (effort) totalled 1680 trap-nights.

Figure 2. Camera set up at Eurobodalla National Park.

In addition to use of wildlife cameras, this survey also involved nocturnal direct visual encounter surveys (spotlighting, stag-watches and call playback), ultrasonic and acoustic recording, koala spot assessment technique (SAT) Surveys, and incidental/opportunistic sightings.

KEY FINDINGS

A total of twenty-eight mammal species were recorded at the site during the survey period, including four arboreal, eleven terrestrial mammal species, and thirteen microbat species. Four species of arboreal mammal were observed during the nocturnal spotlight and stag-watch surveys conducted across the site. The most commonly observed species was the brush-tailed possum (*Trichosurus vulpecula*), while sugar gliders (*Petaurus breviceps*), feathertail gliders (*Acrobates pygmaeus*) and greater gliders (*Petauroides volans*) were only recorded once per species.

Given the relatively extensive coverage of spotlighting and stag-watching survey effort across the study, the numbers of arboreal mammal species recorded (other than the brush-tailed possum) are considered low, particularly in relation to the observed quality of habitat in the National Park. The results also indicate there is a low likelihood of the koala (*Phascolarctos cinereus*) occurring at the site, with no evidence of the species'

[1] May-Stubbles et al. 2022. Increasing fire severity negatively affects greater glider density. Wildlife Research 29: 709–718.

presence found through the SAT surveys, spotlighting, stag-watching, call playback, or camera deployments.

A total of twelve terrestrial mammal species (10 native and 2 introduced) were recorded during the survey period, with most records made via camera capture. The most commonly recorded native terrestrial mammal species present at the site, represented by the most frequently captured on camera, were swamp wallabies (*Wallabia bicolor*), red-neck wallabies (*Notamacropus rufogriseus*), eastern grey kangaroos (*Macropus giganteus*) and long-nosed bandicoot (*Perameles nasuta*).

A number of small mammals were also captured on the cameras and included most commonly the native bush rat (*Rattus fuscipes*). There were also several camera captures of a small antechinus species; however, positive identification of these was difficult due to poor picture quality. It is considered likely that many of these were the agile antechinus (*Antechinus agilis*) although it is possible the brown Antechinus (*A. stuartii*) and the dusky antechinus (*A. swainsonii*) are also present at the site. One white-footed dunnart (*Sminthopsis leucopus*), listed as vulnerable under the NSW Biodiversity Conservation Act 2016, was also observed at the site during spotlighting surveys (**Figure 3**).

Figure 3. White-footed dunnart photographed during an incidental/opportunistic sighting.

Introduced species had a low number of detections over the site, with only single individuals of red fox (*Vulpes vulpes*) recorded at 3 camera sites and a feral cat (*Felis catus*) at one camera site. NSW National Parks and Wildlife Service (NPWS) undertake a baiting program for foxes and an opportunistic shooting program for foxes and feral cats at this site due to the presence of the beach-nesting hooded plover (*Thinornis rubricollis*) and other migratory shorebirds. This program is likely also assisting in the protection of small terrestrial mammals.

MANAGEMENT OUTCOMES

The Brou Lake area of Eurobodalla National Park faces several major threats to the continued survival of threatened species. Discussed below are existing and recommended management actions suitable for threatened species in the National Park.

Fox Control: Smaller mammal species in reserves such as Eurobodalla National Park can be greatly impacted by even low densities of foxes, so a strong commitment to controlling fox numbers is required. NPWS currently undertakes fox baiting programs across their tenure, including at Brou Lake, for the protection of beach-nesting birds. The program seems to be working to keep fox numbers low, with low numbers of fox detections on camera (single sightings on 3/20 cameras only), and no evidence of foxes in the form of scats/tracks in visits to the site. Fox control within the Brou Lake area of the National Park is considered a warranted continued management action, even outside of the breeding season of beach-nesting birds given its strong potential to benefit other species such as small mammals.

Cat Control: As for foxes, NPWS currently undertake opportunistic shooting programs for cats within the National Park. The proximity of the Brou Lake section of the park to the Brou Lake Waste Disposal Facility means that controlling cats is an ongoing issue. However, only one cat was seen on cameras, indicating the shooting program is working to keep cat numbers down and should be continued.

Habitat connectivity: Eurobodalla National Park is hindered by its challenging narrow width and disjointed areas. As discussed, Brou Lake provides suitable habitat features for a range of threatened species and creating a link to habitats west of the highway would increase the likelihood species could use these and make use of the site as a refugia in extreme events such as fire.

MONITORING GREATER GLIDER UPTAKE OF NEST BOXES IN A POST FIRE ENVIRONMENT

Location: Southern New South Wales, Australia

Project Partners: Ana Gracanin, Maaike Hofman, Stephen Willson, Jordyn Clough, Tyler Brown, Katarina Mikac from the University of Wollongong

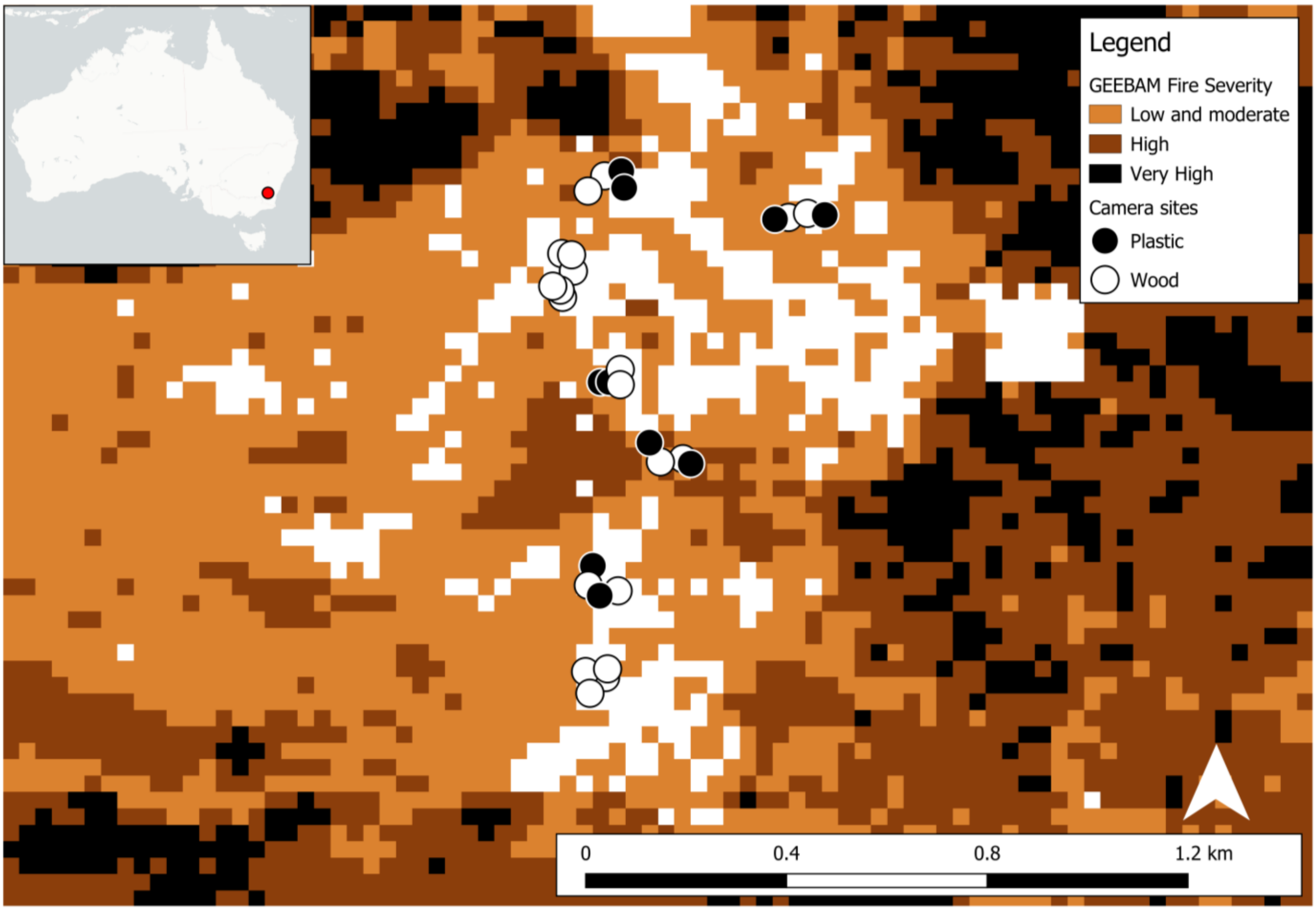

Figure 1. Locations of 30 nest boxes installed for greater gliders on a private property located near Tallaganda, NSW, overlaid on the 2019/20 wildfire severity Google Earth Engine Burnt Area Map data.

PROJECT OVERVIEW AND AIMS

The greater glider (*Petauroides volans*) is a nocturnal, canopy-dwelling, gliding marsupial that is endemic to the east coast of Australia. Greater gliders feed almost exclusively on the leaves and buds of eucalyptus trees and are reliant on large tree hollows for sheltering and raising offspring. The species has experienced significant decline because of habitat loss[1], fire[2] and the effects of climate change[3].

Tree hollows play a crucial role in the life of greater gliders, making them essential for their persistence. Greater gliders rely on tree hollows for shelter, nesting, and raising their young. Hollows provide a safe place from predators, extreme weather conditions, and disturbance. Unfortunately, the availability of natural tree hollows has been declining due to deforestation and habitat fragmentation. Furthermore, fire can also be a potential threatening process for hollow bearing trees. Although fire can assist in the hollow development in trees, it can also destroy existing hollows, with the net effect dependent upon the intensity/frequency of fire[4].

Following the 2019-2020 catastrophic wildfires it is estimated that greater gliders experienced an

[1] Kavanagh & Bamkin 1995. Distribution of nocturnal forest birds and mammals in relation to the logging mosaic in south-eastern New South Wales, Australia. Biological Conservation 71: 41–53.
[2] May-Stubbles et al. 2022. Increasing fire severity negatively affects greater glider density. Wildlife Research 1–10.
[3] Wagner et al. 2020. Climate change drives habitat contraction of a nocturnal arboreal marsupial at its physiological limits. Ecosphere 11: e03262.
[4] Flanagan-Moodie et al. 2018. Prescribed burning reduces the abundance of den sites for a hollow-using mammal in a dry forest ecosystem. Ecological Management 429: 233–243.

immediate population loss of 85%[5]. More than half of greater glider presence records since 2000 occurred within burnt areas[2]. Fire has had a significant impact on the abundance and distribution of this species, and recently the species has been uplisted to endangered.

One potential conservation strategy to support the recovery of this species, is through the installation of nest boxes to replace lost hollows. Furthermore, nest boxes could potentially facilitate population increases in the long-term. Larger populations are more robust and capable to responding to stochastic changes and thus have greater viability into the future.

There is little known about greater glider nest box preferences and usage. Nest boxes were installed on a private property impacted by the 2019-2020 bushfires as well as habitat loss. The aim of this study was to monitor the usage of nest boxes by greater gliders for an entire year to evaluate the efficacy of nest boxes as a conservation tool for this endangered species.

METHODS

Thirty reverse entry nest boxes constructed by Hollow Log Homes were installed on a private property northwest of Braidwood, NSW, Australia (**Figure 1**). The nest box installation work was carried out to offset damage that had occurred on greater glider habitat, part of a Biodiversity Conservation Trust agreement. The landowners of the property found many trees that had been cut down during the incident, where approximately thirty of which contained hollows large enough for greater gliders. These hollows were within the known measurements of hollows preferred by greater gliders[6]. To replace the loss of these hollows, greater glider nest boxes were installed within the vicinity of these areas where hollow-bearing trees were lost (up to 200m away).

Nest boxes were installed by qualified tree climbers at an average height of 11.6m (ranging between 6 – 17m) (**Figure 2**). To monitor the usage of each nest box by animals, a motion sensor camera was installed on a platform facing down into the reverse entry section of the nest box (**Figure 3**).

To compare nest box usage by greater gliders, eight additional natural hollows were monitored. Where boxes were installed, spotlighting surveys were conducted to identify greater gliders using existing natural hollows[7]. Once eyeshine was detected in a hollow, and the species confirmed as a greater glider, the tree was assessed for safety and for accessibility for camera installation. Over four nights, sixteen hollows were identified as in use by greater gliders, of which eight was accessible using tree climbing techniques. Cameras were installed on these natural hollows and temperature loggers placed inside. As data analysis is still ongoing, this report outlines initial results and observations.

Figure 2. Internal measurements of the nest box design used in the study.

Figure 3. Left: monitoring camera facing down into entrance hole of nest box. Right: example of hollow bearing tree lost due to fire.

KEY FINDINGS

After one year of monitoring, our results showed that all nest boxes were readily used by greater gliders present in the study area. The data revealed that 100% of the nest boxes were used at some point by greater gliders. At the six-month mark, during inspections of nest boxes, 27 gliders (20 adults and 7 juveniles) were found inside the nest boxes and ten across the hollows (6 adults, 4 juveniles). During the pack down of the cameras in May 2023, 24 greater gliders were found inside nest boxes, and eight across the natural hollows monitored.

[5] Legge et al. 2021. Estimates of the impacts of the 2019-20 fires on populations of native animal species. Threatened Species Recovery Hub.
[6] Hofman et al. 2022. Greater glider (*Petauroides volans*) den tree and hollow characteristics. Australian Mammalogy 45: 127–137.
[7] Gracanin et al. 2021. Greater glider (*Petauroides volans*) live capture methods.Australian Mammalogy 44: 280-6.

Over the course of one year, 163,013 photos of wildlife were taken. The most common species on cameras was the target species (159,027 photos; 98% of all images were of greater gliders). On several occasions, both on camera and during physical inspections, two to three greater gliders were seen sharing a nest box (**Figure 4**).

The average time it took for a greater glider to come and investigate a nest box was 11.5 days (minimum 6 hours, maximum 44 days). Across the annual monitoring, the average amount of time that a nest box was used by greater gliders was 46% (as a proportion of dates where greater gliders were observed on camera). The least amount of usage for a nest box was 5% and the most was 95%.

During summer, greater gliders were observed exiting the nest box completely or partially (**Figure 5**), often when temperatures were over 20 degrees. Furthermore, juvenile greater gliders were also seen exhibiting frequent daytime activity. Juvenile behaviour was observed as being active around the nest box, both during day and night. Juveniles were recorded occupying 19 of the 30 nest boxes.

Figure 4. Two greater gliders inside one of the nest box installations.

Inside the eight hollows monitored, frequency of usage ranged from 1% to 97%. Hollows that were frequently in use during the monitoring were observed to have contained juveniles. Other species were observed entering or investigating these hollows, including masked owl and yellow-tailed black cockatoos. The yellow-tailed black cockatoo was observed repeatedly returning and excavating the hollow, despite the presence of a female glider and her juvenile.

Figure 5. Cropped camera trap image of a juvenile greater glider exploring outside of its nest box.

MANAGEMENT OUTCOMES

Our study found that greater gliders readily used nest boxes. Initially, greater gliders often took many visits investigating a nest box before choosing to occupy it as a den for the day. However, despite the initial neophobia, greater gliders readily used most of the nest boxes available. This indicates the potential use of nest boxes for greater glider conservation. Furthermore, the high uptake of nest boxes to use as a den for raising young indicates their ability to support population growth and recovery in areas impacted by fire and logging.

Whether nest boxes are applicable in all environments however remains to be tested. Our study occurred in an area with a cooler climate compared to that of greater glider populations that are found on the coast and further north. In our study, during summer, gliders were affected by warmer temperatures inside nest boxes, and could be seen on camera spending hours at a time with half of their body outside of the nest box. In more warmer environments, nest boxes may not be a viable option, however the use of insulation or other hollow supplementation tools could prove effective in replacing lost hollows or encouraging further population growth.

NUNGATTA THREATENED NATIVE MAMMAL AND INVASIVE PREDATOR POST-FIRE MONITORING

Location: Southern New South Wales, Australia

Project Partners: Darren McHugh, Katie Oxenham and Bernadette Lai from NSW National Parks and Wildlife Service

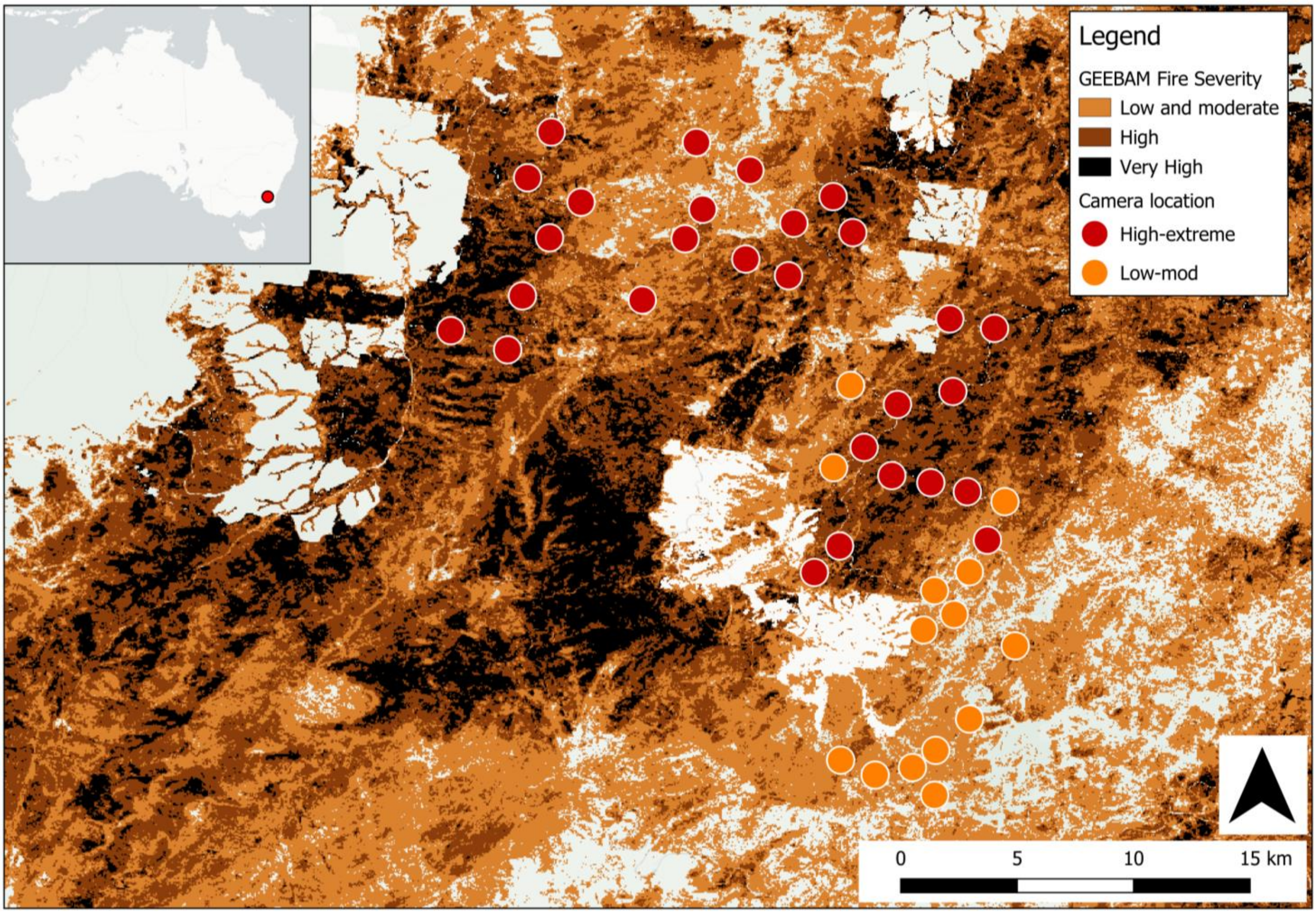

Figure 1. Camera locations across South East National Park, overlaid on the 2019/20 wildfire severity Google Earth Engine Burnt Area Map data. The different coloured circles indicate camera sites with habitat impacted by different fire severity during the 2019-20 bushfires. Note that only sites/cameras included in the analysis below are shown above.

PROJECT OVERVIEW AND AIMS

South East Forests National Park is located in the Bega Valley Shire at the south-eastern extremity of coastal NSW Australia. It comprises around 130,000 hectares of forests inland from Eden, Merimbula and Bega. During the 2019-20 bushfires 58% of the Bega Valley Shire was burnt, with the forested parts of this region – including South East Forest National Park – some of the hardest hit. More than half of these fire-impacted forests burnt at high or very high severity, meaning that most of the tree canopy was burnt in addition to all ground vegetation cover. This represented a significant threat to priority and threatened vegetation communities and fauna species present in the area.

South East Forests National Park is home to a number of native small to medium-sized mammals that have poor conservation status, including potoroos (*Potorous longipes;* listed as endangered and *P. tridactylus;* listed as vulnerable), and southern brown bandicoots (*Isoodon obesulus*; listed as endangered). The rarity of these species is largely due to predation by invasive predators including red foxes (*Vulpes vulpes*) and feral cats (*Felis catus*). Habitat modification and fire, coupled with several years of drought, has also played a role in supressing their numbers.

In fire-impacted landscapes invasive predators may pose an increased risk to threatened native species like potoroos and bandicoots. In the short-term, predators like red foxes and feral cats may be attracted to areas recently impacted by fire to catch fleeing prey. Over longer periods predation risk may also be elevated in burnt habitats, as vegetation cover, which can provide important refuge from predation, is reduced or altered. Monitoring vulnerable native mammals and the invasive predators that threaten them in locations burnt by fire is important, not only to understand species recovery trends but to also inform any management or conservation actions to aid in that recovery.

This project sought to assess and improve the post-fire recovery of key threatened species of potoroo (*P. longipes;* and *P. tridactylus*) and bandicoot (*I. obesulus*) in the South East Forest National park, by: (i) determining the presence of these threatened native animals, as well the invasive predator species known to impact them, in habitat affected by fire in South East Forest National Park, and to (ii) monitor the effectiveness of on-ground control works targeting invasive predator populations and especially the red fox.

This project also collected baseline data contributing to the construction of a new feral predator-free area that will be established at this site by NSW National Parks and Wildlife (NPWS). This feral predator–free area will involve implementing 2,085 hectares of conservation fencing[1]. Once established it will protect more than 13 threatened animal species and aid in the re-establishment of up to 2 native mammal species currently listed as extinct in New South Wales.

METHODS

Forty-five motion-sensor cameras (Swift Enduro; Outdoor Cameras) were deployed throughout South East Forest National Park, in the 'Nungatta' area, where the new feral predator-free area will be established (**Figure 1**). Nungatta is located on the border of NSW and Victoria, approximately 50km inland from the east coast of Australia. Cameras were deployed in comparable dry sclerophyll habitat types, which were affected by different fire severities during the 2019-20 bushfires. Namely, 28 sites were selected that were affected by high to extreme fire severities (habitat where the fire had burnt all ground cover and most or all canopy cover; **Figure 2**) and 14 sites were selected that were impacted by low to moderate fire severities (habitat where the fire had burnt all ground cover but little to no canopy cover).

Cameras were secured around knee height at the base of trees, spaced at approximately 1 km from each other, along fire trails. The focal point of each camera was on the middle of the fire trail, as roads are often used as movement corridors for predators, which were the primary target species group of this survey.

Cameras were deployed from April to November 2022. Red fox management occurred in early May and was ongoing until September 2022. It involved ground baiting, shooting and trapping and was undertaken by NSW NPWS officers as part of the regular yearly control practice in the region to limit the impact of invasive predators on threatened native mammals in the region.

Figure 2. Camera set up on a tree (top), monitoring a fire trail in an area where the fire burnt the entire canopy (bottom).

Camera images were identified and sorted to species where possible. For images of animals that could not be identified to species, the closest taxonomic grouping was used e.g. "Aves", "Macropod" etc., or "Unknown". For the purpose of visualisation in this report, less common species were grouped (e.g. "Possum Species", "Passerine Birds", "Doves and Pigeons", "Small Mammal <500g").

Once all images were classified, species/species group detection events were calculated by grouping all images of a species/species group that were taken on a single camera and within 30 minutes of each other into single events. These detection events were then totalled across each camera. To account for differences in

[1] NSW Government Department of Environment and Heritage. 2022. Nungatta feral predator-free area. Available from: https://www.environment.nsw.gov.au/topics/parks-reserves-and-protected-areas/park-management/return-of-threatened-and-declining-species/nungatta-feral-predator-free-area.

camera monitoring effort (some cameras stopped functioning due to low battery of full memory cards or were stolen), "encounter rates" for each species or species group were calculated, by dividing the total number of detection events for each species/species group at a camera by the total number of days that camera was active and then multiplying that number by 100. This final value was then averaged over all cameras within each fire severity category, or between different months.

Over the survey period, several cameras were stolen. To ensure that there were enough cameras to accurately represent data, this report only includes results from April to September 2022.

KEY FINDINGS

Across the project 25 species were detected on camera traps, with red foxes, and then feral cats, dingoes (*Canis Lupus Dingo*), common wombats (*Vombatus ursinus*) and red-necked wallabies (*Notamacropus rufogriseus*) the top 5 most commonly detected species on camera. Across the survey no long-footed potoroos or long-nosed potoroos were recorded, however there was one sighting of a southern brown bandicoot.

Most species were encountered relatively similarly across the two fire categories. This was perhaps unsurprising, due to the substantial vegetation regrowth following high rainfall events in the years following the 2019-20 bushfires. Exceptions were red foxes, dingoes and eastern grey kangaroos (*Macropus giganteus*), which were encountered more in habitat burnt by lower severity fire, and feral rabbits (*Oryctolagus cuniculus*), which were encountered more in habitat burnt by more severe fires (**Figure 3**). Southern brown bandicoots were only encountered in habitat burnt by low moderate fires, while hares (*Lepus europaeus*), echidnas (*Tachyglossus aculeatus*), doves and pigeons (Family: Columbidae) and ringtail possums (*Pseudocheirus peregrinus*) were only recorded in habitat impacted by high-extreme severity burns (**Figure 3**).

In total, seven invasive species were recorded across the study, with deer (sambar *Rusa unicolor* and common fallow *Dama dama*), hares and feral pigs (*Sus scrofa*) detected in addition to red foxes and feral cats. Management activities only targeted red foxes, and appeared to have an effect, with fox activity declining from June to August and September (**Figure 4**). On the other hand, feral cats, as well as dingoes (another common mammalian predator species detected in this area) did not change their activity over time (**Figure 4**).

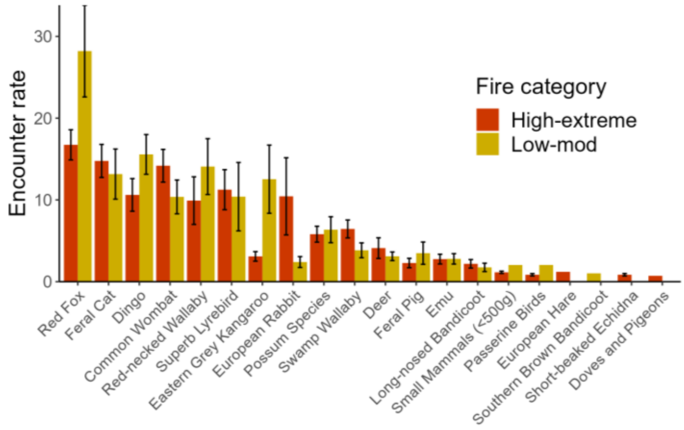

Figure 3. Average encounter rate for native species recorded across habitat burnt by high-extreme fire and low-moderate severity fire.

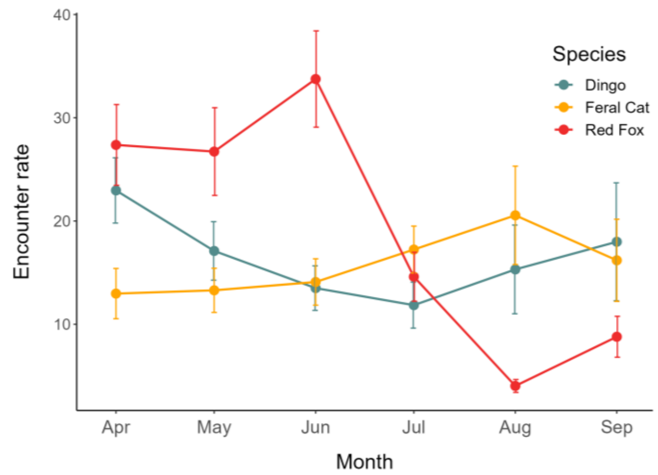

Figure 4. Average encounter rate for red foxes, feral cats and dingoes recorded across time (months). Baiting occurred in May and was ongoing.

Non-predator species including eastern grey kangaroos (*Macropus giganteus*), possum species (including common brushtail possums *Trichosurus vulpecula* and common ringtail possums *Pseudocheirus peregrinus*), swamp wallabies and superb lyrebirds (*Menura novaehollandiae*) did not change their activity over time, although common wombats did become more active from July to September (**Figure 5**). Interestingly, feral rabbit activity also appeared to increase following predator control (**Figure 5**), however it is difficult to determine whether this was due to a decline in red fox activity, or if it reflected seasonal activity patterns.

MANAGEMENT OUTCOMES

This survey revealed a range of invasive predators active in the Nungatta region of South East Forest National Park, and contributed to targeted management of these species. In particular, it showed high activity of red foxes, which were the most commonly encountered species during this survey, particularly in areas impacted by low to moderate burns. These findings also supported the decision to manage red foxes in this region, with control activities successfully undertaken from mid-May to mid-September in 2022. Baits were initially laid at around 53 bait stations, with baits replaced every 6 weeks.

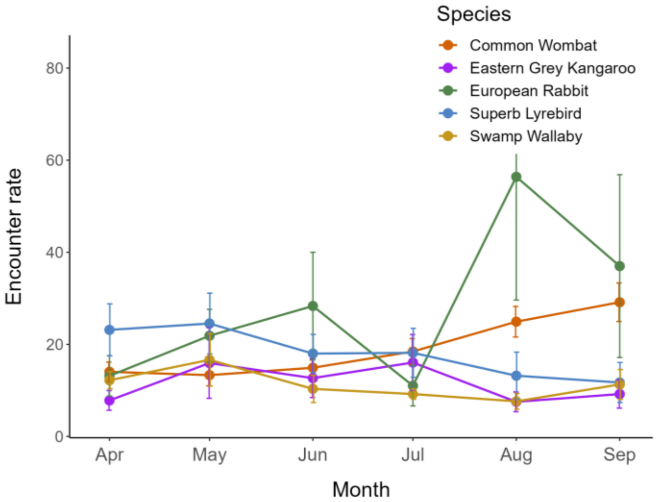

Figure 5. Average encounter rate for wombats, possum species, lyrebirds, rabbits and swamp wallabies recorded across time (months).

By continuing to monitor predator activity following predator control, this survey was also able to show that these management activities may have resulted in a decline in red fox activity, particularly from July until September 2022. Future surveys should include monitoring a site where no predator control activities are carried out, to contrast results and ensure that any decline in red fox activity is as a direct result of predator control and not due to seasonal changes in population. However, the fact that average fox encounter rates neared zero following predator control provides good evidence to suggest that these activities were at least in part responsible for red fox decline.

Few southern brown bandicoots and no potoroos were recorded across this survey. As fire trails were the focal point of cameras and no lures were used, this may partially explain why there were so few records, although surveys conducted in the same location (Nungatta and surrounds) at similar times that did use lures/other focal points to specifically track potoroo and bandicoot presence had similar findings (**see *Eyes on Recovery case study: East Forest long-footed potoroo survey***). Instead, low southern brown bandicoot and potoroo activities may have been due to the high number of invasive predators recorded in the region, paired with the substantial fire impacts from the 2019-20 bushfires.

These results support the need to continue invasive predator management in this region. Although, there were no observed increases in southern brown bandicoots or potoroo detections following predator control (and the subsequent decline in red fox activity). It is likely that these threatened species were not able to recover from predation impacts in the 4-6 months monitored post management. Further monitoring is required to determine long-term recovery following predator control (and to determine for how long red fox activity stays low). However, species reintroduction paired with extensive and continuous predator control is probably required to expedite their return and recovery. While continuous predator control can be costly and time-intensive, the creation of a well maintained, feral-free fenced area guided by data from a comprehensive Ecological Health Monitoring Program that will be implemented as part of NPWS' Feral Predator-Free Area program will help to provide reintroduced species adequate protection from predation threats.

SOUTH EAST FOREST LONG-FOOTED POTOROO POST-FIRE SURVEY

Location: Southern New South Wales, Australia

Project Partners: Joss Bentley from Ecosystems and Threatened Species, NSW Government Department of Planning and Environment

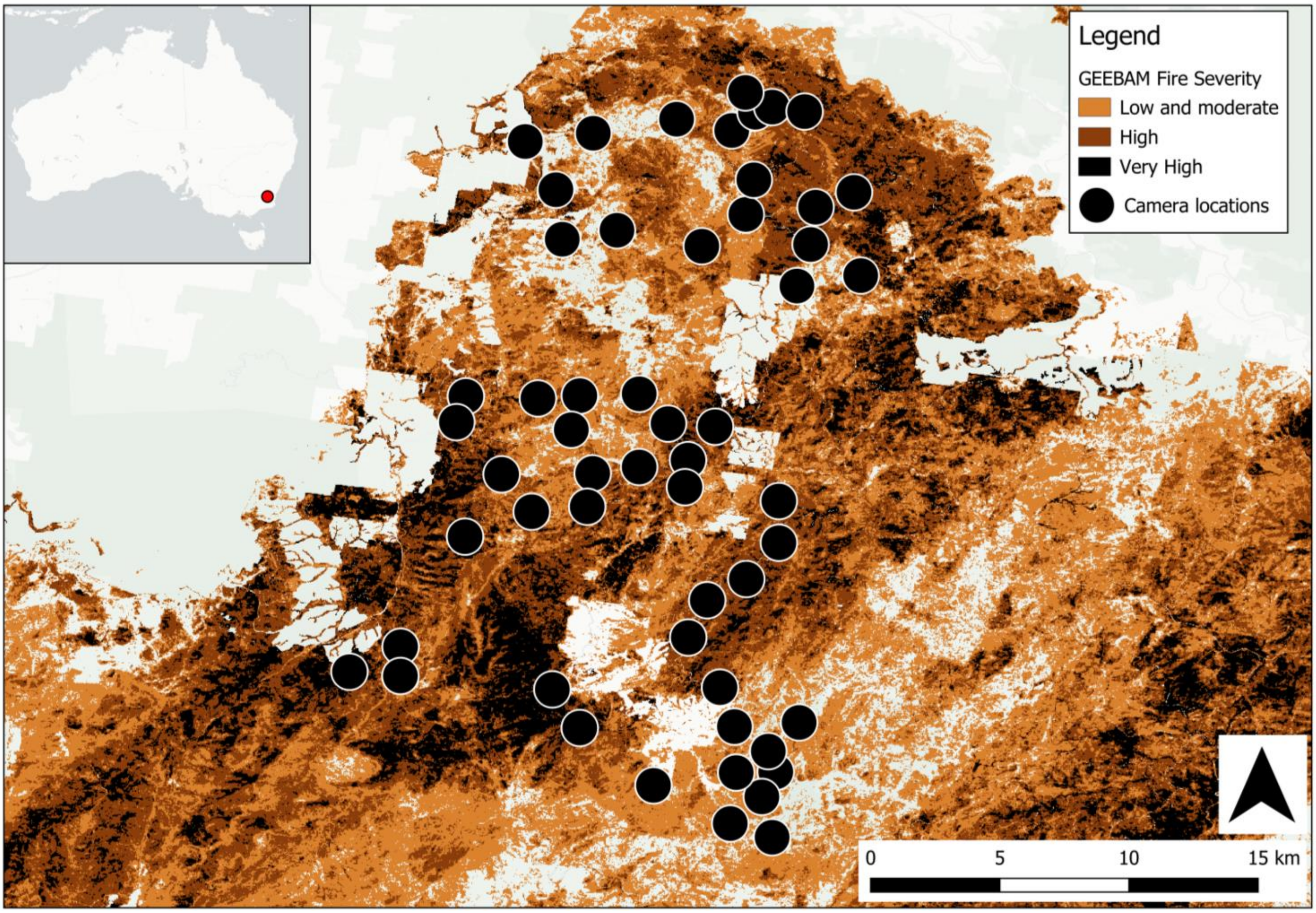

Figure 1. Camera location (black circles) across South East National Park (note that camera locations include two cameras), overlaid on the 2019/20 wildfire severity Google Earth Engine Burnt Area Map data.

PROJECT OVERVIEW AND AIMS

The long-footed potoroo (*Potorous longipes*) is a ground-dwelling, medium sized (up to 2.2kg) mostly nocturnal marsupial that occurs in south eastern Australia. This species requires habitat with an abundant supply of underground fruiting fungi, as well as dense forests and vegetation cover to provide shelter from introduced predators such as red foxes (*Vulpes vulpes*) and feral cats (*Felis catus*).

There are currently three known populations of long-footed potoroos: one in East Gippsland, the second in the Barry Mountains in north-eastern Victoria and the third in south-eastern New South Wales (NSW). The distribution of the long-footed potoroo in these locations is still relatively uncertain, with doubts as to whether the species is extant in NSW.

In 2016-17, a species distribution model was built to predict areas with suitable habitat for long-footed potoroos (**Figure 2**). In NSW, suitable habitat was mostly restricted to parts of South East Forest National Park, where all previous records of the long-footed potoroo occurred within the state. A camera survey was then undertaken across these areas, and areas where historical records were obtained to determine whether the potoroo was still present in this region.

While the survey detected 43 animal species, it did not detect long-footed potoroos[1]. As the survey effort was extensive (over 100 cameras used across more than 50 sites), this result indicated either that this species was incredibly rare in the environment or that it was no longer present. Further surveys across more sites and subsequent years were, however, recommended to confirm these findings.

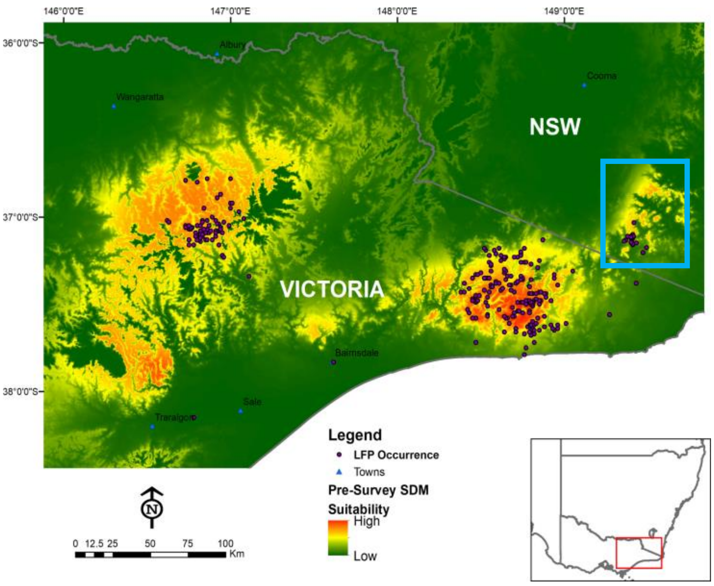

Figure 2. Long-footed potoroo occurrence and habitat suitability across their known range in southern NSW and Victoria (image taken from Wauchope-Drumm et al. 2020). This project's location is indicated by the blue rectangle.

Before further long-footed potoroo surveys could be completed, South East Forest National Park was impacted by the 2019-20 bushfires. As a result of these fires, approximately 82% of the species' total predicted distribution was impacted[2]. This event represented a significant threat to an already vulnerable native species and warranted need for monitoring to not only determine whether there were any potoroos still present in the reserve, but to also measure the impact of the fires on other key priority native species present in this region.

The main aim of this project was therefore to: (i) continue the search for the long-footed potoroo in the fire-impacted South East Forest National Park, and (ii) determine the impacts of the 2019-20 fires on species richness and the occurrence of other threatened species known to inhabit this area like the long-nosed potoroo (*P. tridactylus*; listed as vulnerable), and the southern brown bandicoot (*Isoodon obesulus*; listed as endangered).

METHODS

A total of 110 cameras (Reconyx, PC800 Professional/ HyperFire 2 Covert) were distributed across 55 locations in South East Forests National Park (**Figure 1**). Two cameras were positioned at each survey site, with the first camera located 100m east of the second camera. In total, 5 cameras malfunctioned across the survey, bringing the total functioning cameras to 106, across 55 locations.

All cameras were oriented to the south and positioned 20 cm above the ground pointed at a lure located 2 m in front of the camera. Lures of peanut butter and truffle oil were used, as they have been found to be successful in attracting potoroos to camera traps. Lures were made using drain cowls with end caps and were secured to star pickets to keep them in place for the duration of the monitoring effort. Cameras were deployed for an average of 52 days, with cameras set up for at least 40 days at each site (with the exception of three cameras that stopped taking pictures after 14–29 days). Cameras were not all deployed at the same time due to logistical constraints, but where all deployed over summer (between November 2021 to February 2022).

Camera images were identified and sorted to species where possible. For images of animals that could not be identified to species, the closest taxonomic grouping was used e.g. "Aves", "Macropod" or "Unknown". Once images were classified, species detection events were calculated by grouping all images of a species that were taken on a camera and within 30 minutes of each other into single events. These detection events were then totalled across each camera. To account for differences in camera monitoring effort, "encounter rates" for each species were calculated, by dividing the total number of detection events for each species at a camera by the total number of days that camera was active and multiplying that number by 100. This final value was then averaged over all cameras.

The post 2019-20 fire survey was compared to a pre-fire survey, which was conducted in 2017. During this survey, a total of 227 cameras were deployed across 60 transects (although only 58 transects supplied data, with some cameras faulty or malfunctioning). Two to 6 cameras were used per transect, see Wauchope-Drumm et al. (2020) for further survey method details.

[1] Wauchope-Drumm et al. 2020. Using a species distribution model to guide NSW surveys of the long-footed potoroo (*Potorous longipes*). *Austral Ecology* 45: 15– 26.

[2] Ward et al. 2020. Impact of 2019–2020 mega-fires on Australian fauna habitat. Nature Ecology & Evolution. 4:1321–1326.

KEY FINDINGS

Overall, 58 species were detected in the post-fire survey effort. This included 5 threatened species: the pilotbird (*Pycnoptilus floccosus*; listed as vulnerable), the southern brown bandicoot (*Isoodon obsesulus*; listed as endangered), the long-nosed potoroo (*Potorous tridactylus,* listed as vulnerable) and the spotted-tail quoll (*Dasyurus maculatus*; listed as vulnerable). The white-footed dunnart (*Sminthopsis leucopus*), listed in NSW as vulnerable, was also detected on camera. No long-footed potoroos were detected during the post-fire survey.

The most commonly encountered species were all native, including bush rats (*Rattus fuscipes*), swamp wallabies (*Wallabia bicolor*), quail species (especially painted button quails *Turnix varius*), and superb lyrebirds (*Menura novaehollandiae*) (**Figure 3**). Several invasive species were also recorded across the post-fire survey including feral cats, sambar deer (*Rusa unicolor*), fallow deer (*Dama dama*), European rabbits (*Oryctolagus cuniculus*), red fox, feral pigs (*Sus scrofa*), European hare (*Lepus europaeus*), black rats (*Rattus rattus*).

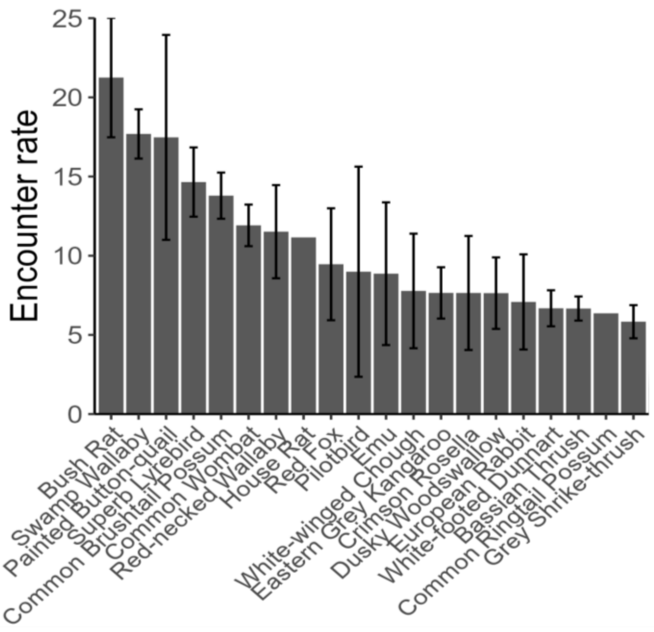

Figure 3. Average encounter rate for the top 10 most frequently recorded species across sites in the post-fire monitoring period in South East Forest National Park.

When comparing pre- and post-fire survey periods, substantially fewer species were detected in the pre-fire period (46 species). This was despite there being more sites monitored in the pre-fire period (pre: 58 sites, post: 55 sites). The majority of species were detected in a similar proportion of sites in the pre- compared to the post-fire survey period. There were, however, a few notable examples of animals that either appeared at substantially more (i.e. 14% to 34% more sites) or less (i.e. 13% to 41% more sites) sites in the post-fire compared to the pre-fire period (**Table 1**).

For example, bassian thrushes (*Zoothera lunulata*) were recorded at 34% less sites, long-nosed bandicoots (*Perameles nasuta*) were recorded at 21% less sites and superb lyrebirds (*Menura novaehollandiae*) were recorded at 19% less sites in the post-fire period (**Table 1**). On the other hand, white footed dunnarts were recorded at 41% more sites, lace monitors (*Varanus varius*) were recorded at 21% more sites and common brushtail possums (*Trichosurus vulpecula*) were recorded at 20% more sites in the post-fire period (**Table 1**). Southern brown bandicoots and long-nosed potoroos were all recorded at relatively similar proportions of sites across the pre- and post-fire periods.

Table 1. Percent of sites where different species were recorded across pre- and post-fire cameras surveys.

Species	% sites (n=58) pre-fire	% sites (n=55) post-fire	% diff
Bassian thrush	38%	4%	-34%
Long-nosed bandicoot	45%	24%	-21%
Superb lyrebird	91%	73	-19%
Short-beaked echidna	48%	31%	-17%
Red fox	24%	9%	-15%
Agile Antechinus	52%	38%	-14%
Painted button-quail	0%	13%	+13%
Eastern pygmy possum	3%	13%	+13%
White-winged Chough	9%	24%	+15%
Bush rat	62%	78%	+16%
Red-necked wallaby	33%	49%	+16%
Eastern grey kangaroo	19%	38%	+19%
Common brushtail possum	66%	85%	+20%
Lace monitor	19%	40%	+21%
White-footed dunnart	10%	51%	+41%

MANAGEMENT OUTCOMES

The failure of two successive surveys to detect long-footed potoroos in the South East Forest National Park does not necessarily mean the species is locally extirpated. However, it makes it unlikely that there is a large population currently persisting in the area. This has management implications given that this was the only known population of long-footed potoroos in NSW, with the two other populations persisting in Victoria. Further work is needed to examine threats to the species and if changes in management actions are required, for example, increased invasive predator control or changes in fire regimes. In future, rewilding from extant populations could also be considered.

IMPACTS OF THE 2019-20 SUMMER BUSHFIRES ON TERRESTRIAL SPECIES IN THE FOOTHILL FORESTS OF SOUTH-EASTERN AUSTRALIA

Location: New South Wales and Victoria, Australia

Project Partners: Grant Linley and Dale Nimmo from Charles Sturt University

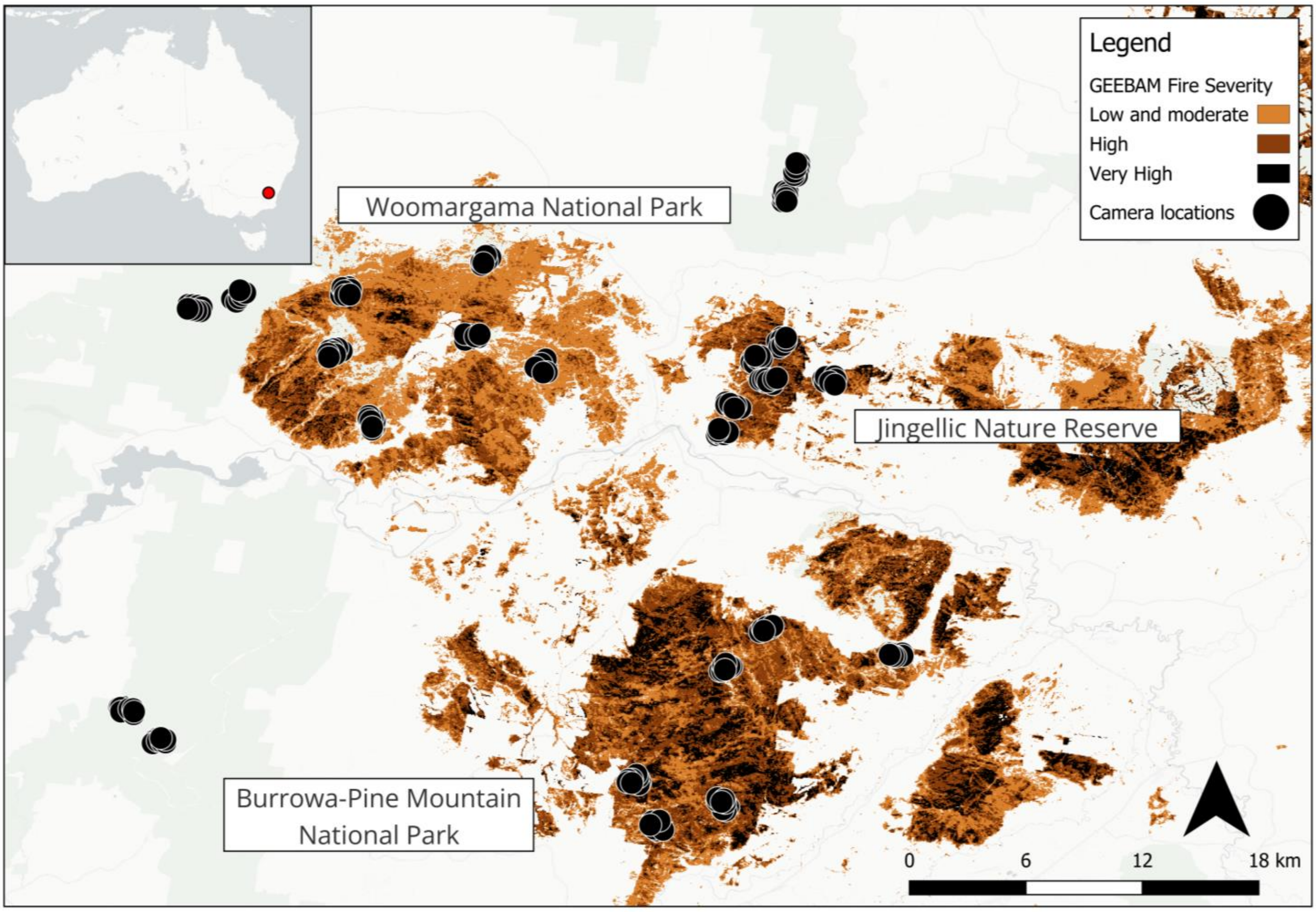

Figure 1. Camera location (black circles) in three national parks/nature reserves across southern New South Wales (NSW) and northern Victoria, overlaid on the 2019/20 wildfire severity Google Earth Engine Burnt Area Map data.

PROJECT OVERVIEW AND AIMS

Globally, fire has played a vital evolutionary role in shaping ecosystems for millions of years, including in Australia, where fire regimes have caused dramatic changes in biodiversity over millennia. Faced with an increasingly flammable continent, owing to a warming and drying climate, Australia is transitioning into an era where extremely large and severe fires are increasingly common.

The Corryong and Green Valley megafires were two large fire complexes that eventually joined, burning vast areas (600,000 ha) of foothill forests and woodlands, as well as sensitive alpine ecosystems, across the Upper Murray region of north-eastern Victoria and southern New South Wales. Within this fire complex, 50% of the habitat burnt was sclerophyll forest, which contains a range of threatened species habitats. These megafires provide the opportunity to address some fundamental questions about how megafires impact wildlife. This study aims to assess the impacts of the 2019-20 Corryong (Victoria) and Green Valley (NSW) megafires on terrestrial wildlife, with a specific focus on how the extent of high severity fires and unburned refuge habitat shape wildlife distributions at the landscape-scale. Our study region is regarded as a "data shadow" for south-eastern Australia in terms of wildlife data due to a long-term lack of biodiversity monitoring. Therefore, another key aim of this study is to contribute to filling parts of this "data shadow" gap through wide-spread monitoring in this region. This project will add to a growing body of research around the impacts of fires on both native and introduced species, and how to best mitigate their future impacts.

METHODS

The project took place within two large fire complexes, the Corryong and Green Valley fires, which occurred in north-eastern Victoria and south-eastern New South Wales. These two complexes eventually joined and burnt 600,000 ha of foothill forests and woodlands, as well as sensitive alpine ecosystems. Within these fire complexes, data was sampled from three large wilderness areas: Woomargama National Park, Jingellic Nature Reserve and Burrowa-Pine Mountain National Park (**Figure 1**).

A "whole of landscape" study design was used to examine the influence of pyrodiversity, unburned refuges and fire severity on terrestrial species. This approach is ideally suited to testing hypotheses regarding the influence of landscape patterns on biodiversity and has been used previously to test the influence of pyrodiversity on biodiversity. Using maps of the 2019-20 Australian bushfires, we selected 24 study landscapes. Each circular landscape is 1 km diameter, chosen to capture clear gradients in (i) the extent of unburned "refuge" vegetation within a landscape, and (ii) spatial variation in fire severity classes, as a measure of pyrodiversity (**Figure 2**).

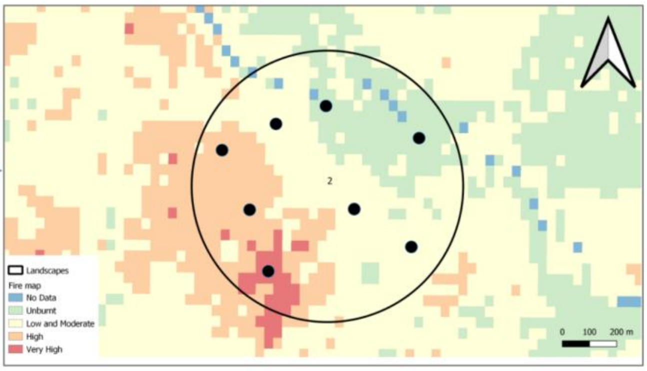

Figure 2. Example of one of the 24 landscapes (each containing 8 cameras) chosen to capture a clear gradient from those dominated by high severity fires to those containing large, unburned refuges.

Landscapes were selected and assessed to ensure that they did not overlap, were located away from farmland and forestry plantations, occurred in Eucalyptus woodlands, and had a narrow elevational range (338-890 m) and rainfall range (814-1150 mm/year). A total of 18 of the 24 landscapes were located within the boundaries of the 2019-20 fires, while a further six "reference landscapes" were located outside of the fire grounds. These landscapes are 100% unburned and hence act as unburned control landscapes. Landscapes within the fire grounds varied in the proportional extent of unburned refuge, from 0.01%-~60%.

Eight camera trap sites were established within each of the 24 study landscapes, resulting in 192 sites in total. The study design will use area proportionate sampling, whereby cameras will be allocated in proportion to the percentage of each burn severity within a given landscape. The fire severity classes consisted of five different measures of burn severity based on the intensity and damage from the fire: 1) non-native or non-woody vegetation, 2) unburnt, 3) low and moderate, which had low to medium canopy scorch, 4) high, which had high canopy scorch, and 5) very high where the entire canopy was burnt (**Figure 3**). Sites were located >100 m from each other to increase independence, and at least 50 m from roads and tracks. Each site consisted of a lured camera trap, which was deployed and remained in place for at least one year. In addition, vegetation surveys were undertaken to determine the extent of fire damage and recovery, in combination with more specific vegetation surveys, which focused on assessing the damage to refuge areas.

Figure 3. Typical habitat burnt by 'very high' fire severity wherein the tree canopy was entirely burnt.

Camera traps (Reconyx HC600 Hyperfire and Enduro Swift) were tied to a tree, 50 cm off the ground, facing downwards (20˚ angle) to account for both small mammals and any larger native or invasive species (**Figure 4**). Each camera trap was focused on a lure consisting of a tin of sardines nailed to a stake 15 cm from the ground, located two metres in front of the camera. In addition, a cork tile was located at the bottom on the baited stake and covered with a mix of tuna and linseed oil, sunflower seeds and honey.

Camera images were identified and sorted to species where possible using the Wildlife Insights online platform. For images of animals that could not be identified to species, the closest taxonomic grouping was used e.g. "Aves", "Macropod" etc., or "Unknown". For the purpose of visualisation in this report, some common species were grouped (e.g. "Possum Species", "Passerine Birds", "Doves and Pigeons", "Small Mammal <500g").

Once all images were classified, species/species group detection events were calculated by grouping all images of a species/species group that were taken on a single camera and within 30 minutes of each other into single events. These detection events were then totalled across each camera. To account for differences in camera monitoring effort (some cameras stopped functioning due to low battery of full memory cards), "encounter rates" for each species or species group were calculated, by dividing the total number of detection events for each species/species group at a camera by the total number of days that camera was active and then multiplying this number by 100. This final value was then averaged over all cameras within each fire category (i.e. either outside/within fire extent categories or different fire severity categories).

Figure 4. Typical camera trap set up, with the camera fastened to a tree, approximately 50cm off the ground.

KEY FINDINGS

Across the project 90 species were detected on the 192 camera traps deployed within the three national parks and reserves. This number included 6 threatened species, including eastern pygmy possums (*Cercartetus nanus*; listed as vulnerable) and flame robins (*Petroica phoenicea*, listed as vulnerable), recorded across all three national parks/nature reserves, greater gliders (*Petauroides volans*, listed as endangered), recorded in Woomargama National Park, hooded robins (Melanodryas cucullate, listed as vulnerable) and pink robins (*Petroica rodinogaster*, listed as vulnerable), recorded in Jingellic Nature Reserve, and pilotbirds (*Pycnoptilus floccosus*, listed as vulnerable), recorded in Burrowa-Pine Mountain National Park.

Thirteen invasive fauna species were also recorded across the survey, with the most commonly encountered species including domestic/feral goats (*Capra hircus*), house/black rats (*Rattus rattus*), European rabbits (*Oryctolagus cuniculus*) and red foxes (*Vulpes vulpes*).

Many of the more common species were encountered similarly within and outside of the fire extent, although common brushtail possums (*Trichosurus vulpecula*) were encountered at greater rates within the fire extent, as were Australian magpies (*Gymnorhina tibicen*), domestic/feral goats, and mountain brushtail possums (*Trichosurus cunninghami*) (**Figure 5**). Agile antechinus (*Antechinus agilis*) were encountered at greater rates outside the fire extent (**Figure 5**). Some of these results could reflect site- or location-based differences pre-fire, as most cameras outside of the fire extent were relatively geographically distinct from those within the fire extent (**Figure 1**).

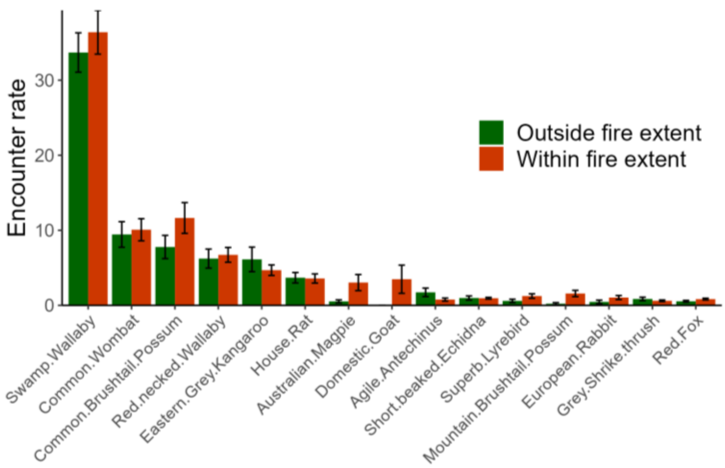

Figure 5. Average encounter rate for the 15 most commonly encountered species within compared to outside the fire extent.

Within the fire extent, there was far more variation in species encounter rates, with some species like the swamp wallaby (*Wallabia bicolor*) showing highest encounter rates in more severely burnt habitat, with lowest encounter rates in unburnt patches of habitat (**Figure 6**). Other species like the common brushtail possum showed opposite trends, with highest encounter rates in unburnt patches of habitat within the fire extent and lowest rates in the highest severity burnt patches (**Figure 6**). Similarly, eastern grey kangaroos (*Macropus giganteus*) and Australian magpies both had highest encounter rates in unburnt habitat compared to severely burnt habitat and domestic/feral goats were only encountered in unburnt patches of habitat within the fire extent (**Figure 6**).

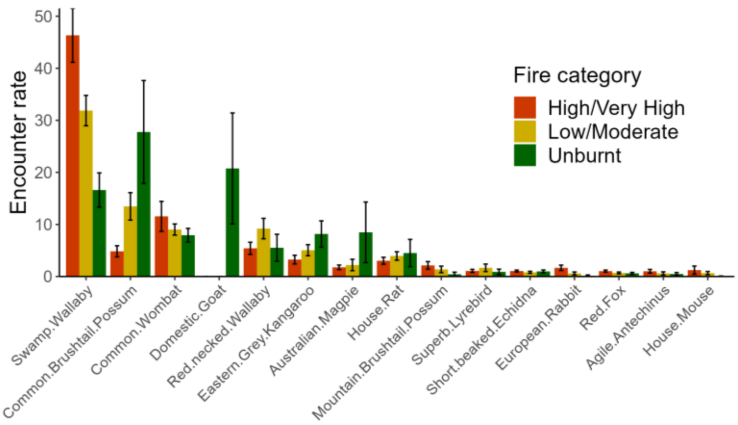

Figure 6. Average encounter rate for the 15 most commonly encountered species across different fire categories within the fire extent.

MANAGEMENT OUTCOMES

The project deliverers vital information on the status of native wildlife in fire affected areas which will feed into national and state prioritisations aimed at alleviating fire impacts and hastening recovery. Specifically, it (i) improves understanding of the impacts of the 2019-20 fires on Australia's wildlife, (ii) enhances knowledge of the importance and location of unburned refuges for priority species and pyrodiversity for biodiversity, which will (iii) allows for better decision making on which areas require active interventions following increasingly large fires.

As this survey effort has also been carried out in locations where little to no recent widespread monitoring has occurred, it has also updated species lists, including new records of endangered and vulnerable species and invasive species. Indeed, many of the threatened species recorded throughout this survey have not previously been recorded in these national parks and reserves. These updates will help to inform management activities such as future hazard reduction burns, targeted introduced predator control to alleviate impacts to threatened species and construction of park or reserve infrastructure or roads (e.g. to mitigate impacts on threatened species).

WOMBAT-POWERED RECOVERY: HARNESSING AN ECOSYSTEM ENGINEER TO INCREASE BUSHFIRE RESILIENCE

Location: New South Wales, Australia

Project Partners: Grant Linley and Dale Nimmo from Charles Sturt University

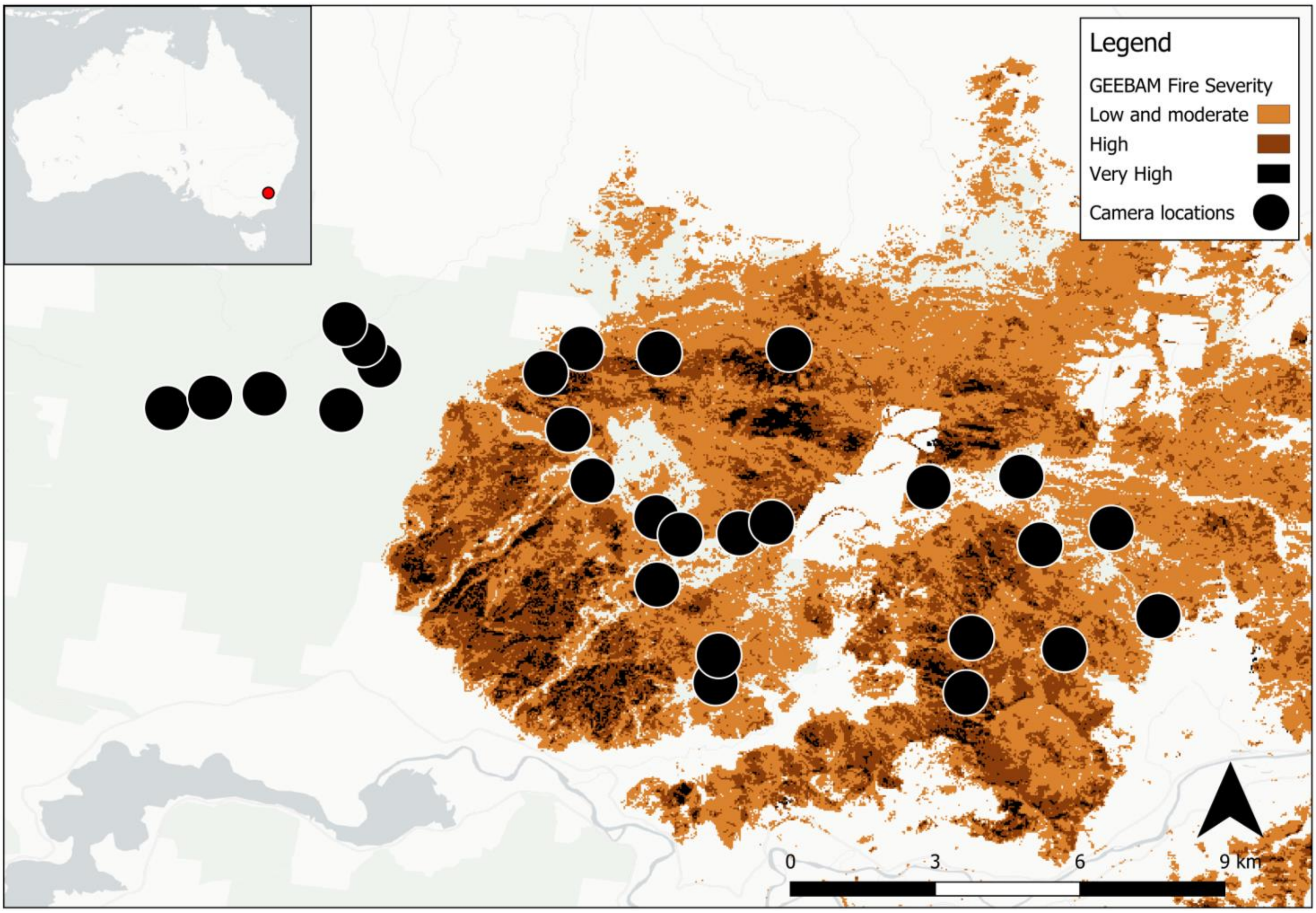

Figure 1. Study area and focal wombat burrows for the wombat-powered recovery project in Woomargama National Park, New South Wales, overlaid on the 2019/20 wildfire severity Google Earth Engine Burnt Area Map data. Each wombat burrow was paired with a nearby control site within the same fire severity class and vegetation type.

PROJECT OVERVIEW AND AIMS

The 2019–20 Australian wildfires were a series of megafires that occurred across southern and eastern Australia over the 2019–20 spring and summer. The total area which was burnt between August 2019 and March 2020 was > 12.6 million hectares, making it the largest fire season for southeastern Australia since European colonization[1]. The 2019–20 wildfires were fuelled by drier than usual ecosystem conditions due to prolonged drought[2]. This led unprecedented fire behaviour, including a record number of firestorms[3]. Landscape features that usually act as barriers to fire, such as wet gullies, rocky outcrops, riparian strips, rivers and cliffs, failed to do so under such extreme fire conditions[1]. The fire burned an unprecedented area at high severity, accounting for almost half of all high severity fire in Australia over the last 33 years[4].

[1] Wintle et al. 2020. After the megafires: what next for Australian wildlife? Trends in Ecology & Evolution 35: 753-757.
[2] Abram et al. 2021. Connections of climate change and variability to large and extreme forest fires in southeast Australia. Communications Earth & Environment 2: 1-17.
[3] Kablick et al. 2020. Australian PyroCb Smoke generates synoptic-scale stratospheric anticyclones. Geophysical Research Letters 47: e2020GL088101.
[4] Collins et al. 2021. The 2019/2020 mega-fires exposed Australian ecosystems to an unprecedented extent of high-severity fire. Environmental Research Letters 16: 044029.

During this unprecedented fire season, reports emerged of benevolent wombats herding native wildlife into their fireproof burrows. These stories went viral (**Figure 2**). While widely dismissed[5], an element of truth could be gleaned from these reports. Wombats may have the capacity to enhance the survival of co-occurring wildlife—as accidental heroes.

Figure 2. A viral tweet suggesting that wombats were herding wildlife into their fire-proof burrows during the 2019-20 megafires.

Wombats are ecosystem engineers. Ecosystem engineers exist globally and provide a range of ecosystem services, including creating refugia in the form of burrows[6,7,8]. Burrows and warrens created by fossorial species provide a vital role in maintaining and creating refugia for a range of vertebrate and invertebrate species[9,7]. Wombat warrens consist of a large network of protected underground tunnels which have stable temperatures when compared to surface temperatures[10]. One study found warrens with 28 entrances and nearly 90 metres of tunnel[11]. Wombats have multiple warrens within their home range, with most being unoccupied at any given time. Partly because of this, they are used by a range of taxa: a 2015 study observed ten wildlife species using wombat burrows[6]. Temperatures within burrows are highly stable compared to surface temperatures[11]. Thus, they probably provide rare 'cool spots' during bushfires. In addition to enhancing survival during fire, wombat burrows might act as a nucleus for post-fire recovery, by providing a cool shelter that helps native wildlife avoid predation.

In some cases, the reaction of conservationists to the bushfire catastrophe has been to race towards 'techno-fixes'; applying high-end technology to enhance bushfire recovery. Yet, exceedingly few of these can be applied at scale. An alternative is to draw on the ecological interactions embedded within ecosystems, to maximise or restore the services that are naturally provided. Wombat burrowing is one such service that we know astonishingly little about. Wombats, through the course of their usual activities, provide potential bushfire refuges throughout millions of hectares of fire prone forests. Yet they continue to suffer persecution and have declined across vast areas. If wombat burrows do enhance recovery of wildlife, then the implications are significant. It would mean that the decline of wombats over recent decades compromises the resilience of wildlife to wildfire, and that conservation and recovery of wombat populations could enhance bushfire resilience. This would be particularly important given increases in the frequency, severity, and size of fires that has already occurred and is projected to continue.

This project examined the role of wombats in hastening wildlife recovery by monitoring the use of wombat burrows by native species (focussing on mammals and reptiles) at a range of sites, including a subset within the boundaries of the 2019/20 bushfires. Our aim was to document the range of species that are associated with wombat burrows and investigate whether these associations differ depending on fire severity. We predicted that a diversity of species would be observed using wombat burrows, and that these associations would be strongest in burned sites due to the impact of fire on shelter resources, and hence an increased reliance on wombat burrows by native species.

[5] Nimmo, D.G. 2020. Tales of wombat 'heroes' have gone viral. Unfortunately, they're not true. The Conversation. Available from: https://theconversation.com/tales-of-wombat-heroes-have-gone-viral-unfortunately-theyre-not-true-129891.
[6] Thornett E. et al. 2017. Interspecies co-use of southern hairy-nosed wombat (*Lasiorhinus latifrons*) burrows. Australian Mammalogy 39: 205-212.
[7] Andersen et al. 2021. Burrow webs: Clawing the surface of interactions with burrows excavated by American badgers. Ecology and Evolution 11(7):11559-11568.
[8] Lundgren et al. 2021. Equids engineer desert water availability. Science 372: 491-495.
[9] Read et al. 2008. Ecological roles of rabbit, bettong and bilby warrens in arid Australia. Journal of Arid Environments 72: 2124-2130.
[10] Finlayson et al. 2003. Monitoring the activity of a southern hairy-nosed wombat, *Lasiorhinus latifrons*, using temperature dataloggers. Australian Mammalogy 25: 205-208.
[11] Shimmin et al. 2002. The warren architecture and environment of the southern hairy-nosed wombat (*Lasiorhinus latifrons*). Journal of Zoology, 258: 469-477.

METHODS

Site description
Woomargama National Park is located on the Southwest slopes of NSW near Holbrook and is approximately 24,000 hectares of protected forest (**Figure 1**). The park primarily consists of wet and dry old growth sclerophyll forest[12]. While there are a variety of forest types across the park that include a range of dominant Eucalypt species, wet sclerophyll forests often include combinations of Robertson's peppermint, broad-leaved peppermint, and Norton's box, while dry sclerophyll forests include combinations of brittle gum, peppermints, red stringybark, and long-leaved box.

Experimental design
Fire severity is the loss of organic matter above and below ground due to burning[13]. Fire severity is often measured in categories that capture increasing biomass consumption, from 'unburned' vegetation, where vegetation is unaltered or affected by direct heat from fire, 'low/moderate severity' where understory plants have been charred/consumed and some partial canopy damage, and 'high severity' where all understory is burnt as well as the canopy being scorched or consumed[13]. The experimental design of this study uses such a scheme to classify sites into four treatments, based on national fire severity maps developed by the Department of Agriculture, Water and Environment[14]. The treatments were:

- Unburned: unburned sites outside of the footprint of the 2019–20 wildfires
- Low/moderate severity: sites burned at low to moderate severity during the 2019–20 wildfires
- High severity: sites burned at high or very high severity during the 2019–20 wildfires

In addition, we had one further treatment that were also unburned by the 2019–20 wildfires, but differed with respect to their context:

- Refuge: unburned islands within the perimeter of the 2019–20 wildfires that escaped the fire

A total of 28 sites were selected: 21 within the perimeter of the 2019–20 wildfires divided equally among refuge, low/moderate, and high severity fire classes, and 7 within nearby unburned areas. Each site consists of two paired camera traps (Reconyx HC600 Hyperfire), one at a burrow and the other nearby (~50m) in a similar area (e.g., aspect and habitat). At each burrow, a camera was fastened to a stake approximately 2m from the burrow entrance, at a 20° angle downward, to capture smaller animals entering and exiting the burrow. The same set-up was used for monitoring control sites. Cameras remained in place 300 nights, resulting in >16,000 trap nights in total.

KEY FINDINGS

The 56 cameras (28 burrow, 28 control) were established in July 2021, with a SD card swap occurring in November 2021 and a final SD card and camera trap retrieval occurring in April 2022. We have very recently finished processing hundreds of thousands of camera trap images obtained from the camera traps, using Wildlife Insights, an online platform developed by Google that uses Artificial Intelligence to identify wildlife in camera trap images. This processing >740,000 images including > 360,000 wildlife images of > 60 wildlife taxa, making it one of the largest Australian contributions to the Wildlife Insights platform. The findings suggest an extremely wide array of species make use of wombat burrows, including mammals, reptiles, and birds. In total, 51 species were detected at wombat burrows. Thirteen species were detected only at wombat burrows (i.e., not at nearby control cameras), including a range of bird species such as red-browed and white-throated treecreepers (*Climacteris erythrops, Sericornis frontalis*) and scarlet robins (*Petroica boodang*).

A wide range of behaviours were observed in and around the wombat burrows, from animals simply moving past, inspecting the burrow entrance, foraging around the burrows, and entering the burrows. One interesting pattern is the tendency of wombat burrows to act as temporary pools following downpours. These were visited by wildlife, and may serve an important role in water provision, particularly in landscapes where water is scarce or spatially and temporally unpredictable. The provision of water by other ecosystem engineers has attracted interest recently[8].

We calculated simple effect sizes (log10 ratios) to identify species associated with wombat burrows overall, and in each fire severity class (unburned, refuge, low/moderate severity, high severity). This revealed a relatively even split between species associated with burrows (i.e., more likely to be recorded on a camera trap at a burrow than at a control site) and control sites (**Figure 3**). Species associated with wombat burrows included a range of native species,

[12] Benson 2008. New South Wales Vegetation Classification and assessment: Part 2 plant communities of the NSW South-western slopes bioregion and update of NSW Western Plains plant communities, version 2 of the NSWVCA database. Cunninghamia 10: 599-673.

[13] Keeley 2009. Fire intensity, fire severity and burn severity: a brief review and suggested usage. International Journal of Wildland Fire 18: 116-126.
[14] DAWE. 2020. Australian Google Earth Engine Burnt Area Map. A Rapid, National Approach to Fire Severity Mapping. Department of Agriculture, Water and the Environment, Commonwealth of Australia, Canberra.

including agile antechinus (*Antechinus agilis*), yellow-footed antechinus (*Antechinus flavipes*), bush rats (*Rattus fuscipes*), a range of bird species, and the lace monitor (*Varanus varius*).

Analysing effect sizes separately for each fire severity class reveals some interesting trends. While the relatively even split of wombat-and-control-associated species is evident in the unburned and refuge treatments (**Figure 3**), there does appear to be a shift towards a greater fraction of species being associated with wombat burrows than controls in the burned sites, particularly in the sites that burned at high severity (**Figure 3**). Here again, species including agile antechinus, bush rats, and lace monitors are associated with wombat burrows in severely burned sites, as well as Echidna (*Tachyglossus aculeatus*), and some ground-dwelling birds such as the painted button-quail (*Turnix varius*) and spotted quail-thrush (*Cinclosoma punctatum*).

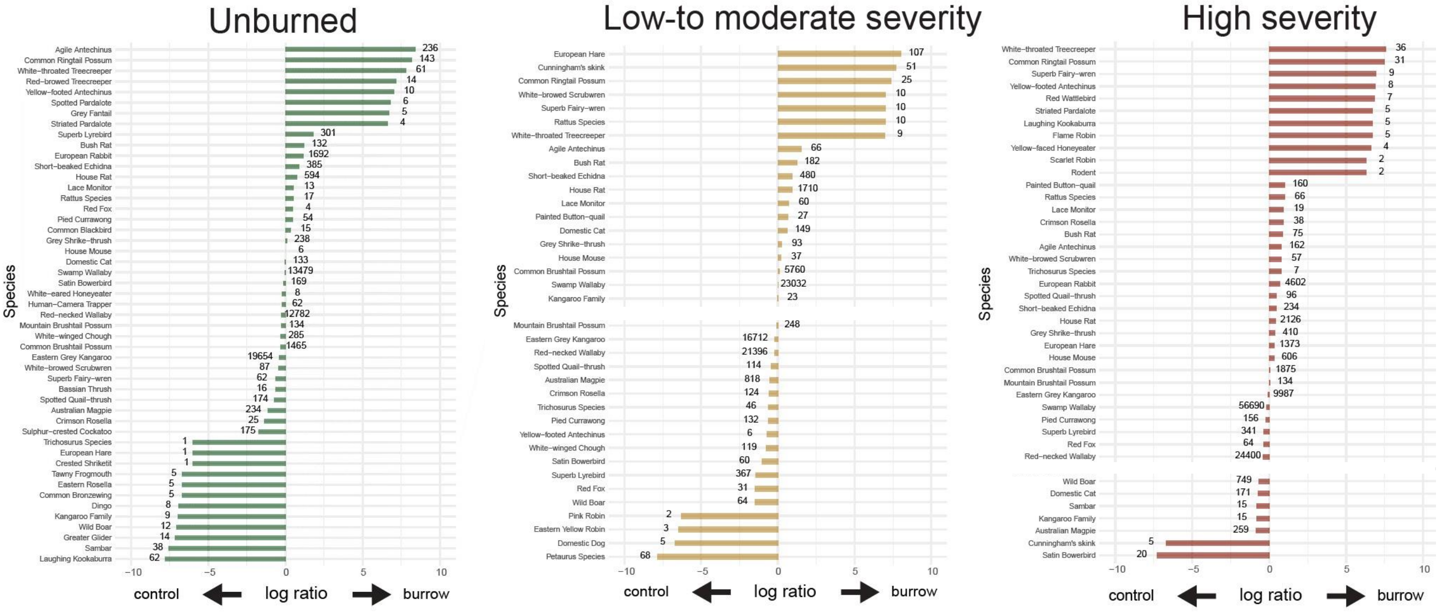

Figure 3. Effect size, shown as log10 ratios, comparing the overall number of images of species at wombat burrows and nearby control cameras at low-to-moderate and high severity sites. Positive log10 ratios indicate a positive association with wombat burrows compared to controls (i.e., more common photographed by cameras facing wombat burrows), whereas negative log10 ratios indicate a negative association (i.e., more commonly photographed by control cameras). Numbers indicate the number of images of each species.

SOUTHERN ARK PREDATORS & PRIORITY SPECIES PROJECT

Location: East Gippsland Victoria, Australia

Project Partner: Andy Murray from the Southern Ark Program, the Victorian Government Department of Energy, Environment and Climate Action (DEECA)

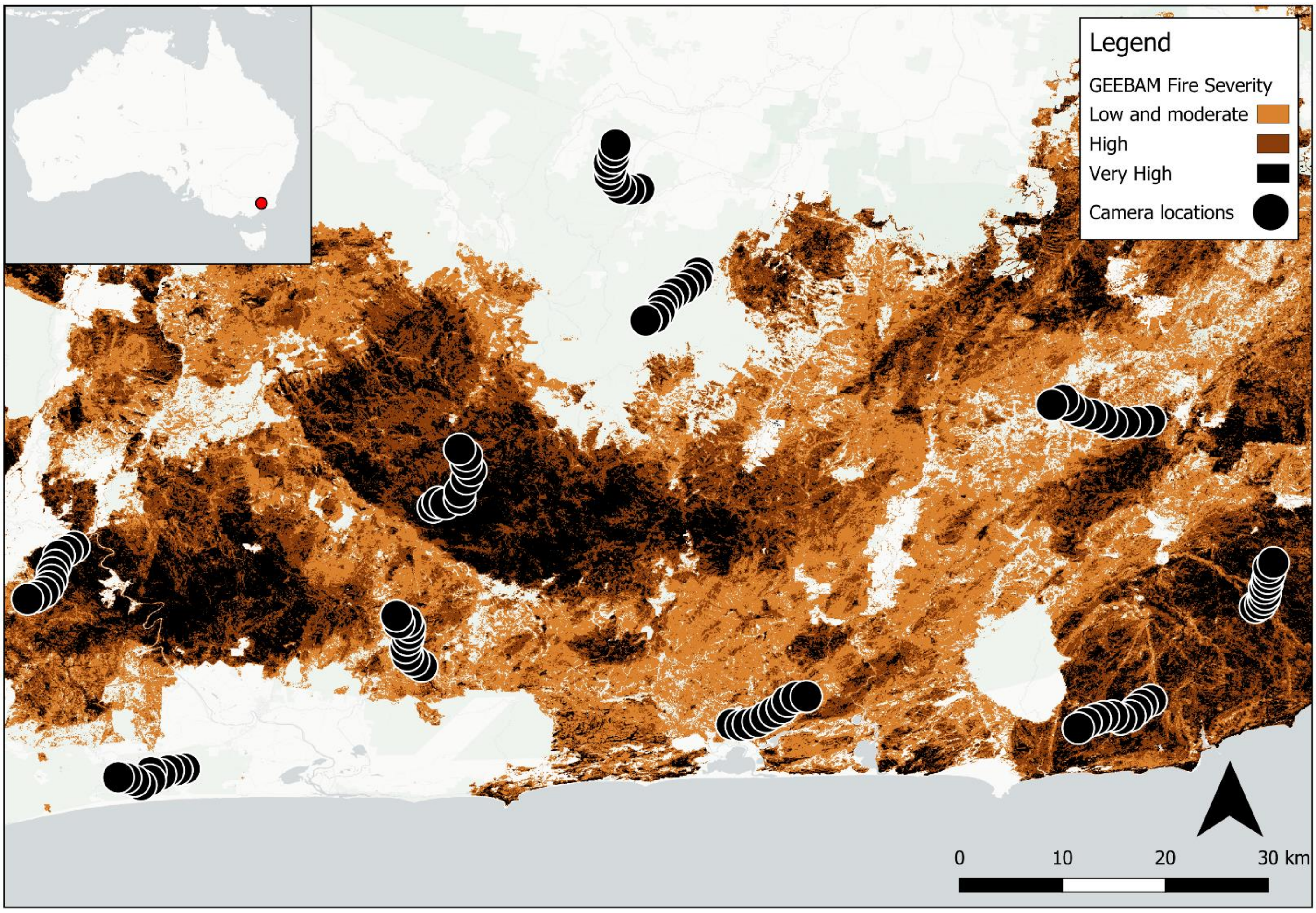

Figure 1. Locations of the 100 cameras set up across 10 transects in burnt and unburnt habitats across East Gippsland, Victoria, overlaid on the 2019/20 wildfire severity Google Earth Engine Burnt Area Map data.

PROJECT OVERVIEW AND AIMS

The 2019–20 bushfire season resulted in approximately 1.5 million hectares of eastern Victoria being burnt. At least 244 plant and animal species had more than 50% of their modelled habitat in these burnt areas, with 43 species having more than 50% of their modelled habitat impacted by high-severity fires[1]. Of these species, many were identified as rare or threatened, in particular:

- Long-footed potoroos (*Potorous longipes*) had 79% of their modelled habitat in Victoria burnt, with 51% impacted by high-severity fire,
- Southern brown bandicoots (*Isoodon obesulus*) had 25% of their modelled habitat in Victoria within the fire extent, with 19% impacted by high-severity fire.

Other threatened medium-sized terrestrial species may also have been significantly impacted by the bushfires, including the long-nosed potoroo (*Potorous tridactylus*).

The long-footed potoroo and the southern brown bandicoot are both listed as Endangered under the EPBC Act 1999 and the Victorian Flora and Fauna Guarantee Act 1988. Predation by red foxes (*Vulpes*

[1] Victorian Government Department of Environment, Land, Water and Planning (DELWP) 2020. Victoria's bushfire emergency: biodiversity response and recovery. version 2. DELWP, Melbourne, Victoria.

vulpes) and also feral cats (*Felis catus*) is a known key threatening process for these species as well as more common species like long-nosed potoroos in the region. Predator activity, including red fox and feral cat activity often increases in post-fire environments[2], compounding the impacts faced by native species vulnerable to predation by these animals.

This project focuses specifically on the East Gippsland region, in eastern Victoria. Approximately 1.1 million hectares were burnt across this region during the 2019-20 bushfire season. In East Gippsland there is a large-scale (~1 million hectares) fox control project known as the Southern Ark, managed by the Department of Energy, Environment and Climate Action (DEECA) and Parks Victoria. Southern Ark has significantly reduced fox density, however, it was relatively unknown how the bushfires had impacted fox numbers in the region, as well as other predator species like cat and dingoes, and threatened native animals.

This project addressed this gap by assessing the impacts on fire on fauna dynamics in East Gippsland. Specifically, it aimed to evaluate how fire and fire severity impacted native and introduced wildlife, including fox, cat and dingo population numbers, as well as native species including the long-footed potoroo, the long-nosed potoroo and southern brown bandicoots. A particular focus of this project was on predator species, as monitoring protocols were designed to target these animals and extensive yearly monitoring targeting native mammals (e.g. potoroos and bandicoots) is undertaken separately in the region.

METHODS

Study area

This survey was conducted within the Southern Ark project area, encompassing the eastern corner of Victoria, from the Snowy River valley to Cape Howe. Southern Ark operates a year-round fox-baiting program along a network of roads and tracks throughout its project area. Baits are spaced on average 690 m apart (range 3–2,144 m) and are replaced every 6 weeks.

Camera trap methods

Camera surveys for this project were undertaken by the Southern Ark operations team and are ongoing. Findings in this report relate to images and data collected between November 2021 and April 2023.

In total, across this monitoring effort 10 transects of 10 cameras (totalling 100 cameras across the survey) were deployed (**Figure 1**). Transects were either positioned in burnt (7 transects) or unburnt (3 transects) locations within East Gippsland and transects positioned in burnt locations were spread across habitat impacted by high/very high severity fire (4 transects) (**Figure 2**) or low/moderate severity fire (3 transects). At each transect, cameras were positioned along roads or fire trails at around 1km from each other. Rather than being positioned directly on the road, cameras were set approximately 5–10 metres into tree cover to reduce the theft potential while still increasing the chance of detecting predator species (which generally use roads and paths for dispersal).

Figure 2. Typical example of a transect location impacted by high/very severity fire.

Cameras were a mix of Enduro Swift and Reconyx (PC900) and were generally positioned at about 0.5 m from the ground, tied to a tree, with the focal point at around 2 m on a lure. A selection of different lures were trialled to attract animals and increase camera detection probability. The most commonly applied lure was a small stick or stake dipped in a mixture of fish oil.

Camera images were uploaded to the online image processing platform Wildlife Insights, where they were identified and sorted to species where possible. For images of animals that could not be identified to species, the closest taxonomic grouping was used e.g. “Aves”, “Macropod”, “Unidentified Small Mammal <500g” etc., or “Unknown”.

Once all images were classified, species detection events were calculated by grouping all images of a species that were taken on a single camera and within

[2] Hradsky et al. 2019. Responses of invasive predators and native prey to a prescribed forest fire. Journal of Mammalogy 98: 835–847.

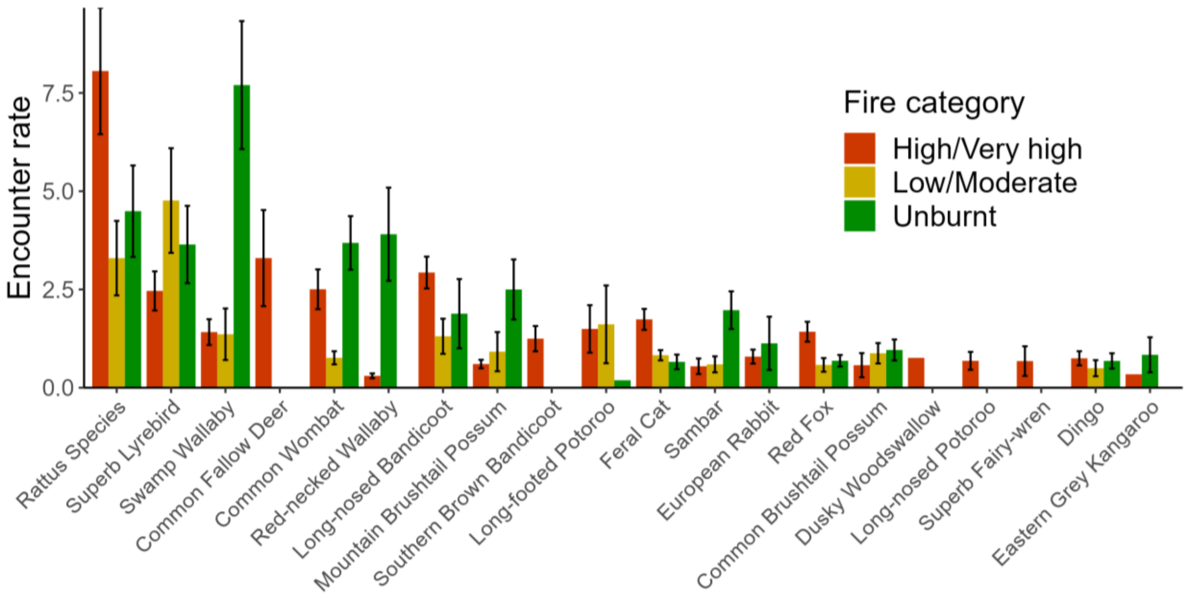

Figure 3. Average encounter rate for the top 20 more commonly encountered species recorded across the survey period in East Gippsland, Victoria.

30 minutes of each other into single events. These detection events were then totalled across each camera. To account for differences in camera monitoring effort (some cameras stopped functioning due to low battery of full memory cards), "encounter rates" for each species or species group were calculated, by dividing the total number of detection events for each species at a camera by the total number of days that camera was active, and then multiplying this number by 100. This final value was then averaged over all cameras within each of the different fire categories.

KEY FINDINGS

A total of 291,680 images were processed and considered for this report. This included more than 173,000 images that contained wildlife species. The most commonly pictured species were rat species (*Rattus* sp.; 2090 events), swamp wallabies (*Wallabia bicolor*; 1744 events), and superb lyrebirds (*Menura novaehollandiae*; 1367 events) (**Figure 3**).

Across the survey, long-footed potoroos were detected on 7 transects and 24 cameras, primarily in the burnt locations in the north-west of the study region (**Figure 4**). They were encountered at a similar rate in locations impacted by low/moderate and high/very high severity fire but were only recorded at one camera in an unburnt location (**Figure 3**). On the other hand, the southern brown bandicoot was only recorded at 2 transects and 14 cameras in the south-eastern parts of the study region and were only encountered in locations impacted by high/very high severity fire (**Figures 3; 4**). The long-nosed potoroo was detected on 1 transect and 2 cameras in a location impacted by high/very high fire severity (**Figures 3, 4**).

Dingoes, red foxes and feral cats were detected across almost all of the 10 survey transects (dingo: 10, red fox: 9 transects, cat: 10 transects), with feral cats encountered at greater rates and at more cameras (84 cameras), than dingoes (59 cameras) and foxes (60 cameras) (**Figures 3, 4**). Feral cats and red foxes were also encountered at greatest rates in locations burnt by high/very high severity fire, while dingoes were encountered at comparable rates across the different fire categories (**Figures 3, 4**).

In terms of common native wildlife, some species were encountered at greater rates in locations burnt by high/very high severity fire, like rats (*Rattus sp.*), while other species were encountered at greater rates in unburnt habitat, like swamp wallabies (*Wallabia bicolor*), red-necked wallabies (*Notamacropus rufogriseus*), and mountain brushtail possums (*Trichosurus cunninghami*) (**Figure 3**).

MANAGEMENT OUTCOMES

Long-footed potoroos and long-nosed bandicoots were encountered across most of the study region during this survey, including in burnt locations. Further, some native species like the southern brown bandicoot were only found in burnt locations. Collectively, these results could indicate that these species are either recovering well across the region or were not heavily impacted by the 2019-20 bushfires.

This notion is supported by data from the camera trap monitoring program Southern Ark operates on a yearly basis to track native mammal populations across ~720

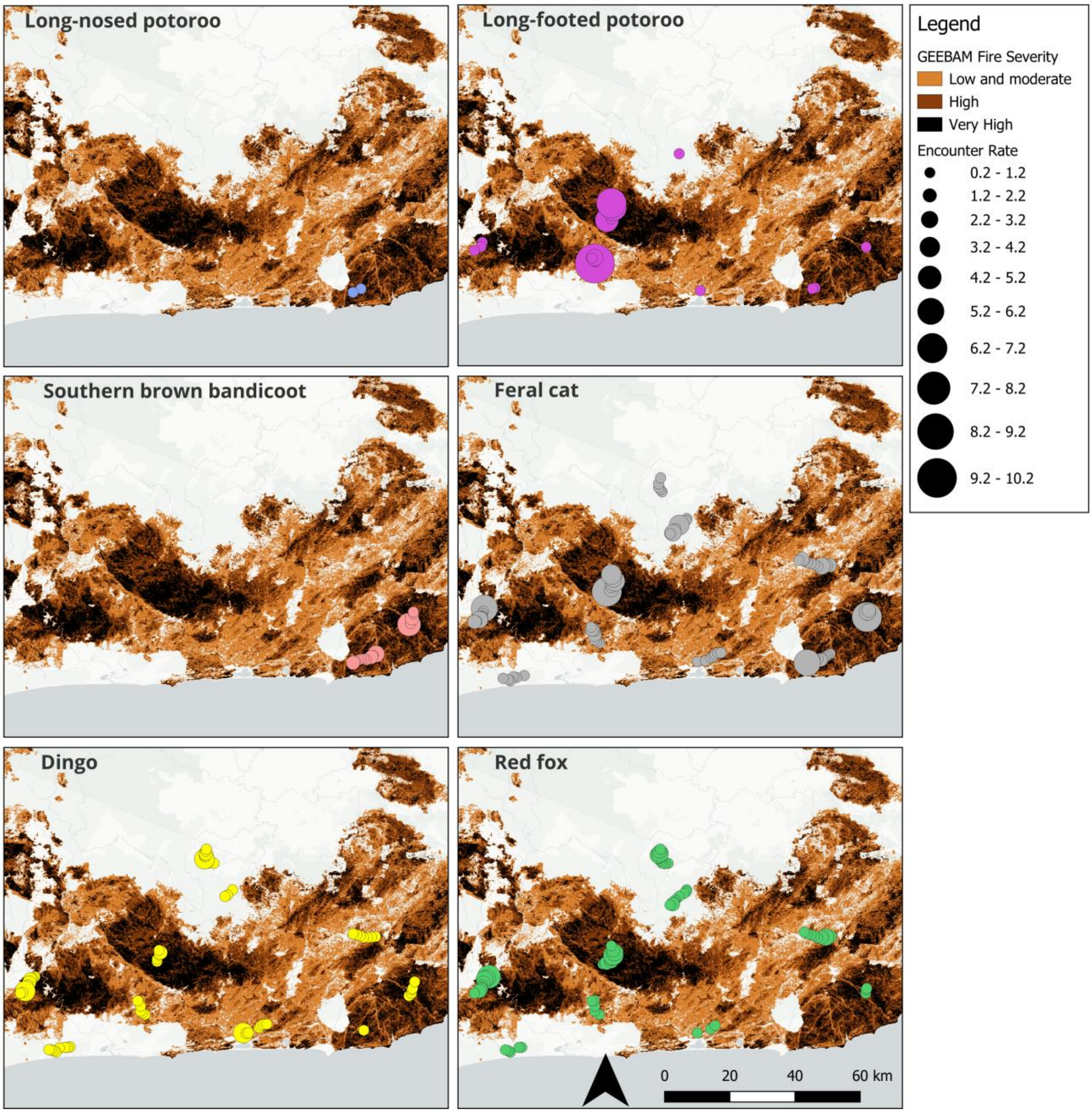

Figure 4. Locations and encounter rates where different threatened, priority and predator species detected across cameras in the study region.

sites in far East Gippsland. This data indicates that long-nosed and southern brown bandicoot species, as well as long-footed potoroos were increasingly detected at sites post-fire, from 2021 to 2022 (**Table 1**)[3]. The higher-than-average rainfall following the fires in 2021–2022 would have likely played a role in the recovery of these species, and explains why some species, especially long-nosed bandicoots and southern brown bandicoots, were detected at noticeably more sites in 2022 (**Table 1**).

Table 1. Total number of sites (out of 700±20 sites) where each species was recorded over time. Results collated from yearly East Gippsland surveys (per. com. Andy Murray), see Robley et al. 2022. for further results, methods.

Year	Long-footed Potoroo	Long-nosed Bandicoot	Southern Brown Bandicoot	Long-nosed Potoroo
2016-17	209	173	6	29
2021	202	117	19	3
2022	259	466	107	16

In contrast to the bandicoot species and the long-footed potoroo, long-nosed potoroos were encountered in relatively few locations across our (and the native mammal) survey, with only two cameras detecting this species in our survey. While the fires probably exacerbated declines of long-nosed potoroos in the region, two years of below average rainfall between 2017–2019 (**Figure 5**) were likely also an important contributing factor to their low numbers (**Figure 3, Table**

[3] Robley et al. 2022. The response of native species to the 2019–20 bushfires and introduced predators in far East Gippsland. Arthur Rylah Institute for Environmental Research Technical Report Series No. 329. Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

1). Other species like the southern brown bandicoot, were probably also strongly impacted by this drought period, indicated by the very low number of sites where they were detected during the 2016-2017 native mammal survey (**Table 1**). Worryingly, the high rainfall event did not appear to have as much of a positive impact on the long-nosed potoroo (**Figure 3, Table 1**), indicating that this species should be tracked carefully in the coming years to ensure that numbers stay steady and do not decline.

Further comparison with pre-fire data would be a valuable addition to this study, to determine if the species have been lost or are recorded in lower numbers in some locations that they were previously found. For example, the fact that long-nosed potoroos and southern brown bandicoots were only found in the southeastern part of the region during this post-fire survey effort probably warrants further investigation. Further, and more targeted monitoring of native species found more often in unburnt locations during the survey, like mountain brushtail possums, is also recommended.

Assessing predator control practices: Red fox encounter rates across the study region were relatively low, at least compared to other invasive predator species (e.g. feral cats), and many native mammals detected across the survey (e.g. long-nosed bandicoots). While this may provide some evidence that baiting is effectively suppressing fox numbers post the 2019-20 bushfires, further comparison between baited and non-baited locations is required to be confident that these observations reflect the effects of predator control.

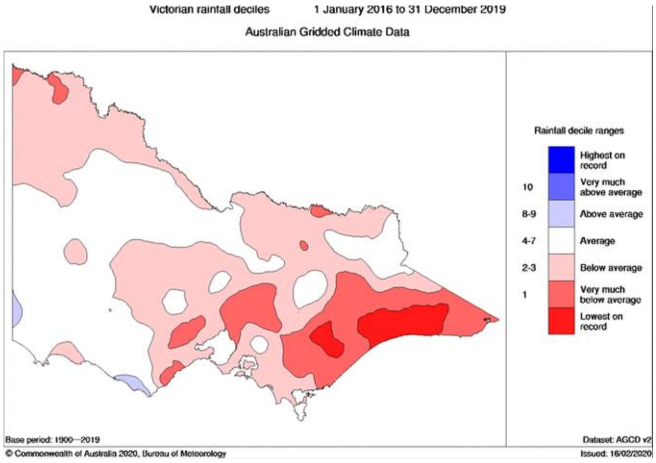

Figure 5. Forty-eight-monthly rainfall deciles for Victoria (01/01/2016 – 31/12/2019; Bureau of Meteorology 2021). Rainfall deciles rank the rainfall over the period of interest in terms of the relative quantity of rain that fell in that period compared with the total distribution of all recorded rainfalls over the same period.

While dingo encounter rates were similar across burnt and unburnt locations, both feral cat and red fox encounter rates were higher in burnt locations. Invasive predators like foxes and cats often exhibit increases in activity in fire-impacted habitat, which could correspond to greater risk of cat and fox predation imposed on native species in these bushfire-impacted areas. Feral cat predation in particular could be significant, given cats were the most frequently encountered predator compared to foxes and dingoes. Introducing more targeted cat control in certain locations impacted by the fire (see **Figure 4**), could therefore be most helpful to reduce the potential impacts of this introduced predators on native wildlife.

KANGAROO ISLAND DUNNART PROJECT

Location: Kangaroo Island South Australia, Australia

Project Partners: Paul Jennings, Hannah Byrne-Willey and Kelly Gledhill from the Kangaroo Island Landscape Board

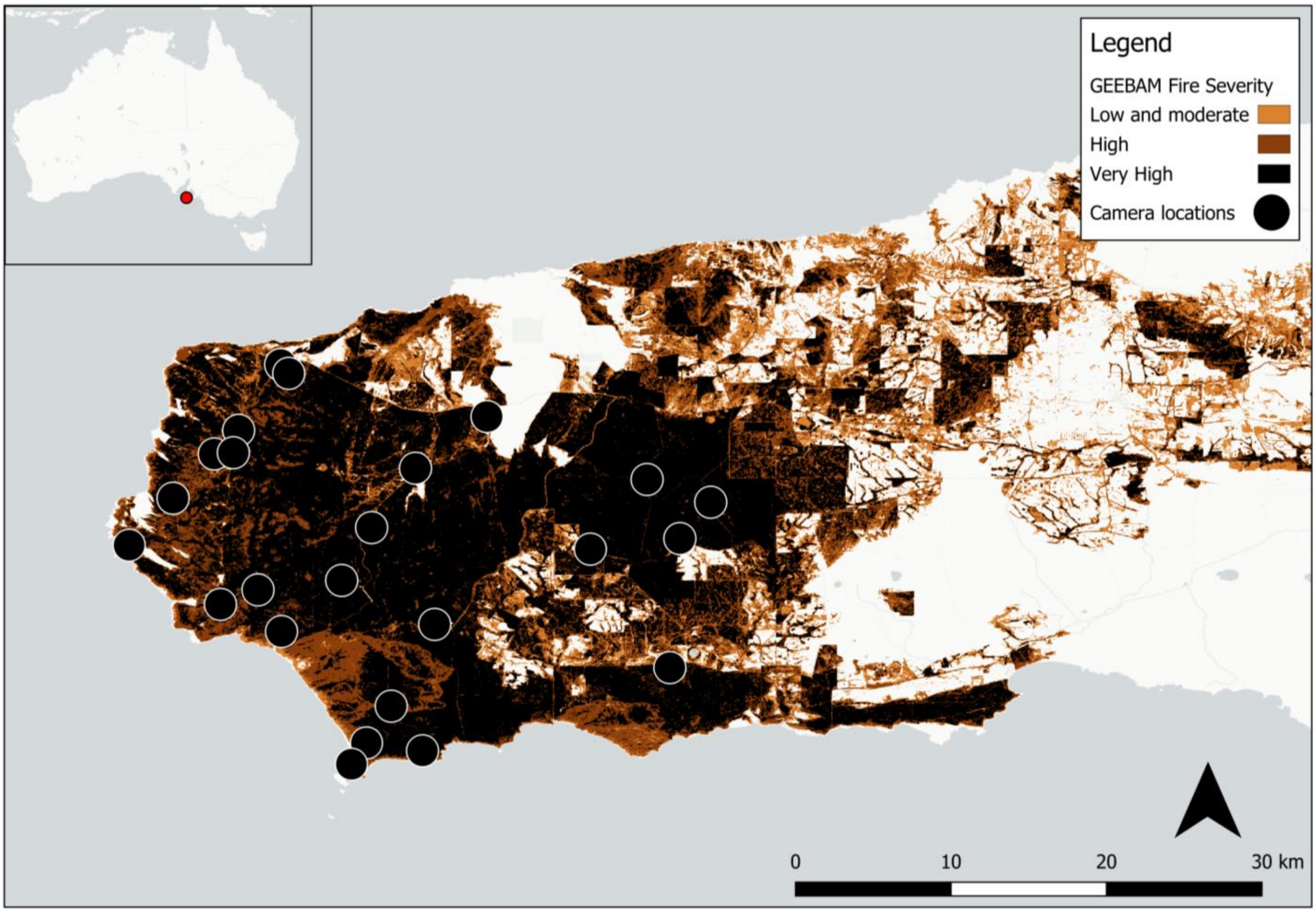

Figure 1. Location of KI dunnart monitoring sites on Kangaroo Island within Flinders Chase National Park, Ravine des Casoars Wilderness Protection Area and Kelly Hill Conservation Park, overlaid on the 2019/20 wildfire severity Google Earth Engine Burnt Area Map data.

PROJECT OVERVIEW AND AIMS

The Eyes on Recovery Kangaroo Island dunnart project was launched following the devastating 2019-2020 Kangaroo Island bushfires. Over approximately 50 days a series of bushfires burnt 211,255 hectares, impacting 48% of the island. This included the Ravine des Casoars Wilderness Protection Area and Flinders Chase National Park to Stokes Bay on the island's north coast. In total, 131,455 hectares of remnant native vegetation was impacted, 85,733 hectares of which lie within conservation estate and the remainder within agriculture, forestry and private property.

The Kangaroo Island dunnart (KI dunnart, *Sminthopsis fuliginosus aitkeni*) is listed as Endangered under the Environment Protection and Biodiversity Conservation (EPBC) Act 1999. It is also listed as Endangered under the National Parks and Wildlife Act 1972 (South Australia: January 2020 list). It is the only species of dunnart found on Kangaroo Island and is endemic to the island. The current distribution of the KI dunnart was previously unknown, although since 1990, all records were from the western end of the island within Flinders Chase National Park, Ravine des Casoars Wilderness Protection Area and remnant native vegetation on private land.

The recent 2019 – 2020 bushfires burnt all but one of the 14 sites where KI dunnarts were recorded in previous (2017-2019) survey efforts. In total, >96% of its predicted remaining habitat was severely burnt[1], raising significant concern for the species immediate

[1] 1 Ward et al. 2020. Impact of 2019–2020 mega-fires on Australian fauna habitat. Nature Ecology and Evolution. 4: 1321–1326.

and ongoing survival. Adding to the bushfire impacts, predation by feral cats (*Felis catus*) was also recognised as the key threat impacting the recovery of the KI dunnart (determined from the National Environmental Science Program (NESP) Bushfire Recovery Workshop held in February 2020 and the draft Conservation Advice (2019) for the Kangaroo Island Dunnart). Therefore, this project aimed to establish a monitoring program to detect the presence and distribution of both KI dunnarts and feral cats across the fire-impacted western parts of the island. Monitoring targeted unburnt remnant vegetation as well as fire affected areas where the species was known to occur pre–fire and was used to inform rapid on-ground recovery actions.

METHODS

This monitoring project commenced in October 2020 and concluded in November 2022. Across the project, 100 cameras were deployed at 25 long-term monitoring sites (**Figure 1**). At each monitoring site a 30m long, 300mm high drift-line fence was installed. Approximately 5m from each end a motion activated Swift Enduro camera was attached to a hardwood stake and orientated facing the drift-line fence (**Figure 2**). In addition, two stand-alone cameras were installed on tracks or wildlife corridors within close proximity (typically <100m) of the drift-line to detect larger wildlife and feral cats (**Figure 3**).

Figure 2. Drift-line set up in a burnt habitat.

Sites were stratified by burnt vs unburnt and by fire severity where possible (25 sites were surveyed in total, 17 burnt and 8 unburnt). Of the burnt sites 11 were high severity (>0.75) and 6 medium severity (0.5 – 0.75).

This project complimented the broader KI Landscape Board KI Dunnart Recovery Project which surveyed 280 sites island-wide, between February 2020 and December 2021. The objective of this project was to map the post-fire distribution of the KI dunnart to support priority conservation recommendations and management actions. A long-term monitoring strategy was established based on island-wide survey results, which commenced in autumn 2022. This involves monitoring 70 sites in both autumn and spring to detect changes in the occupancy of KI dunnarts across their range in response to habitat regeneration and management actions, such as feral cat control. Sites were selected to give temporal and spatial replication and to determine which environmental and habitat variables, such as burnt vs unburnt habitat, time since fire, rainfall, elevation, vegetation type and understorey complexity, predict the occurrence of the KI dunnart.

Figure 3. Stand-alone camera set up on Kangaroo Island.

KEY FINDINGS

KI dunnarts were detected at 23 of the 25 Eyes on Recovery sites active between October 2020 and November 2022. By January 2021 dunnarts had been detected at 30% of sites, by November 70% of sites had detected dunnarts and by July 2022 this had increased to over 90% of sites (**Figure 4**).

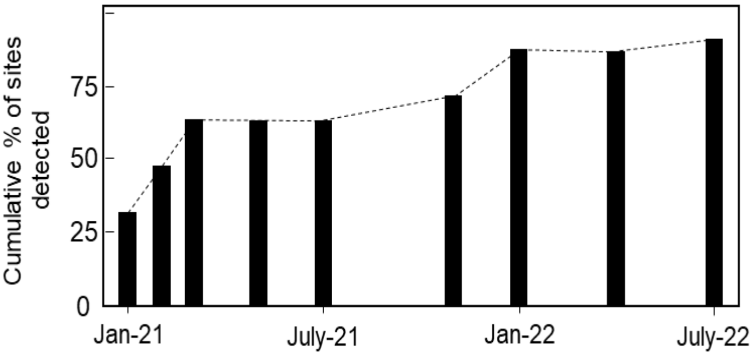

Figure 4. Cumulative percent of sites where KI dunnarts were detected (n = 25), during the Eyes on Recovery KI dunnart project.

Kangaroo Island Landscape Board KI dunnart recovery project:

This project surveyed 280 sites across KI following the 2019-2020 bushfires to determine the status of the species. KI dunnarts were detected at 102 of these sites with their current distribution restricted to 19% of the island within areas of intact habitat in the island's western region.

Repeat surveys in autumn and spring of 70 long-term monitoring sites indicated positive trends in several metrics including time to detection, frequency of detections and the number of sites detected during a 50-night survey period. Between 2021 and 2022, time to detection decreased from 25.5 nights to 7.3 nights. Frequency of detections increased from 2.3 detections per survey period to 4.6 detections and the number of sites where KI dunnarts were detected increased from 50% to 70% of sites.

Feral cats were detected at between 50 and 80% of sites during each deployment period.

MANAGEMENT OUTCOMES

Monitoring data collected during these projects identified a significant decline in critical habitat elements such as den sites and complex understory as a result of increased frequency and scale of fire events. These critical habitat elements are essential for the recovery and persistence of species like the Kangaroo Island dunnart following widespread and severe bushfire events. Project findings helped to inform the Climate Ready Refuges Project (see ***Eyes on Recovery case study: WWF climate-ready refuges project***)

These projects also improved and informed the efficiency of feral cat control to provide landscape- scale protection for threatened species post-fire recovery. Specifically, data collected on feral cat and KI dunnart presence informed control strategies that were targeted where KI dunnart sub-populations were detected.

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WWF CLIMATE-READY REFUGES PROJECT

Location: Kangaroo Island South Australia, Australia

Project Partners: Paul Jennings, Hannah Byrne-Willey, Kelly Gledhill and Mikaela Bandiera from the Kangaroo Island Landscape Board

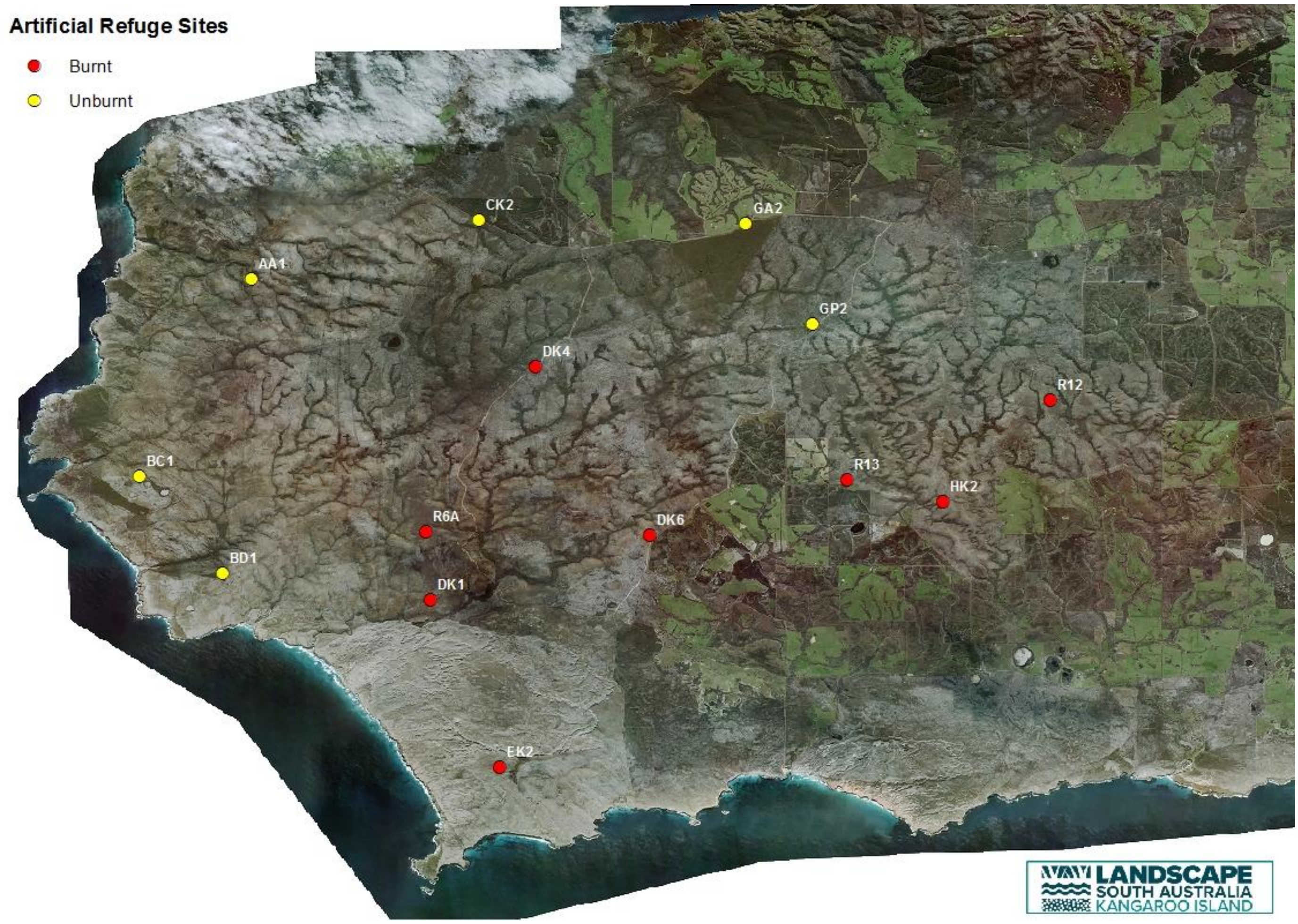

Figure 1. Location of KI dunnart artificial refuge sites on Kangaroo Island within Flinders Chase National Park and Ravine des Casoars Wilderness Protection Area. Red dots represent sites installed in burnt habitat and yellow dots in unburnt habitat.

PROJECT OVERVIEW AND AIMS

Availability of habitat refuges in burnt and degraded habitats has been demonstrated to be important for survival of threatened species following bushfires. Hollow logs are slow to develop and there has been a significant reduction in their availability due to habitat modification, climatic change and fire regimes. These structures provide shelter, breeding and nesting habitat, as well as protection.

Catastrophic bushfires burnt ~131,455 ha of native vegetation and impacted 48% of the western and central regions of Kangaroo Island in 2019-20. This included >96% of the core habitat of the Endangered Kangaroo Island dunnart. The central focus of this study was to address the loss of habitat refuges and complex understory as a result of increased frequency and scale of fire events.

We provide preliminary information on the thermal suitability, fire resistance and use of artificial refuges installed for the Kangaroo Island dunnart (*Sminthopsis fuliginosus aitkeni*). We trialled corrugated iron sheeting and terracotta tiles and tested their thermal suitability at burnt and unburnt sites within known KI dunnart habitat. Camera traps were used to monitor KI dunnart activity at artificial refuges. To test fire resistance of the artificial refuges, we installed refuges immediately prior to a prescribed burn in open and closed canopy habitats. Temperatures were monitored outside (ambient), directly beneath refuges and within depressions (nests) under refuges.

We observed that KI dunnarts visited a significant proportion (68%) of refuges. At burnt sites (n = 20) 100% of refuges were visited and 75% were entered, whilst at unburnt sites 35% of refuges (n = 20) were visited and 25% entered. Surveys of artificial refuges proved very successful with 31 individuals (9 females and 22 males) sampled over three separate fortnightly trapping events.

Corrugated iron and terracotta tile artificial refuges showed similar thermal properties under typical ambient temperature ranges. Long-term climate data suggest that artificial refuges are thermally suitable throughout the majority of the year on Kangaroo Island where only 4% of days exceed 30°C and <1% exceed 35°C.

Preliminary results show that both artificial refuge types can provide protection during fire. Site selection appears to be the key determining factor and placement of refuges is recommended in open canopy habitats. Nests constructed under artificial refuges were cooler and further improved the thermal suitability compared to surface soil temperatures under refuges.

Findings support that habitat augmentation may play a key role in providing critical habitat refuges for the Kangaroo Island dunnart and could aid their rapid recolonisation and survival following prescribed burning and bushfires. Targeted on-ground actions are required to reverse loss of critical habitat elements and ensure habitat and biodiversity are climate ready and continue to thrive.

This project aimed to provide preliminary information on the thermal suitability, fire resistance and use of artificial refuges by the Kangaroo Island dunnart.

The four key project aims were to: **(1)** Trial different artificial refuge types in burnt and unburnt habitat and monitor use (visitation and entry) of artificial and natural refuges by the Kangaroo Island dunnart. **(2)** Investigate the fire resistance of different artificial refuge types during a prescribed burn and monitor the thermal suitability of refuges under different fire scenarios. **(3)** Investigate the thermal range of different artificial refuge types exposed to high and low ambient temperatures to determine which are most suited to providing refuge for the Kangaroo Island dunnart. **(4)** Provide initial advice based on results of these trials to support use of artificial refuges for the Kangaroo Island dunnart and recommendations for future projects.

METHODS

Artificial and natural refuge trials

Artificial refuges were installed at 14 sites across the known range of the Kangaroo Island dunnart (**Figure 1**). Sites were stratified into an equal number of burnt and unburnt for comparison. At each site two artificial refuge materials were trialled – corrugated iron sheeting (1500mm L x 900mm W) and paired terracotta tiles (300mm L x 200mm W). Each site had five replicates of each artificial refuge type placed in a roughly straight line 30m apart parallel to an existing driftline survey site (**Figure 2**). Under each artificial refuge the ground was cleared of surface vegetation and the soil scooped out to make small depressions 'nests' (approximately 200mm around and 100mm deep), which were filled with dry leaf litter found at the site. Four nests were constructed under each corrugated iron sheet and one under each of the terracotta tiles.

At four sites (two burnt and two unburnt) motion activated cameras were installed to monitor visitation and entry of dunnarts and other fauna at each artificial refuge. To provide a comparison between artificial refuge and natural den use five natural den sites were monitored using motion activated cameras at each of these same four sites (**Figure 3**).

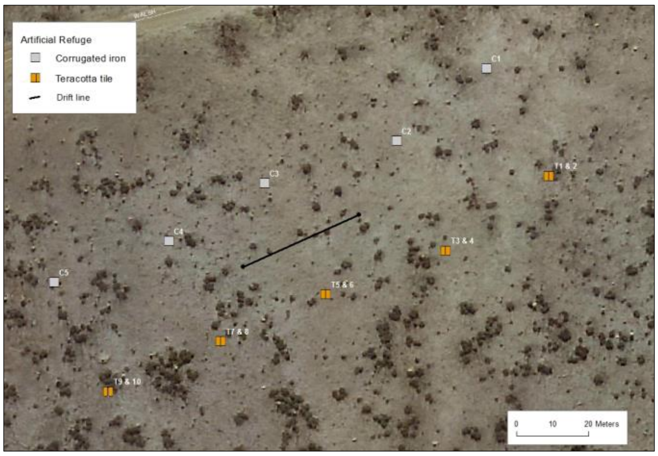

Figure 2. Aerial view of KI dunnart artificial refuge layout at burnt site HK2.

Figure 3. Motion activated camera set up on artificial refuges and natural dens, yakka stump (left), corrugated iron (middle), paired terracotta tile (right).

Artificial refuges at each site were surveyed for dunnart occupancy on three separate occasions approximately 2 weeks apart between 9 May 2023 and 20 June 2023. To trap artificial refuges a purpose made pen was placed around each refuge before lifting to prevent escape and allow easy capture of individuals. Captured dunnarts were processed (morphology, sex, weight, scat and genetic sample taken) at the site and released back underneath the artificial refuge. Data was recorded for other vertebrate species found under artificial refuges, any recent nest activity noted, and dunnart scats present were collected for later analysis.

Prescribed burn artificial refuge trial

Artificial refuges were installed immediately prior to a prescribed burn conducted on April 5, 2023. The trial compared two artificial refuge materials – corrugated iron sheeting and terracotta tiles, in open and closed canopy native vegetation against ambient temperatures during the prescribed burn. To measure temperature twin probed thermocouples (HOBO Thermocouple Data Logger U12-014) were buried below ground, with one probe at soil surface level and the other at the base of a depression 'nest' (as described above), below each refuge type and location. To measure ambient temperature thermocouples were buried below ground with both probes at the soil surface level. Temperatures were logged at 30 second intervals from time of installation until time of removal once the fire ground was deemed safe to enter. A temperature of 40°C was considered to be a lethal threshold for survival of dunnarts, based on lethal limits of laboratory rats[1].

Artificial refuge thermal suitability trial

Artificial refuges were installed in an open area exposed to full sun. The trial compared two artificial refuge materials – corrugated iron sheeting and terracotta tiles in different arrangements, one as a single layer refuge and the other with a second refuge placed on top and separated by a timber spacer. The second arrangement was for comparison of temperature difference when an insulating layer was provided by a second refuge layer, as a practical alternative to achieve a better thermal rating. Kestrel Drop D2 temperature loggers were installed under each refuge treatment and immediately adjacent the refuges to monitor ambient temperature. Temperatures were logged at 1-hour intervals over a one-week period during a period of high temperatures.

We sourced climate statistics (2002-2023) from the Bureau of Meteorology for Cape Borda, Kangaroo Island. Cape Borda is within the Ravine des Casoars Wilderness Protection Area and is in close proximity to sites surveyed as part of this study. Mean average daily maximum air temperature and the average number of days each month when the daily maximum air temperature was equal to, or exceeded 30, 35 or 40°C was used to compare thermal suitability of refuges against expected ambient temperatures across the study area.

KEY FINDINGS

Artificial and natural refuge trials

Dunnarts were detected visiting (inspecting) artificial refuges at three of the four sites that were monitored using motion activated cameras (**Figure 4**). No dunnarts were detected at site GA2, a large unburnt area of dense, structurally complex native vegetation which has had consistently low dunnart detections using standardised driftline methodology since the 2019-2020 KI bushfires. Both burnt sites had 100% visitation at artificial refuges and the second unburnt site had 35% visitation. Of these visitations KI dunnarts were observed entering artificial refuges on 75% of occasions at burnt and 25% at unburnt sites.

Figure 4. KI dunnart approach and entry under a terracotta tile refuge.

Visitation and entry at natural dens were similar to that observed at artificial refuges, with three of the four sites detecting KI dunnarts. Again, no dunnarts were detected at natural dens monitored at site GA2. Both burnt sites had 100% visitation at natural dens and the second unburnt site had 50% visitation. Of these visitations KI dunnarts were observed entering natural dens on 80% of occasions at burnt and 40% at unburnt sites.

Trapping of dunnarts using artificial refuges proved extremely successful. 31 dunnarts were captured from five of the 14 sites where artificial refuges were installed. Of these individuals 11 were recaptures from this project or from previous trapping efforts at one site. A total of 9 females and 22 males were caught. Multiple dunnarts were captured together under artificial refuges on several occasions. On one occasion four dunnarts were observed, on two occasions three dunnarts were

[1] Hankenson et al. 2018. Effects of Rodent Thermoregulation on Animal Models in the Research Environment. Comp Med 68:425-438.

observed and on three occasions two dunnarts were observed sharing artificial refuges. Interestingly, Kangaroo Island dunnarts were the most sampled species under artificial refuges, with the house mouse, *Liopholis* skink sp. and *Limnodynastes* frog sp. also captured.

All dunnarts were caught under corrugated iron, with none caught under terracotta tile refuges. The study period coincided with a series of heavy rainfall events and surface water runoff which caused terracotta tile refuges to become saturated and unsuitable for dunnart occupancy. Alternatively, nests under corrugated iron remained mostly dry and suitable for dunnart occupancy.

Prescribed burn artificial refuge trial

Ambient temperature increases were observed at approximately 13:15 following ignition. In closed canopy the maximum ambient temperature reached was 58.4°C with the thermal threshold of 40°C exceeded for a period of 1 hour and 1 minute. In open canopy the maximum ambient temperature reached was 68.2°C with the thermal threshold exceeded for a period of 2 hours and 22 minutes. Higher comparative ambient temperatures in open canopy could possibly be explained by radiant heat projected from the ignition point and as the fire activity increased approaching the trial site. This difference between closed and open canopy ambient temperatures suggests that fire activity and corresponding temperature is highly variable, which is often the case under more mild prescribed burning conditions that achieve mosaic burns.

In closed canopy corrugated iron reached a maximum temperature of 67.8°C at soil surface level and 47.9°C in the nest, with the thermal threshold of 40°C exceeded for 38 and 2 minutes, respectively. Terracotta tile in closed canopy reached a maximum of 108°C at soil surface level and 149.7°C in the nest, with the thermal threshold of 40°C exceeded for 3 hours 45 minutes and 3 hours 34 minutes, respectively.

In open canopy corrugated iron reached a maximum temperature of 44.6°C at soil surface level and 41.6°C in the nest, with the thermal threshold of 40°C exceeded for 15 minutes and 30 seconds and 1 minute, respectively. Terracotta tile in open canopy reached a maximum of 61.6°C at soil surface level and 26.6°C in the nest, with the thermal threshold of 40°C exceeded for 3 minutes and 30 seconds and 0 minutes, respectively.

In closed canopy, the nest under corrugated iron was on average 9.3°C (SD 5.4) cooler than soil surface temperature under the refuge. Conversely, the nest under terracotta tile was 53.4°C (SD 4.4) hotter than soil surface temperature under the refuge. In comparing artificial refuge type corrugated iron was on average 62.7°C (SD 5.2) cooler than terracotta tile (**Figure 5**).

In open canopy the nest under corrugated iron was on average 6.3°C (SD 3.0) cooler than soil surface temperature under the refuge. The nest under terracotta tile was 16.1°C (SD 3.9) cooler than soil surface temperature under the refuge. In comparing artificial refuge type terracotta tile was on average 9.7°C (SD 1.6) cooler than corrugated iron (**Figure 5**).

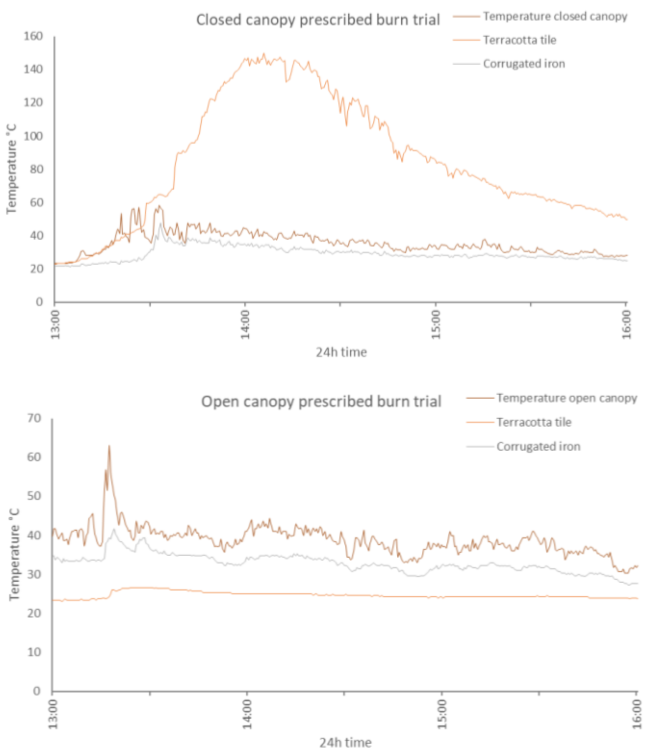

Figure 5. Ambient and artificial refuge temperatures in open (top) and closed (bottom) canopy habitats during a prescribed burn.

In both closed and open canopy habitats nests were on average between 7.3°C (SD 3.3) and 4.1°C (SD 1.1) cooler than surface soil temperatures under corrugated iron refuges, respectively. Terracotta tile nests were on average 9.9°C (SD 21.9) hotter in closed canopy habitats and 20.9°C (SD 7.16) cooler in open canopy habitats.

These preliminary results show that artificial refuges can provide suitable protection during fire. Site selection appears to be the key determining factor with placement of refuges recommended in open canopy habitats. Within closed canopy habitats fire behaviour and intensity is highly variable and often prolonged when compared to open canopy habitat. This can be explained by the higher and coarser fuel loads available to burn. In open canopy habitats terracotta tiles proved to be more thermally suited than corrugated iron and did not exceed the 40°C thermal threshold in nests constructed under refuges. However, corrugated iron only exceeded this threshold for 1 minute. Nests constructed under artificial refuges further improved the thermal suitability compared to surface soil temperatures under refuges.

Figure 6. Measuring the head length of a Kangaroo Island dunnart captured beneath an artificial refuge.

Artificial refuge thermal suitability trial

Corrugated iron and terracotta tile artificial refuges showed similar thermal properties under typical ambient temperature ranges experienced on Kangaroo Island. At 0°C corrugated iron and terracotta tile temperatures were 2.8°C and -1.6°C, respectively. At 10°C they were 13.8°C and 11°C, at 20°C they were 24.8°C and 23.6°C, at 30°C they were 35.8°C and 36.1°C, at 35°C they were 41.3°C and 42.4°C, respectively.

The highest mean monthly maximum temperatures at Cape Borda were 24.6°C and 24.2°C, in January and February, respectively. The mean number of days ≥30°C (Oct-Apr) annually was 14.9 and ≥35°C (Nov-Mar) was 3.6. There were no days exceeding 40°C. This long-term climate data suggest that artificial refuges are thermally suitable (<40°C thermal threshold) throughout the majority of the year on Kangaroo Island where only 4% of days exceed 30°C and <1% exceed 35°C.

To investigate practical options of improving the thermal suitability we insulated artificial refuges. Insulated (double layer) corrugated iron and terracotta tiles showed similar trends in thermal properties compared to uninsulated (single layer) artificial refuges. At low temperatures (0-15°C) both insulated refuge types were warmer than uninsulated artificial refuges. At warmer temperatures (20-40°C) both insulated refuges were cooler. At 0°C insulated corrugated iron and terracotta tile temperatures were 7.1°C and 8.2°C warmer than uninsulated artificial refuges, respectively. At 10°C they were 3.4°C and 4°C warmer, at 20°C they were 0.2°C and 0.1°C cooler, at 30°C they were 3.9°C and 4.2°C cooler and at 35°C they were 5.8°C and 6.2°C cooler, respectively.

MANAGEMENT OUTCOMES

KI dunnarts visited 100% of artificial refuges at burnt sites and just 35% at unburnt sites. These results suggest that artificial refuges provide critical habitat elements utilised by KI dunnarts following catastrophic bushfire. Severe fire leads to an extended period of depauperate habitats as native vegetation recovers eventually returning to pre-fire conditions. Recently burnt open habitats represent a significant threat to native wildlife as feral cats preferentially hunt and are more successful in these areas leaving species like the KI dunnart exposed to higher predation risk.

Artificial refuges proved to be an effective monitoring technique for the capture of individuals. Traditional pitfall trapping techniques have proven to be labour intensive and unreliable for consistent captures of KI dunnarts, requiring large numbers of trap nights for trap success (1 individual per 1000 trap nights from Gates pers. com.). Using artificial refuges we achieved trap success of 1 individual per 8.5 corrugated iron lifts. This passive trapping technique also increases animal welfare outcomes for individuals as they are captured immediately after lifting the refuge, processed on site (**Figure 6**) and returned promptly under the refuge where they were caught.

Artificial refuges using readily available materials in corrugated iron sheeting and terracotta tiles represent practical habitat augmentation techniques, are easily deployed and require minimal long-term maintenance. These materials demonstrated suitable thermal properties at expected ambient temperatures and also during a prescribed burn when exposed to fire. Site selection appears to be the key determining factor and placement of refuges is recommended in open canopy habitats to provide the best protection when exposed to fire. Long-term climate data suggest that artificial refuges are thermally suitable throughout the majority of the year on Kangaroo Island where only 4% of days exceed 30°C and <1% exceed 35°C. To improve the thermal properties of artificial refuges we discovered that by placing a second layer, temperatures under refuges were higher at lower temperatures and lower at high temperatures, offering a simple and practical solution to increasing thermal suitability further.

Findings support that habitat augmentation may play a key role in providing critical habitat refuges for the Kangaroo Island dunnart and could aid their rapid recolonisation and survival following prescribed burning and bushfires. Targeted on-ground actions are required to reverse loss of critical habitat elements and ensure habitat and biodiversity are climate ready and continue to thrive.

Future projects and trials would benefit from focusing on measuring the long-term use of artificial refuges in the years following fire to gain a better understanding of usage by KI dunnarts and other native wildlife.

Trials should be conducted looking at the application of artificial refuges that support persistence of the KI dunnart in fragmented or recently modified habitats, for example prescribed burning. Artificial refuges could be trialled in combination with revegetation to reestablish corridors between critical habitats for the KI dunnart and would act as stepping stones to facilitate movement and reduce threats.

We suggest further trials to look at improving thermal properties of artificial refuges through application of coatings such as WATTYL SOLAGARD™, which blocks solar radiation or trialling different materials which have higher thermal properties.