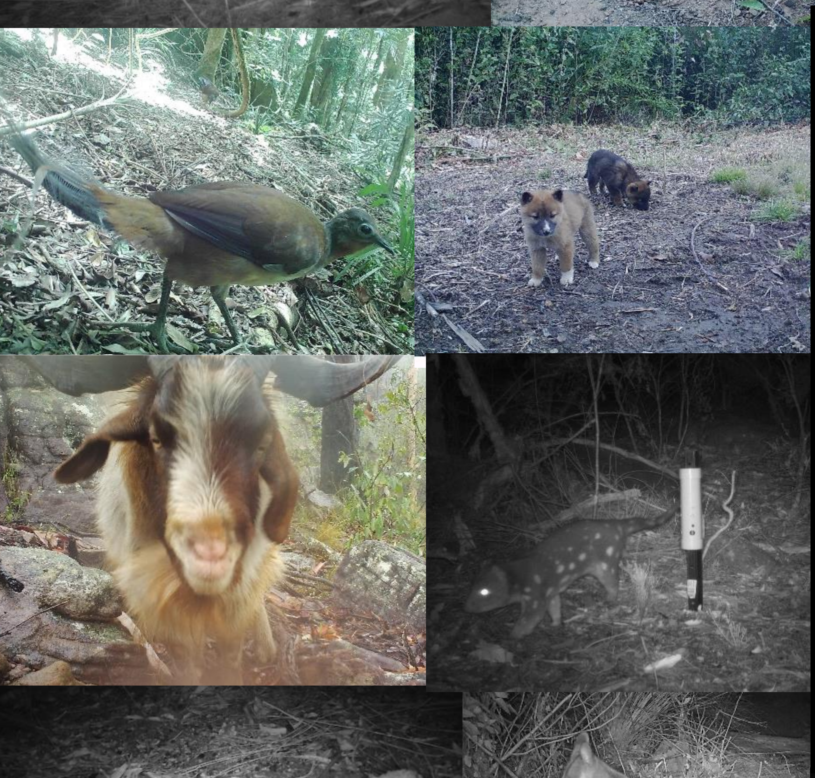

EYES ON RECOVERY

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

Summary Report
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.

Eyes on Recovery was supported by Google.org and enabled by international partners Wildlife Insights, Conservation International and WWF-US. It was collaborative initiative between WWF-Australia and core on-ground partners University of Queensland, Queensland Government Department of Environment, Science and Innovation, NSW National Parks and Wildlife Service, University of Sydney, Science for Wildlife, University of Wollongong, NSW Government Department of Planning and Environment, Charles Sturt University, Victorian Government Department of Energy, Environment and Climate Action, and Kangaroo Island Landscape Board.

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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)

EXECUTIVE SUMMARY

The 2019-2020 summer mega-fires burned more than 10 million hectares across south-eastern Australia, killing or displacing an estimated 3 billion animals. Using remote cameras to track their post-fire recovery can help to protect the future of iconic Australian wildlife species. However, camera monitoring projects produce large datasets that are slow to process and analyse, preventing quick and effective on-ground management action.

Eyes on Recovery was a collaborative initiative between WWF-Australia, WWF-US, Conservation International and a range of on-ground land managers and researchers that addressed this data processing challenge using innovative artificial intelligence (AI) technology. It applied Wildlife Insights, a cloud-based platform that uses machine learning to efficiently identify animals in camera images, to track the recovery of key threatened animals in a range of fire impacted Australian environments.

Eyes on Recovery monitoring helped to inform management actions for native species, such as invasive animal control, changes in fire regimes, and the use of artificial refuges during and after fires. At a local scale, some species were found at lower rates in burnt or severely burnt habitat than in areas that were unburnt or less severely burnt. However, these trends were not universal, and were reversed for some species in some areas.

When analysing the whole dataset across all Eyes on Recovery survey sites, there was no consistent detectable effect of fire on the occupancy rates of key species, which were relatively stable throughout the survey period. Higher than usual rainfall across the south-east of Australia in the years following the fires may have assisted vegetation regrowth and wildlife recovery.

Eyes on Recovery demonstrates a non-standardised approach to large-scale monitoring, where surveys can be targeted towards meeting specific local-scale objectives while also being collated, processed, and analysed to provide a big picture look at fauna distribution and trends.

Unburnt habitat providing refuge at the edge of fire extent (WWF-Au/Emma Spencer)

SETTING THE SCENE

During the 2019-2020 Australian bushfire season more than 10 million hectares burned across south-eastern Australia and an estimated 3 billion animals were killed or displaced.

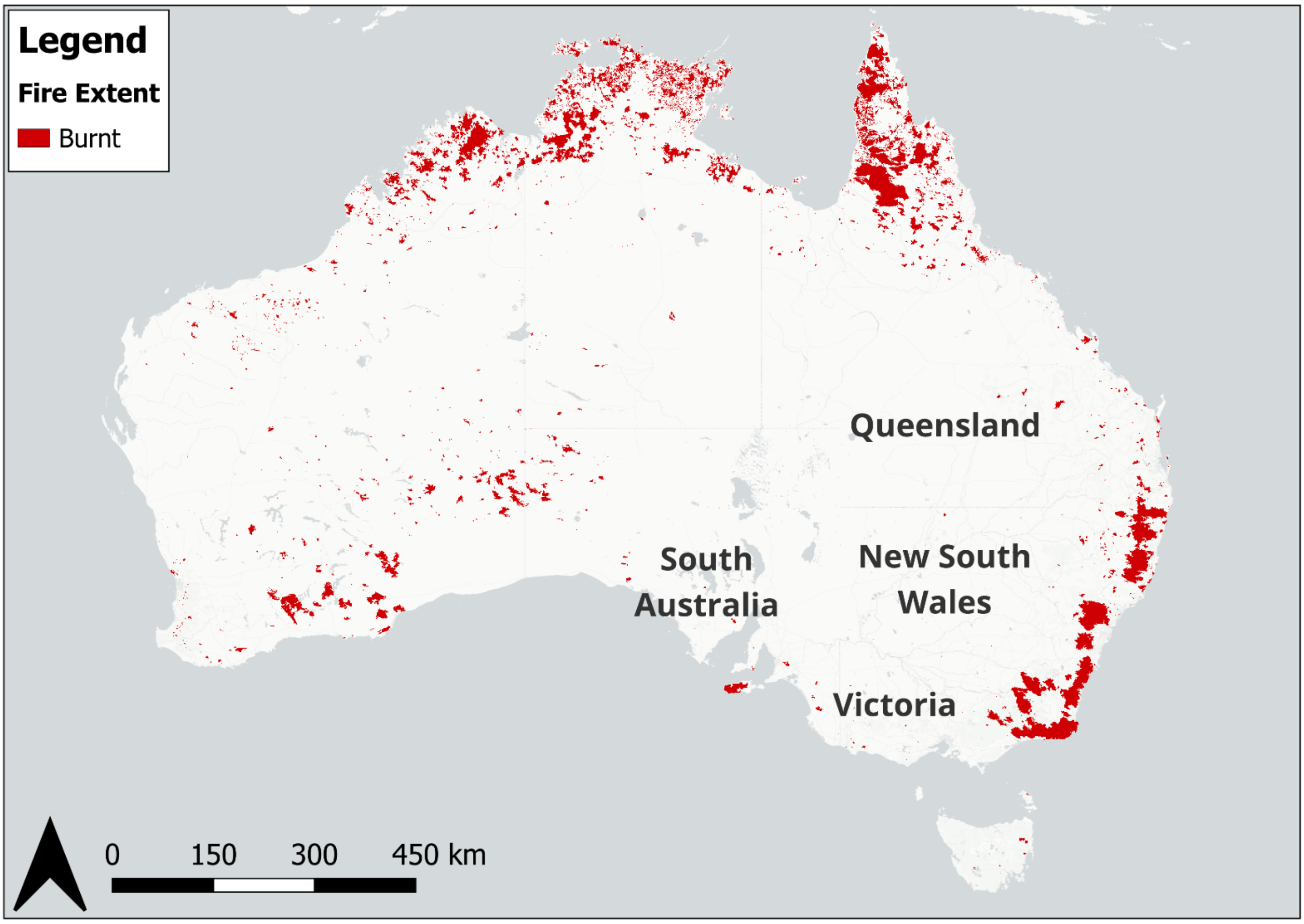

Figure 1. National fire extent during the 2019-2020 bushfire season. Focal Eyes on Recovery states were Queensland, New South Wales, Victoria and South Australia.

THE 2019-2020 AUSTRALIAN MEGAFIRES

Australia is the world's most fire-prone continent, and bushfires are a normal and even necessary part of many Australian ecosystems. However, the 2019-2020 fires in the forests of southern and eastern Australia were of a scale and intensity never seen before[1] (**Figure 1**). For example, the Gosper's Mountain fire that burnt across the Greater Blue Mountains World Heritage Area in New South Wales, the biggest forest fire in Australian history, burnt an area of about seven times the size of Singapore[2]. This was just one of more than 11,000 fires that burned that season in New South Wales alone[2]. In total, more than 10 million hectares, roughly the size of the country Syria, was burned within a single bushfire season[3]. The fires also burned over a longer period, and at a higher severity, than any previously experienced in Australian forests[3].

The impact of these bushfires on people was huge - at least 33 lives were lost and over 3,000 homes were destroyed[4]. There were also extensive impacts on wildlife. In total, an estimated 3 billion animals were killed or displaced by these fires[5]. It was also estimated that 832 native vertebrate species lost habitat due to the fires, 107 of which were already listed as threatened[6]. Seventeen species lost more than half of their habitat to fire[6]. For some of these species, like the critically

[1] Bowman et al. 2020. Wildfires: Australia needs a national monitoring agency. Nature 584: 188-191.
[2] Nguyen et al. 2020. Anatomy of a 'mega-blaze'. Available at: https://www.abc.net.au/news/2020-07-27/gospers-mountain-mega-blaze-investigation/12472044.
[3] Wintle et al. 2020. After the megafires: what next for Australian wildlife? Trends in Ecology & Evolution, 35(9), 753–757.
[4] Royal Commision into National Natural Disaster Arrangements 2020. Report. Commonwealth of Australia, Canberra.
[5] Van Eeden et al. 2020. Impacts of the Unprecedented 2019–2020 Bushfires on Australian Animals. Report Prepared for WWF-Australia.
[6] Ward et al. 2020. Impact of 2019–2020 mega-fires on Australian fauna habitat. Nature Ecology & Evolution. 4:1321–1326.

endangered Kangaroo Island dunnart and the vulnerable long-footed potoroo, almost all their known habitat was burnt. With Australia already considered one of the world's extinction hot spots[7], the impact of these fires on wildlife and their ability to recover was incredibly concerning.

ASSESSING THE IMPACTS

The huge scale and number of species and habitats affected by these fires made assessing this impact a difficult task. Gathering data on wildlife can take a lot of time and effort, while resources are often limited. Management actions need to be timely and responsive to the information gathered.

One tool now frequently used by land managers to address these challenges is wildlife cameras. They are non-invasive and can be left for months at a time to monitor wildlife remotely. As they become more affordable, land managers have been able to deploy large numbers of cameras across landscapes to track wildlife presence and activity in different areas through time. However, using such large numbers of cameras can result in millions of camera images. The time and effort required to sort through these images to identify species has become one of the biggest challenges preventing adaptive management and conservation action in Australia, and across the world.

The main objective of the Eyes on Recovery initiative was to use wildlife cameras to obtain a picture of fauna recovery post-fires across the affected landscapes, from south-east Queensland through New South Wales and Victoria, down to Kangaroo Island in South Australia.

As part of this project, over 1,100 cameras were deployed in collaboration with a range of on-ground partner organisations, including government agencies, universities, and non-profit organisations (**Figure 2**). Each project had a unique focus driven by the needs of on-ground partners, including the need to inform conservation management actions. Bringing this data together through this large-scale collaborative initiative allowed both local and wide-ranging questions around fauna recovery to be addressed.

Figure 2. Deploying cameras in fire-impacted habitat on Kangaroo Island, South Australia.

The challenge of sorting, processing, and storing more than 8.5 million images was addressed using Wildlife Insights, a cloud-based platform that uses machine learning and Artificial Intelligence (AI) to efficiently identify animals in camera trap images (**Figure 3**). This platform had the added benefit of providing oversight across the 17 different camera surveys, and standardising metadata for easier interpretation in the data analysis stage.

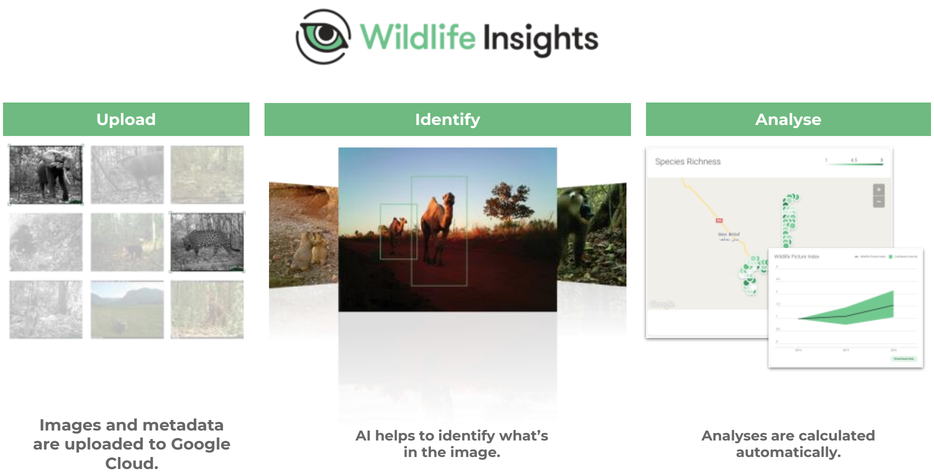

Figure 3. Wildlife Insights is a platform that enables photo identification and analysis through the use of Artificial Intelligence.

[7] . Woinarski et al. 2015. Ongoing unraveling of a continental fauna: decline and extinction of Australian mammals since European settlement. Biological Sciences. 112(15):4531–4540.

Wildlife Insights was originally developed in the northern hemisphere, meaning that species identification models did not include any Australian native species. As such, another key part of Eyes on Recovery was training the identification models to recognise a range of Australian species. This was achieved by introducing over 3 million pre-classified images to the platform to train a model that was able to classify over 150 species found in Australia.

KEY OBJECTIVES

Eyes on Recovery set out to fulfil a range of local objectives, while also attemping to determine the broader-scale impact of the 2019-2020 bushfires on Australian wildlife (**Figure 4**).

The specific Eyes on Recovery aims were to:

1. **Update computer vision models** on the Wildlife Insights platform to identify Australian species,
2. **Analyse and visualise local-scale data** to inform on-ground management activities, and
3. **Assess regional and national post-fire trends** by providing a consolidated analysis of wildlife species data across surveys.

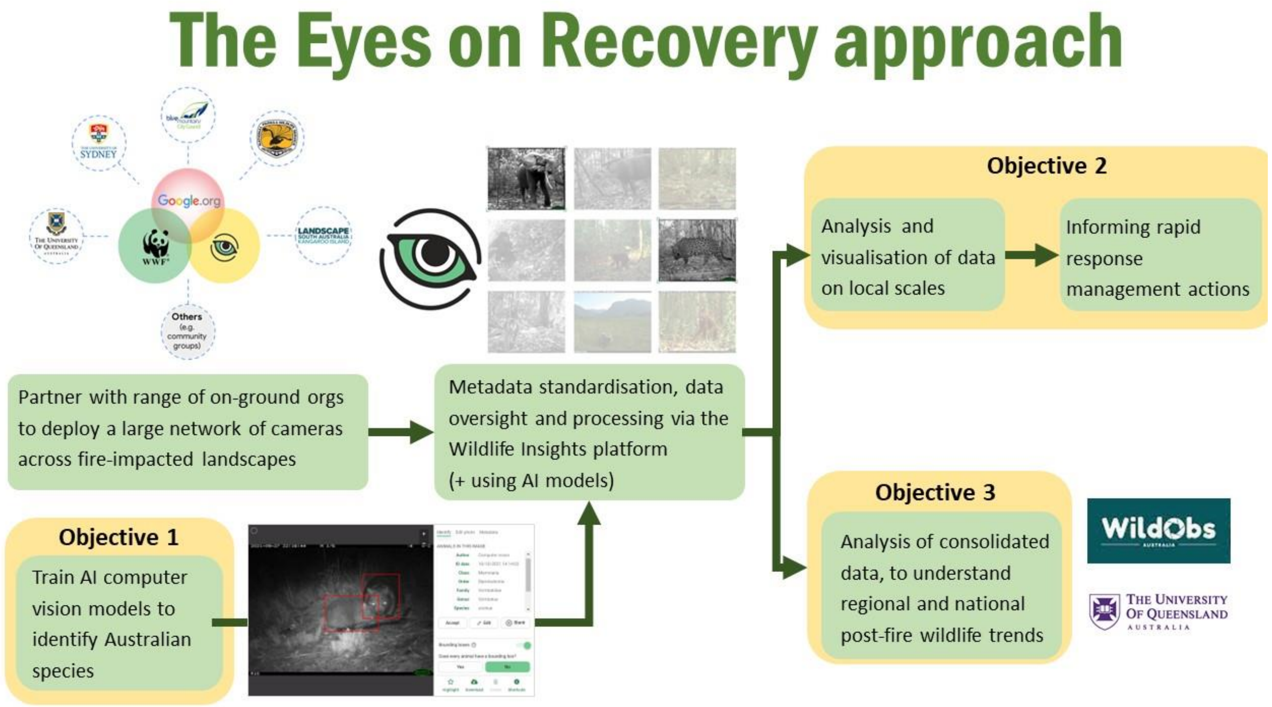

Figure 4. Schematic illustrating the Eyes on Recovery approach to broad-scale post-fire monitoring.

DEVELOPING AI FOR SPECIES IDENTIFICATION

Eyes on Recovery introduced more than 3 million pre-classified images to train species identification models on the Wildlife Insights platform. In total, 159 species found in Australia were included in the model, with 59 species identifiable at >80% precision.

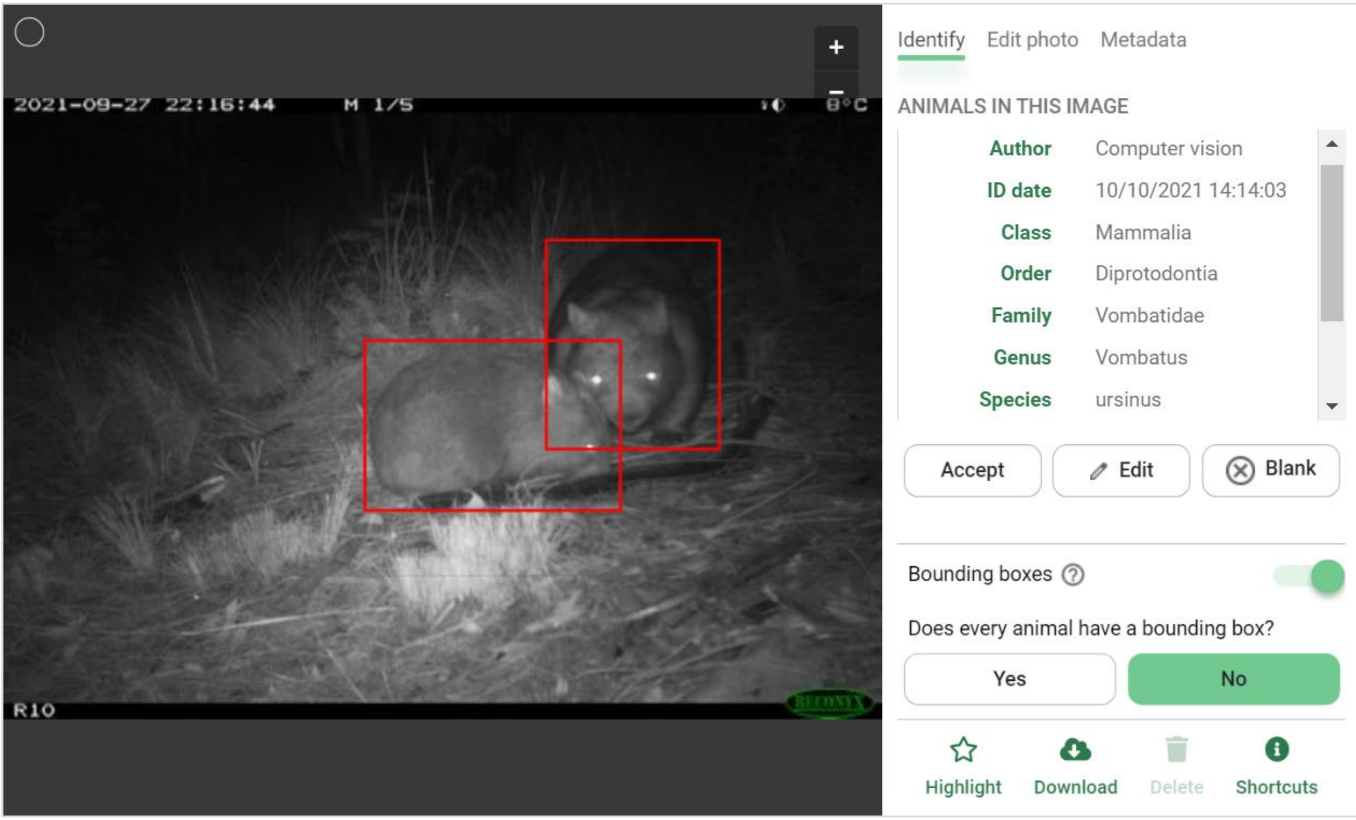

Figure 5. Wildlife Insights species identification model detects common wombats in an image taken as part of the Eyes on Recovery project.

WILDLIFE INSIGHTS AI

Wildlife Insights applies AI technology to reduce the time required to convert camera trap data into valuable biodiversity insights. It does so by using computer vision models that are trained with millions of pre-classified images of, for example, different wildlife species, humans and vehicles. Training is provided via Google's open source TensorFlow library and is a continuous process, with models improving over time as more images are incorporated. Once Wildlife Insights models have been trained, they can be applied to new camera images to provide automatic classification. There are two key ways in which AI models can help to sort and classify images:

1. Eliminating images without wildlife: Wildlife researchers often spend hours manually sifting through their data to remove images that do not contain animals (or 'false triggers'). In fact, in some camera surveys more than 90% of images are false triggers. The Wildlife Insights AI models have been trained to identify images that do not contain animals, providing more time to focus on images of species. These models accurately classify images as false triggers only when they have a high confidence, minimising the risk of discarding valuable animal images.

2. Species classification: At the time of writing, the Wildlife Insights model was proficient in recognising more than 1,295 species and 237 higher-level taxonomic classes from around the world (**Figure 5**). The model strives to provide predictions at the most specific taxonomic level they are confident in. For example, if the model detects a kangaroo in an image but is uncertain about the exact species, it will display 'Kangaroo Family' as the prediction. Similar to humans, AI models improve their ability to recognise and identify animals when exposed to diverse images of a particular species. As more images are uploaded and catalogued in Wildlife Insights, the AI models can be further trained to enhance their accuracy.

TRAINING A POWERFUL MODEL FOR AUSTRALIA

The Wildlife Insights AI models have been trained using the most comprehensive labelled dataset of camera trap images to date, encompassing over 35 million images spanning 1,295 species. The Eyes on Recovery project specifically contributed 3 million new pre-classified images to the training dataset, including the addition of 54 native Australian species. It also helped to improve classification for 13 introduced species in the Wildlife Insights models, from deer species (like sambar, *Rusa unicolor* and fallow, *Dama dama*) to feral predators (red foxes, *Vulpes vulpes* and cats, *Felis catus*) and smaller animals like European rabbits (*Oryctolagus cuniculus*) and house mice (*Mus musculus*). Of these species 47 native and 12 introduced species were included in the model with a high (>80%) precision (**Table 1**). In addition to more common native species like the eastern grey kangaroo (*Macropus giganteus*) and common wombat (*Vombatus ursinus*), harder to detect threatened species were also included in the model including long-nosed potoroos (*Potorous tridactylus*), koalas (*Phascolarctos cinereus*) and spotted-tailed quolls (*Dasyurus maculatus*).

Table 1. Selection of species found in Australia that were incorporated in the Wildlife Insights AI models through Eyes on Recovery. Table shows precision and recall as measures of the accuracy of image classifications made by the models. Precision measures the proportion of predictions made by the model that are correct. Recall measures the proportion of relevant images that were correctly identified by the model. In simple terms, the closer precision and recall are to 1, the better the model is at identifying the species.

Common name	Species name	Group	Precision	Recall
Wonga Pigeon	*Leucosarcia melanoleuca*	Native bird	0.957	0.969
Australian Brush-Turkey	*Alectura lathami*	Native bird	0.979	0.965
Laughing Kookaburra	*Dacelo novaeguineae*	Native bird	0.986	0.964
Crimson Rosella	*Platycercus elegans*	Native bird	0.990	0.828
Superb Lyrebird	*Menura novaehollandiae*	Native bird	0.983	0.941
White-Winged Chough	*Corcorax melanorhamphos*	Native bird	0.983	0.933
Eastern Whipbird	*Psophodes olivaceus*	Native bird	0.874	0.784
Green Catbird	*Ailuroedus crassirostris*	Native bird	0.958	0.773
Satin Bowerbird	*Ptilonorhynchus violaceus*	Native bird	0.983	0.760
Short-Beaked Echidna	*Tachyglossus aculeatus*	Native mammal	0.988	0.969
Common Wombat	*Vombatus ursinus*	Native mammal	0.994	0.948
Common Brushtail Possum	*Trichosurus vulpecula*	Native mammal	0.968	0.943
Spotted-Tailed Quoll	*Dasyurus maculatus*	Native mammal	0.984	0.868
Eastern Grey Kangaroo	*Macropus giganteus*	Native mammal	0.973	0.932
Red-Necked Wallaby	*Notamacropus rufogriseus*	Native mammal	0.970	0.910
Australian Magpie	*Gymnorhina tibicen*	Native mammal	0.967	0.910
Swamp Wallaby	*Wallabia bicolor*	Native mammal	0.982	0.958
Tammar Wallaby	*Macropus eugenii*	Native mammal	0.960	0.800
Parma Wallaby	*Macropus parma*	Native mammal	0.917	0.494
Common Wallaroo	*Macropus robustus*	Native mammal	0.952	0.741
Long-Nosed Potoroo	*Potorous tridactylus*	Native mammal	0.975	0.698
Northern Brown Bandicoot	*Isoodon macrourus*	Native mammal	0.847	0.683
Long-Nosed Bandicoot	*Perameles nasuta*	Native mammal	0.906	0.654
Lace Monitor	*Varanus varius*	Native reptile	0.942	0.797
Feral Horse	*Equus caballus*	Introduced mammal	0.966	0.919
Fallow Deer	*Dama dama*	Introduced mammal	0.959	0.986
Red Fox	*Vulpes vulpes*	Introduced mammal	0.971	0.962
Domestic Pig	*Sus scrofa scrofa*	Introduced mammal	0.901	0.903
Domestic Cattle	*Bos taurus*	Introduced mammal	0.973	0.860
Domestic Cat	*Felis catus*	Introduced mammal	0.980	0.786
European Rabbit	*Oryctolagus cuniculus*	Introduced mammal	0.885	0.765
House Mouse	*Mus musculus*	Introduced mammal	0.857	0.608

PROJECT BACKGROUND AND METHODOLOGY

Eyes on Recovery was a mammoth post-fire monitoring project, spanning 9 landscapes and 4 Australian states, including >20 on-ground project partners who assisted in deploying more than 1,100 wildlife cameras that collected over 8.5 million camera images.

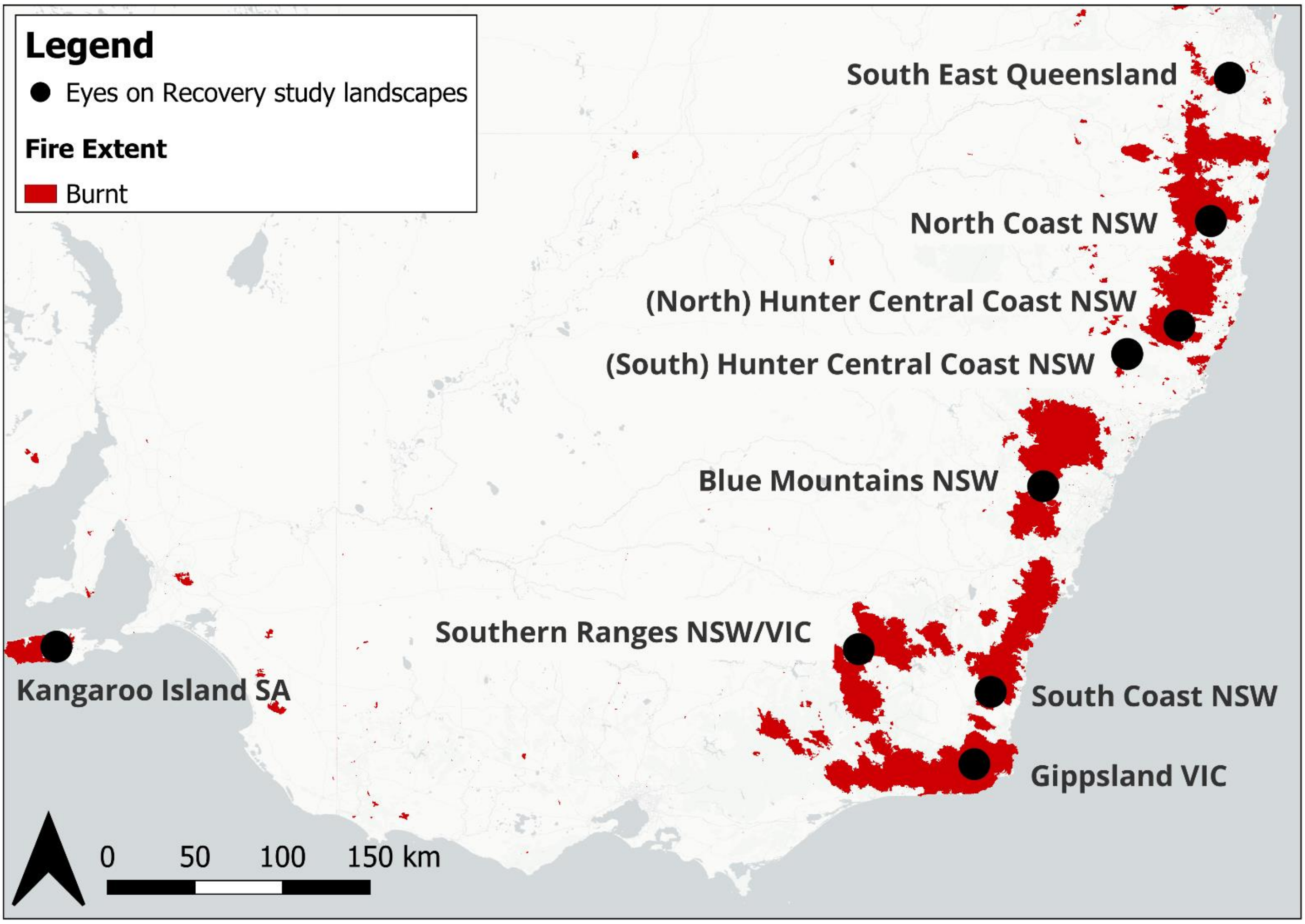

Figure 6. The nine Eyes on Recovery landscapes overlaid over fire extent (red) across south-eastern Queensland, New South Wales, Victoria and South Australia across the 2019-2020 Australian bushfire season

Eyes on Recovery comprised 17 separate camera trap surveys in 9 landscapes affected by the 2019-2020 bushfires (**Figure 6**). The design of each survey was partner-led and focused on answering pressing local management questions. This meant that across the surveys a variety of different camera trap methods were used.

On Kangaroo Island, for example, land managers were particularly interested in tracking the recovery of the critically endangered Kangaroo Island dunnart (*Sminthopsis fuliginosus aitkeni*). To increase the probability that cameras would detect dunnarts (because they are very small, with a head-body length of 80–90 mm), cameras were set up close to the ground, targeted on drift-line fences (**Figure 7**). Other surveys incorporated camera methods to increase the likelihood of detecting predator activity (by focusing cameras on roads and trails), for more general mammal monitoring (by using lures to attract animals in forested habitat) and for monitoring animals found in specific habitats like the brush-tailed rock wallaby (*Petrogale penicillata*) (by deploying cameras in rocky habitat preferred by this species) (**Figure 7**). See **Table 2** for a summary of the 17 surveys, including the different method types used.

By allowing use of varied camera survey methodologies opposed to a standardised monitoring approach, Eyes on Recovery was able to effectively inform species- and location-specific post-fire management actions. A summary of some of these management actions are detailed in the **Local-scale Impacts and Management** section below). Further details on the objectives, methods, results, and management impact of each survey are detailed in the **Eyes on Recovery Case Study Reports**.

Cameras on drift-line fences to monitor KI dunnarts

Cameras set up with universal bait lures, for general wildlife monitoring

On-road cameras to monitor predator activity

Monitoring brush-tailed rock wallabies in targeted habitat

Figure 7. Eyes on Recovery surveys included a range of different camera trap methods.

Collating and analysing large survey datasets with non-standardised camera methods can be challenging but 'big data' modelling approaches help to address some of these challenges. To apply these modelling approaches and analyse the many datasets, Eyes on Recovery collaborated with the Wildlife Observatory (WildObs), which is hosted by Australia's Terrestrial Ecosystem Research Network and The University of Queensland. WildObs consolidated the Eyes on Recovery survey datasets and then applied several different methods to visualise, analyse and understand data collected across the projects. These methods centred primarily on visualisation of species encounter rates on maps (to show how species activity varied across the different fire-impacted study landscapes) and species occupancy (to understand trends over time and the effects of fire and other environment variables).

Thirteen of the 17 Eyes on Recovery surveys were included in this consolidated analysis (see **Table 2** for the specific surveys used). Surveys were excluded based on a number of factors, with smaller surveys and surveys that monitored very specific habitat features (e.g. artificial refuges like nest boxes and hollows) excluded from the analysis. For detailed methods and results relating to the consolidated analysis, see the **Eyes on Recovery Consolidated Analysis** report.

Table 2. Surveys included in the consolidated data analysis. Numbers under 'Method' indicate the specific method used, with 1= lured/not lured cameras at 0.5m above ground, 2 = cameras targeting roads, 3= cameras on drift-line fences, 4 = not lured cameras at 1m above ground, 5 = cameras set up on wombat burrows, 6 = cameras set up in brush-tail rock wallaby specific habitat, 7 = cameras set up on artificial habitat (e.g. nest boxes, dunnart climate ready refuges).

Landscape	Survey name	Method	In consolidated analysis?
South east Queensland	South-East Queensland Post-Fire Fauna Survey	1	Yes
South east Queensland	Investigating the Impacts of the Australian 2019-2020 Wildfires on the Threatened Brush-Tailed Rock Wallaby	6	No
North Coast	North-Eastern New South Wales Brush-Tailed Rock Wallaby Monitoring Project	5	Yes
North Coast	North-Eastern New South Wales Potoroo and Parma Wallaby Monitoring Project	1	Yes
Hunter Central Coast	Threatened Macropods Survived the Catastrophic 'Black Summer' Bushfires	1	Yes
Blue Mountains	Blue Mountains Post-Megafire Recovery Survey	4	Yes
Blue Mountains	Can Ecosystems Recover Under a Changing Wildfire Regime in the Greater Blue Mountains World Heritage Area?	1	Yes
Blue Mountains	Post-Fire Evaluation of Critical Weight Range Mammals in the Greater Blue Mountains World Heritage Area	1	Yes
Blue Mountains	Eurobodalla National Park-Brou Lake Area, NSW Post Fire Mammal Fauna Monitoring	1	No
South Coast	Monitoring Greater Glider Uptake of Nest Boxes in a Post Fire Environment	7	No
South Coast	Nungatta Threatened Native Mammal and Invasive Predator Post-Fire Monitoring	2	Yes
South Coast	South East Forest Long-Footed Potoroo Post-Fire Survey	1	Yes
Southern Ranges	Impacts of the 2019-20 Summer Bushfires on Terrestrial Species in the Foothill Forests of South-Eastern Australia	1	Yes
Southern Ranges	Wombat-Powered Recovery: Harnessing an Ecosystem Engineer to Increase Bushfire Resilience	1	Yes
Gippsland	Southern Ark Predators & Priority Species Project	1,2	Yes
Kangaroo Island	Kangaroo Island Dunnart Project	1,3	Yes
Kangaroo Island	WWF Climate-Ready Refuges Project	7	No

LOCAL-SCALE IMPACTS AND MANAGEMENT

Each of the 17 Eyes on Recovery surveys was designed with on-ground partners to answer specific local-scale questions about fire impacts and inform adaptive management to assist in the recovery of species.

Figure 8. Melinda Kerr from the Blue Mountains World Heritage Institute (left) and Dr Emma Spencer from WWF-Australia (right) check an Eyes on Recovery camera trap in the Blue Mountains.

FIRE IMPACTS AT LOCAL-SCALES

The results of each of the 17 Eyes on Recovery surveys were individually analysed to answer and inform local-scale research questions and management. The context, methods and results for each survey are detailed extensively in the **Eyes on Recovery Case Study Reports**. Below are summarised some of the key results found and management activities identified across each of these 17 surveys.

In **south-east Queensland**, there were few differences in species encounter rates between burnt and unburnt habitat in Lamington National Park, but many species in Mount Barney National Park, including long-nosed potoroos (*Potorous tridactylus*), Albert's lyrebird (*Menura alberti*) and small mammal species (mostly *Rattus sp.*) were detected more frequently in habitat that was burnt at low fire severity compared to high or very high severity.

In four National Parks surveyed on the **north coast of New South Wales**, the park with the lowest percentage of burnt area (Cottan-Bimbang National Park, with 70.8% of its area burnt) had the highest number of detected species and the highest encounter rates of native species, including the threatened parma wallaby (*Notamacropus parma*). In contrast, the park with the highest percentage of burnt area (Willi Willi National Park, with 93% of its area burnt) had the lowest number of detected species, and unlike the other parks surveyed, recorded no detections of long-nosed potoroos or koalas (*Phascolarctos cinereus*).

Nine threatened species were identified during camera trapping surveys conducted in fire-impacted habitat within Barrington Tops National Park, Tapin Tops National Park and Bugan Nature Reserve, in the **Hunter Central Coast (north and south) New South Wales** region. This included, NSW state listed endangered greater gliders (*Petauroides volans*) and koalas, and vulnerable flame robins (*Petroica phoenicea*), long-nosed potoroos, parma wallabies, red-legged pademelons (*Thylogale stigmatica*), spotted-tailed quolls (*Dasyurus maculatus*), yellow-bellied gliders (*Petaurus australis*) and brush-tailed phascogales (*Phascogale tapoatafa*).

In the **Blue Mountains New South Wales** (**Figure 8**), species diversity was generally lower in burnt habitat compared to unburnt habitats. Species composition also differed between burnt and unburnt habitat, with some animals (like small <500g mammal species and critical-weight range mammals; or mammals weighing between 35 g – 5.5 kg) encountered at lower rates in burnt environments. Variation in species composition depended on time since fire, with earlier surveys showing greater differences between burnt and unburnt habitats. One survey indicated that previous fire history may influence species composition, with, for example, long-nosed bandicoot abundance lower at sites that experienced past high fire frequency.

On the **south coast of New South Wales**, in South East Forest National Park, some native animals were detected at fewer sites post-fire, when compared to pre-fire surveys of the area (e.g. Bassian thrush *Zoothera lunulata*, long-nosed bandicoot, superb lyrebird *Menura novaehollandiae*). Meanwhile, other species were recorded at more sites post-fire (white-footed dunnart *Sminthopsis leucopus*, lace monitor *Varanus varius* and common brushtail possum *Trichosurus vulpecula).* Red foxes (*Vulpes vulpes*) were detected at fewer sites post-fire compared to pre-fire and were also encountered more frequently in habitat burnt by low-moderate compared to high-extreme severity fire.

In the **Southern Ranges of north-eastern Victoria and southern New South Wales** (upper Murray region), many of the more common native species were encountered similarly within and outside of the fire extent. Within the fire extent, species encounter rates differed with burn status and severity, with some species like the swamp wallaby (*Wallabia bicolor*) showing highest encounter rates in more severely burnt habitat, and lowest encounter rates in unburnt patches of habitat. Other species like the common brushtail possum and eastern grey kangaroo (*Macropus giganteus*) showed opposite trends, with highest encounter rates in unburnt patches of habitat compared to severely burnt habitat.

In **East Gippsland Victoria** species had varied responses to fire, with *Rattus* species, red foxes and feral cats (*Felis catus*) encountered at higher rates in severely burnt habitat than in unburnt or low severity habitat, and swamp wallabies, red-necked wallabies (*Notamacropus rufogriseus*), and mountain brushtail possums (*Trichosurus cunninghami*) encountered at higher rates in unburnt habitat. Long-nosed potoroos were scarce post-fire in the study region, although long-footed potoroos (*Potorous longipes*), southern brown bandicoots (*Isoodon obesulus*), and long-nosed bandicoots (*Perameles nasuta*) all appeared to be recovering well.

On **Kangaroo Island in South Australia**, Kangaroo Island dunnart (*Sminthopsis fuliginosus aitkeni*) appeared to be recovering well, with the dunnarts detected at 30% of sites by January 2021, 70% of sites by November and 90% of sites by July 2022.

MANAGEMENT SOLUTIONS FOR SPECIES

Across the 17 Eyes on Recovery surveys, more than 30 management activities were identified, with many actioned on the ground. Management was varied and ranged from invasive animal control in post-fire habitats to informing low-impact park infrastructure development, hazard reduction activities, and development and implementation of artificial refugia for animals in post-fire landscapes. Several of the management activies actioned as part of the Eyes on Recovery program are detailed below.

Invasive animal control was largely targeted towards predator species including red foxes and feral cats, but also involved feral herbivours such as deer species (e.g. fallow deer; *Dama dama*), goats (*Capra hircus*) and pigs (*Sus scrofa*). Control programs were instigated by government offices like National Parks offices in QLD and NSW, Landscape Boards (e.g. in Kangaroo Island) and City Councils (in the Blue Mountains). Some of these control programs were applied indescriminantly across landscapes where invasive species were indentified in large numbers by the Eyes on Recovery camera traps, while others targeted invasive species in locations where cameras identified specific threatened species, like Kangaroo Island dunnarts on Kangaroo Island and brush-tailed rock wallabies in northern NSW and south-east QLD.

An exciting management outcome from Eyes on Recovery is that surveys found **artificial habitat refuges** can be effective in providing shelter for threatened species during and after fires. For example, camera surveys of nest boxes installed in burnt areas for greater gliders (*Petauroides volans*) found 100% of the nest boxes were used by gliders throughout the monitoring survey. This gives hope that nest boxes could be an effective way to replace tree hollows lost in bushfires (**Figure 9**).

Similarly, tests of different types of artificial refuges for Kangaroo Island dunnarts found dunnarts readily used the refuges, and that refuges were effective in providing shelter not only after fires but also during a prescribed burn (**Figure 10**). Refuges also provided a humane way to capture dunnarts, allowing managers to collect critical information about the species.

Figure 9: Camera trap image of a juvenile greater glider peaking outside of its nest box.

Figure 10: One type of artificial refuge tested for Kangaroo Island dunnarts to use during and after fire.

In several cases, key management actions involved **continued monitoring**, especially where populations of threatened species were detected for the first time. For example, in northern NSW and south-east Queensland, brush-tailed rock wallaby (*Petrogale penicillata*) colonies were discovered in areas that had not been previously surveyed (**Figure 11**). Long-term monitoring in these locations improves understanding of threats while also providing opportunities to inform adaptive management locally. For example, continued monitoring can allow land managers to identify the most current habitat areas to avoid during management burns, or those that require protection during wildfires. Continued monitoring can also inform adaptive invasive predator control, for example, when threatened species begin to decline in a local area, while invasive predators increase in number.

Figure 11: Photo of a brush-tailed rock wallaby captured at a site in northern NSW.

Ultimately, the data collected as part of Eyes on Recovery, including new and known populations of threatened species, will **inform broad management strategies for these species across larger scales**. For example, the findings of this project have been shared with species experts and threatened species officers for consideration in the management of several threatened species under the NSW Assets of Intergenerational Significance and Saving our Species programs.

Species records collected across the Eyes on Recovery surveys have also been uploaded to online repositories for biodiversity data such as BioNet (biodiversity data managed by the NSW Department of Planning and Environment) and WildNet (biodiversity data managed by the Queensland Government). Inclusion in these repositories allows the location and habitat requirements of these species to be incorporated into fire management planning and environmental assessments, leading to better protection during **hazard reduction burns, wildfire suppression**, and **asset maintenance operations**.

LARGE-SCALE SPECIES TRENDS

The collaborative nature of Eyes on Recovery presented an opportunity to analyse data generated across all nine study landscapes to obtain a broad picture of occupancy and trends for key species.

Figure 12. The endangered Kangaroo Island dunnart, endemic to Kangaroo Island off the coast of South Australia (Kangaroo Island Landscape board).

Data from 13 Eyes on Recovery surveys were consolidated and analysed to understand large-scale species occupancy and trends. The methods and results for these consolidated analyses are detailed extensively in the **Eyes on Recovery Consolidated Analysis** report, with a summary of the key findings provided below.

SPECIES TRENDS ACROSS LANDSCAPES

Across the 9 Eyes on Recovery landscapes, 151 species were detected. This included 133 native and 18 introduced species. Of the native species detected, 54 were mammals (including 6 listed as endangered and 4 listed as vulnerable under the federal Environmental Protection and Biodiversity Conservation (EPBC) Act, 89 were birds (including 1 listed as vulnerable under the EPBC Act), and 8 were reptiles.

The most commonly encountered native species were swamp wallabies (*Wallabia bicolor*), red-necked wallabies (*Notamacropus rufogriseus*), and long-nosed bandicoots (*Perameles nasuta*), while feral cats (*Felis catus*) were the most commonly encountered invasive species.

In general, most species were detected in all Eyes on Recovery landscapes that fell within their broad geographic distribution (**Table 3**). This was especially true for the common native species and invasive species investigated across the project. Exceptions to this were: feral pigs (*Sus scrofa*) and eastern grey kangaroos (*Macropus giganteus*), which were not encountered in the south-east Queensland landscape, common wombats (*Vombatus ursinus*), which were not encountered in the North Hunter Central Coast landscape and European rabbits (*Oryctolagus cuniculus*), which were not encountered in in any of the more northern landscapes (i.e. North Hunter Central Coast, North Coast or south-east Queensland landscapes).

These common native and invasive species may have not been detected in these landscapes for a number of reasons. First, extensive pest control or exclusion may have effectively reduced or eliminated the presence of certain invasive species in some landscapes. For example, in south-east Queensland a pig control program ongoing at the time of the survey may explain the lack of pig detections, while rabbits are excluded from many parts of this region via the Darling Downs-Moreton Rabbit Board fence. Second, cameras may have been set up in unfavourable habitat or on the edge of a species geographic range. For example, while eastern grey kangaroos are broadly distributed throughout south-east Queensland, they prefer open habitat for grazing while our surveys in this area occurred in dense forests. Also, while rabbits are broadly distributed across NSW they have historically been detected in low numbers or not at all in some of the Eyes on Recovery landscapes in this area, including parts of the Hunter Central Coast and North Coast landscapes[8]. Third, it is also possible that fire may have impacted some of these species, such as common wombats in the North Hunter Central Coast landscape, but further exploration is required to confirm this possibility.

Of the priority species, **southern brown bandicoots** (*Isoodon obesulus obesulus*), **parma wallabies** (*Notamacropus parma*), **long-nosed potoroos** (*Potorous tridactylus*), **superb lyrebirds** (*Menura novaehollandiae*), **Kangaroo Island dunnarts** (*Sminthopsis aitkeni*) (**Figure 12**) and **Albert's lyrebirds** (*Menura alberti*) were all detected in every landscape within their range.

Other priority species were not detected in some Eyes on Recovery landscapes that fell within their broad general distribution. For example, **spotted tail quolls** (*Dasyurus maculatus*) were not recorded in the Southern Ranges or Gippsland landscapes and were recorded infrequently in most other landscapes. This may reflect the camera methods used in the surveys, as most did not implement effective quoll lures (e.g., chicken carcasses). In some locations like East Gippsland, however, quoll numbers have been very low in the past[9]; fire could have decreased overall numbers further making them harder to detect.

Like quolls, **koalas** (*Phascolarctos cinereus*) and **brush-tailed rock wallabies** (*Petrogale penicillata*) (**Figure 13**) were not detected in all Eyes on Recovery landscapes within their broad geographic distributions and were also encountered at lower rates than could be achieved with species-specific camera survey methods.

Koala populations are rarely surveyed using ground-based cameras as they tend to spend their time predominantly in trees. Higher koala encounter rates in the Hunter Central Coast and south-east Queensland landscapes could indicate larger populations, or conversely might reflect increased ground-based movement (although it is not known whether koalas alter their movements in response to changes in cover/food availability in post-fire habitats[10]).

Brush-tailed rock wallabies were only encountered where cameras were specifically set up to target preferred habitat including rocky escarpments (i.e. in the North Coast/south-east Queensland landscapes). In these landscapes, several wallaby colonies were discovered, including adult and juvenile individuals.

An extensive survey in 2017 failed to detect **long-footed potoroos** (*Potorous longipes*) in areas of the South East Forest National Park in NSW where they had been previously recorded. The Eyes on Recovery survey in this area repeated and extended this 2017 survey, but also failed to detect long-footed potoroos. While this does not necessarily mean the species is locally extirpated, it makes it unlikely that there is a large population currently persisting in the area, which has management implications given that this was the only known population in NSW. In contrast, long-footed potoroos were encountered frequently in East Gippsland, where extensive baiting supresses red foxes (*Vulpes vulpes*) in the region. Interestingly, long-footed potoroos were encountered more frequently in Gippsland than **long-nosed potoroos**.

DRIVERS OF SPECIES OCCUPANCY

When examined on regional scales, fire did not appear to play a strong role in driving the occupancy of any species analysed as part of the combined Eyes on Recovery dataset (**Figure 14**). However, one or both of the fire variables examined (i.e. **fire severity and burnt versus unburnt habitat**) were included in the top models for several species including brush-tailed rock wallabies, southern brown bandicoots, parma wallabies, long-nosed potoroos, Kangaroo Island dunnarts, red foxes, red-necked pademelons and long-nosed bandicoots.

Similarly, species occupancy did not show a great degree of variation over the Eyes on Recovery study periods, suggesting that most species' populations were relatively stable across time and showed no evidence of any 'recovery' post-fire.

There are several reasons why fire did not appear to have a strong influence on species occupancy rates at this regional scale. Firstly, the timing of the surveys may not have occurred soon enough after the fires to detect a consistent impact on species across sites. While the fires occurred in late 2019 and early 2020, most surveys started in early 2021 with some beginning in 2022. Many surveys were delayed due to the Covid-19 pandemic in 2020 and associated restrictions around travel and access to field sites.

[8] Brown et al. 2020. Models of spatiotemporal variation in rabbit abundance reveal management hot spots for an invasive species. *Ecological Applications* 30(4): e02083.
[9] State Wide Integrated Flora and Fauna Teams 2024. Spot-tailed Quoll. Available at: https://www.swifft.net.au/cb_pages/sp_spot-tailed_quoll.php.
[10] Beale et al. 2022. Effects of Fire on Koalas and Their Habitat. Commonwealth of Australia, Canberra. Available at: https://www.dcceew.gov.au/sites/default/files/documents/effect-fire-on-koalas-and-their-habitat.pdf.

Figure 13. Natalya Maitz from The University of Queensland (left) and Dr Tracy Rout from WWF-Australia (right) search for brush-tailed rock wallaby scat at an Eyes on Recovery site in south-east Queensland.

Secondly, relationships between fire severity or status and species occupancy may not be generalisable at the regional scale. Several of our **Eyes on Recovery Case Study Reports** found significant relationships at the local scale between fire variables and species encounter rates, but these relationships differed for each species in each survey, i.e., the effect of fire variables was positive for some species and negative for other species, and this varied in each location. This diversity in species response to fire has also been found in other studies assessing the impact of the 2019-20 fire season[11,12,13] The lack of a consistent relationship between species occupancy and fire variables at the regional scale may simply reflect a lack of strong consistent response across sites, particularly when all cameras are placed broadly within landscapes that were burnt during the 2019/20 fire season.

Thirdly, while there were no strong relationships between species occupancy rates and the fire variables we analysed (GEEBAM fire severity[14] and burnt/unburnt landscapes) this does not discount potential relationships with other fire-related variables. For example, relationships between species occupancy and

	ELEV	R RAIN	H POP	H FOOT	HCAS	FLII	ECO INT	F SEV	B/UB
Spotted-tailed quoll							+		
Koala		+							
Brush-tailed rock wallaby	●							●	
Southern brown bandicoot	●	●	●	●	●	●	●		●
Parma wallaby		●	●						●
Long-nosed potoroo	●	●	●	●	●	●	●		●
Superb lyrebird							−		
Red-legged pademelon							−		
Kangaroo Island dunnart	●	●	●	●	●	●	●	●	●
Red fox						●		●	●
Feral cat		●				●			
Feral pig		●	●		●	●			
European rabbit							−		
Eastern grey kangaroo		+	●						
Red-necked wallaby	−								
Swamp wallaby	−								
Red-necked pademelon	●	●	●	●	●	●	●		●
Long-nosed bandicoot				●				●	●
Northern brown bandicoot		−							
Common wombat		+							
Short-beaked echidna			●			+			
Small mammal (<500g)							−		
Possum species				+			−		

Figure 14. Top models predicting occupancy for native and invasive species. Plus and minus signs indicate variables with significant positive or negative relationships with occupancy, respectively. Circles indicate variables with no significant relationship with occupancy. Variables are (from left to right): elevation, recent rainfall, human population, human footprint, habitat condition, forest landscape integrity, ecoregion intactness, fire severity, burnt/unburnt status. See **Eyes on Recovery Consolidated Analysis** report for more details.

[11] Miritis 2023. After the 'Black Summer' fires: faunal responses to megafire depend on fire severity, proportional area burnt and vegetation type. Journal of Applied Ecology 61: 63-75.
[12] Cristescu 2021. Difficulties of assessing the impacts of the 2019-2020 bushfires on koalas. Austral Ecology 48(1):12-18.
[13] 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.
[14] Australian Government Department of Climate Change, Energy, the Environment and Water 2020. Australian Google Earth Engine Burnt Area Map (AUS GEEBAM) Fire Severity Dataset (2019-2020). Available at: https://fed.dcceew.gov.au/maps/erin::aus-geebam-fire-severity-dataset-2019-2020/explore.

more complex fire information such as the proportion of surrounding area burnt, time since last burn, frequency of burning, and deviation from pre-colonial fire regimes were not examined as part of this analysis but should be priorities for future research.

Finally, there were likely other drivers influencing and interacting with species occupancy across the Eyes on Recovery study region. Vegetation may have regrown in this time, assisted by higher than usual rainfall across the south-east of Australia in years following the fires (**Figure 15**).

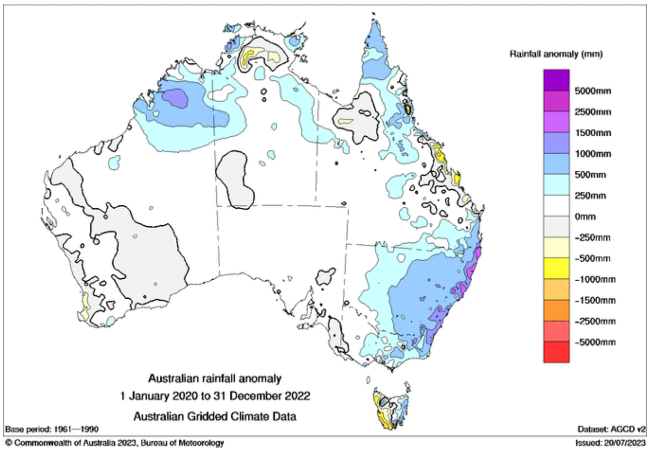

Figure 15: Rainfall anomaly in 2020-2022, compared to base period 1961-1990. Purple/blue colours indicate areas of relative high rainfall (in mm).

Higher recent average rainfall had a positive effect on koala, common wombat and eastern grey kangaroo occupancy. Rainfall is a well-known factor driving patterns in mammal assemblages[15,16] with higher rainfall driving site productivity and reproduction. Higher rainfall may also be particularly important in the aftermath of fire, as it contributes to vegetation regrowth and recovery in areas stripped bare by high intensity burns. Interestingly, **lower recent average rainfall** was correlated with higher occupancy rates for the northern brown bandicoot. The northern brown bandicoot was detected in the south-east Queensland, North Coast, and Hunter Central Coast landscapes (**Table 3**), which are all landscapes where recent rainfall has been unusually high (**Figure 15**). Within this surveyed distribution this species may have been affected by adverse consequences of extreme rainfall events such as flooding and landslides, which were reported anecdotally by some of our partners working in these landscapes. They may have also been impacted by competition with or predation by other species that increased in numbers following the rain.

Greater ecoregion intactness and **forest landscape integrity** were associated with higher spotted-tailed quoll and short-beaked echidna occupancy, respectively. Many native species in Australia are negatively impacted or threatened by processes that impact habitat such as fragmentation and degradation[17]. More specifically, spotted-tailed quoll populations are also known to be restricted to relatively intact patches of forest and show population decline as a result of processes that reduce, degrade and fragment their habitat[18].

Some species were associated with **lower ecoregion intactness**, including European rabbits, small mammals (<500g), possum species, red-legged pademelons, and superb lyrebirds. Some of these species may be positively associated with more degraded or less intact ecosystems[19], particularly invasive herbivores like rabbits and invasive rodents like house mice (*Mus musculus*) and black rats (*Rattus rattus*), which in some landscapes may have formed the majority of the 'small mammal (<500g)' grouping.

The common brushtail possum, which was the most common in the 'Possum species' grouping, thrives in the urban and semiurban regions of Australia[20,21,22], which are typically associated with lower intactness. Supporting this, higher possum occupancy was further associated with higher human footprint. For species not typically associated with degraded landscapes, like superb lyrebirds and red-legged pademelons, the observed relationships could plausibly be caused by other factors associated with low intactness. For example, landscapes closer to human habitation are less intact and are also more protected from fire. Further investigation is needed to explore this possibility.

[15] Heaney 2001. Small mammal diversity along elevational gradients in the Philippines: an assessment of patterns and hypotheses. Global Ecology and Biogeography 10(1):15–39.
[16] Olff et al. 2002. Global environmental controls of diversity in large herbivores. Nature 415(6874): 901–904.
[17] Ward et al. 2021. A national-scale dataset for threats impacting Australia's imperiled flora and fauna. Ecology and Evolution 11(17): 11551-11761.
[18] Victorian Department of Environment, Land, Water and Planning 2016. National Recovery Plan for the Spotted-tailed Quoll *Dasyurus maculatus*. Australian Government Department of the Environment. Available at: https://www.dcceew.gov.au/sites/default/files/documents/national-recovery-plan-spotted-tailed-quoll.pdf
[19] Moore et al. 2022. Invasive rat drives complete collapse of native small mammal communities in insular forest fragments. Current Biology 32(11) 2297-3004.
[20] How & Hillcox 2000. Brush tail possum, *Trichosurus vulpecula*, populations in south-western Australia: demography, diet and conservation status. Wildlife Research 27(1): 81-89.
[21] Goldingay & Jackson 2004. The Biology of Australian Possums and Gliders. Surey
[22] Hill et al. 2007. Human-possum conflict in urban Sydney, Australia: public perceptions and implications for species management. Human Dimensions of Wildlife 12(2): 101-113.

Table 3. Landscapes where each of the analysed species were detected. Tick marks indicate at least one positive detection of the species, while circles indicate landscapes within the species habitat range where they were not detected by any Eyes on Recovery cameras.

Species	South-east QLD	North Coast	(N) Hunter Central Coast	(S) Hunter Central Coast	Blue Mountains	South Coast	Southern Ranges	Gippsland	Kangaroo Island
Spotted-tailed quoll (*Dasyurus maculatus*)	●	✓	✓	✓	✓	✓	●	●	
Koala (*Phascolarctos cinereus*)	✓	✓	✓	✓	✓	●	●	●	✓
Brush-tailed rock wallaby (*Petrogale penicillata*)	✓	✓	●	✓	●	●			
Southern brown bandicoot (*Isoodon obesulus obesulus*)						✓		✓	✓
Parma wallaby (*Notamacropus parma*)	●	✓	✓	✓					
Long-nosed potoroo (*Potorous tridactylus*)	✓	✓	✓	✓				✓	
Superb lyrebird (*Menura novaehollandiae*)	●	✓	✓	✓	✓	✓	✓	✓	✓
Red-legged pademelon (*Thylogale stigmatica*)	✓	●	✓	✓					
Kangaroo Island dunnart (*Sminthopsis aitkeni*)									✓
Albert's lyrebird (*Menura alberti*)	✓								
Long-footed potoroo (*Potorous longipes*)						●		✓	
Red fox (*Vulpus vulpus*)	✓	✓	✓	✓	✓	✓	✓	✓	
Feral cat (*Felis catus*)	✓	✓	✓	✓	✓	✓	✓	✓	✓
Feral pig (*Sus scrofa*)	●	✓	✓	✓	✓	✓	✓	✓	✓
European rabbit (*Oryctolagus cuniculus*)	●	●	●	✓	✓	✓	✓	✓	
Eastern grey kangaroo (*Macropus giganteus*)	●	✓	●	✓	✓	✓	✓	✓	
Red-necked wallaby (*Notamacropus rufogriseus)*	✓	✓	✓	✓	✓	✓	✓	✓	
Swamp wallaby (*Wallabia bicolor*)	✓	✓	✓	✓	✓	✓	✓	✓	
Red-necked pademelon (*Thylogale thetis)*	✓	✓	✓	✓					
Long-nosed bandicoot (*Perameles nasuta)*	✓	✓	✓	✓	✓	✓	✓	✓	
Northern brown bandicoot (*Isoodon macrourus)*	✓	✓	✓	✓					
Common wombat (*Vombatus ursinus)*	✓	✓	●	✓	✓	✓	✓	✓	
Short-beaked echidna (*Tachyglossus aculeatus)*	✓	✓	✓	✓	✓	✓	✓	✓	✓
Small mammal species (<500g)	✓	✓	✓	✓	✓	✓	✓	✓	✓
Possum species	✓	✓	✓	✓	✓	✓	✓	✓	✓

THE PATH AHEAD

Figure 16. East Gippsland eucalyptus forest recovering after bushfire (WWF-Au/Emma Spencer).

Climate change is altering the intensity and frequency of extreme weather-related events such as heatwaves, droughts, floods and bushfires[23]. These events are triggering huge environmental disasters across the planet. It is therefore becoming increasingly important that land managers are supported to rapidly assess landscapes in the wake of these extreme events. This includes tracking impacts on important wildlife species.

While camera traps have for decades been seen as an efficient method for monitoring wildlife, broad-scale camera deployment still requires significant time and resource investment. Online platforms such as Wildlife Insights have the potential to revolutionise this space, as they embed AI to speed image processing. These platforms also help to improve coordination between different organisations, and can encourage improved metadata standardisation, data sharing and the collation of larger datasets to inform management of larger tracts of land.

The Wildlife Insights platform was a key enabler of the Eyes on Recovery initiative. Once the Google-powered AI algorithm embedded in the platform was trained for Australian species, image processing became significantly improved. The platform also served as a project management tool, giving visibility over the status of each survey and allowing multiple users to contribute to image processing easily and efficiently. This was especially useful given the impacts of the COVID-19 pandemic, which meant that much of this initiative had to be completed with minimal in-person contact.

Piloting the development of new technology while at the same time seeking to achieve outcomes through its use was a key challenge throughout Eyes on Recovery. New technology development comes with uncertainty, with the possibility that the technology may fail, take longer to develop than expected, or not deliver the expected outcomes. One objective of Eyes on Recovery was the development and training of the Wildlife Insights AI algorithm for Australian fauna. Simultaneously, this initiative also required millions of images to be rapidly processed, which in-turn depended on the effectiveness of the AI algorithm. This initial lack of a 'trained' algorithm did influence overall image processing times, although surveys were supported early on with greater human oversight.

[23] Cresswell et al. 2021. Overview: climate change and extreme events. In Australia State of the Environment 2021. Australian Government Department of Agricultrue, Water, and the Environment, Canberra. Available at: https://soe.dcceew.gov.au/overview/pressures/climate-change-and-extreme-events.

Eyes on Recovery is a demonstration of a non-standardised approach to large-scale fauna monitoring, managed through collaboration, data sharing, and 'big data' modelling approaches. While standardised monitoring methods provide the most statistical power to answer big questions, they can be very difficult to deploy at large scales. This is particularly true where multiple stakeholders with competing management interests are involved. Eyes on Recovery demonstrates how monitoring can be targeted towards meeting specific local scale needs while at the same time being collated, processed, and analysed to provide a big picture look at fauna distribution and trends. Given the scale of data collected, there is still room for further data exploration, including analyses of species response to other fire-related variables.

As well generating analyses of post-fire species occurrence and trends, Eyes on Recovery helped prepare for future disasters by contributing to much-needed baseline knowledge on wildlife distribution and composition. This baseline knowledge is lacking in many areas of Australia and will facilitate more accurate assessment of future disaster impact. By training the Wildlife Insights AI algorithm on native and invasive species in southern and eastern Australia, Eyes on Recovery has enabled quicker processing of camera images taken in these areas. This facilitates more rapid assessment and management response to future disaster events. Further work is needed to train the AI algorithm on species in other areas of Australia, particularly in northern Australia, western Australia, and Tasmania.

Figure 17. Checking images on a camera in the Blue Mountains.