NSW National Parks and Wildlife Service

Ecological Health Performance Scorecard report

Royal National Park, Heathcote National Park and Garawarra State Conservation Area 2022–23

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Acknowledgement of Country

Department of Climate Change, Energy, the Environment and Water acknowledges the Traditional Custodians of the lands where we work and live.

We pay our respects to Elders past, present and emerging.

This resource may contain images or names of deceased persons in photographs or historical content.

Artist and designer Nikita Ridgeway from Aboriginal design agency – Boss Lady Creative Designs, created the People and Community symbol.

Cover photo National parks staff conducting surveys in Royal–Heathcote–Garawarra. Zain Kruyer//DCCEEW

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Cultural and historical connections

The ancient landscape now known as Royal National Park, Heathcote National Park and Garawarra State Conservation Area, and their surrounding lands and watercourses, have been under the care of the Dharawal language group peoples for thousands of years. Aboriginal people have a deep spiritual and cultural connection to this Country.

There is continuing connection between Aboriginal people of the Dharawal language and other Aboriginal families, groups and people. The continued role of Indigenous people as custodians is integral to protecting, managing and interpreting the needs of Royal–Heathcote–Garawarra (DPE 2022a).

Royal National Park is Australia's oldest conservation reserve proclaimed in 1879 and covers an area of approximately 18,912 ha. With Heathcote National Park to the west (2,826 ha) reserved in 1943, and Garawarra State Conservation Area to the south (999 ha) reserved in 1987, these parks support an array of ecosystems on the north-eastern edge of the Woronora Plateau.

Royal National Park, Heathcote National Park and Garawarra State Conservation Area are geographically located within the Sydney Basin biogeographic region*. They are bounded in the north by the residential areas of southern Sydney, in the south by Wollongong's suburbs, in the west by part of the Sydney drinking water catchment and Holsworthy Army Base, and the coast to the east.

* IBRA7; Sydney Catchment subregion

Hacking River, Royal National Park. Nick Cubbin/DCCEEW

Scorecard location

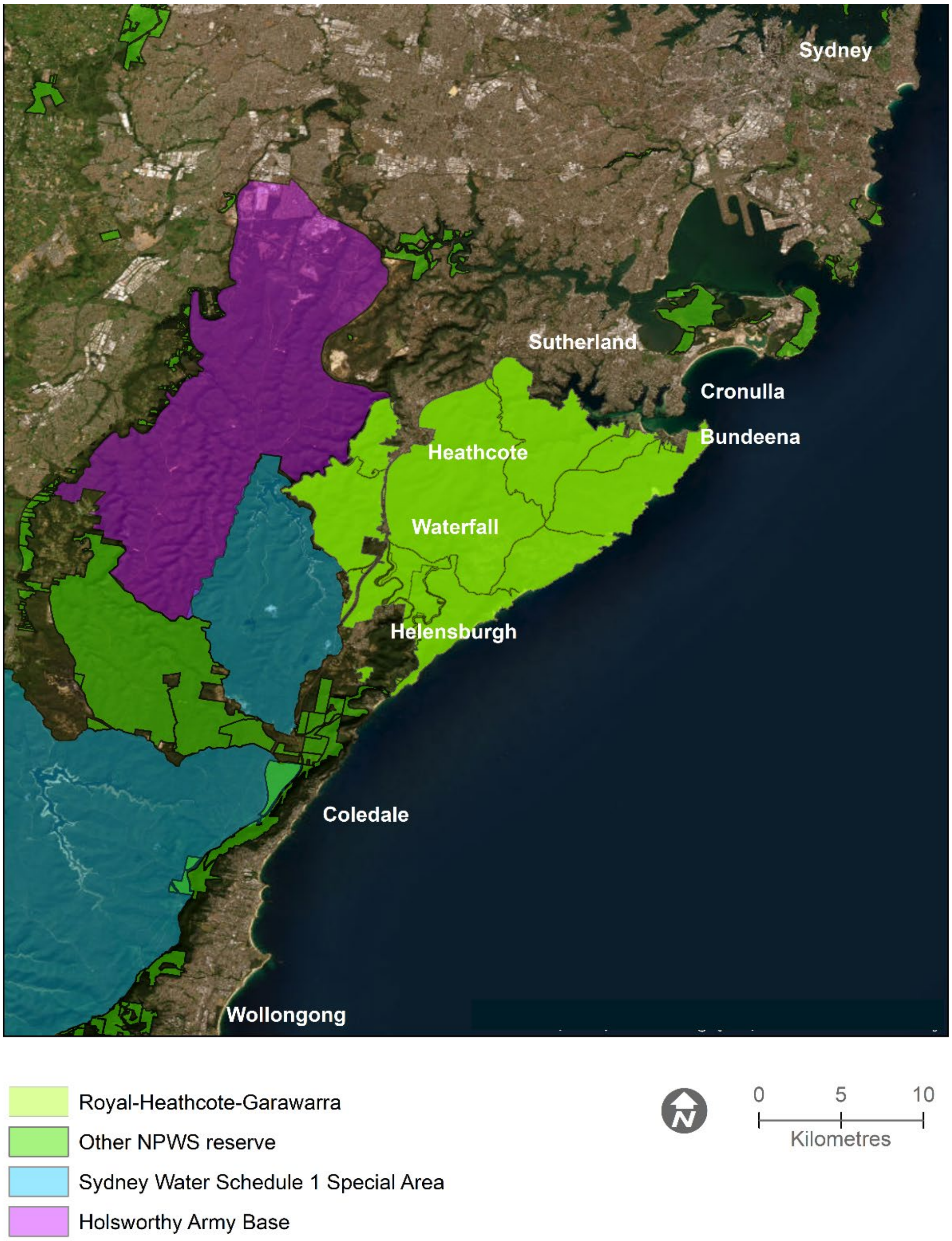


Figure 1 **The Royal–Heathcote–Garawarra Ecological Health Performance Scorecard site**

Located on the NSW coast with the residential areas of southern Sydney to the north, the suburbs of Wollongong to the south and flanked on its western side by the Holsworthy Army Base and part of the Sydney drinking water catchment Special Area

Summary

Measuring ecological health

Our national parks are extraordinary places. They make up over 10% of New South Wales across various desert, alpine and coastal ecosystems. Almost 800 of the approximately 900 threatened species in New South Wales are found on the national park estate. Royal National Park, Australia's first national park and one of the first national parks in the world, was established in 1879. Along with the adjacent Heathcote National Park and Garawarra State Conservation Area, it protects a suite of important natural and cultural habitats and a diversity of native species on the southern edge of Sydney, Australia's largest city of over 5 million people. For these reasons, the Royal–Heathcote–Garawarra (RHG) complex is a fitting choice as the first site implementing the NPWS Ecological Health Performance Scorecards program ('Scorecards').

The Scorecards program is a world-leading initiative that aims to systematically measure and report on the ecological health (state or condition of the environment) of the NSW national park estate. The objectives of the Scorecards program are to:

- Improve our understanding of the ecological health of NSW national parks by systematically measuring and reporting on the status and trends of key ecological health attributes.
- Improve conservation outcomes by informing park management and resource allocation decisions. The Scorecards will provide valuable data which will help improve park management and increase the ecological return on investment in our national parks.

To achieve these objectives, the Ecological Health Performance Scorecards program will measure and report at regular intervals on:

- the population or health of conservation assets including:
  - indicator, threatened and/or declining species
  - habitats and ecological processes
- the extent of threatening processes (for example, feral animals, weeds, disease and climate change)
- fire regimes.

The collection of data on these attributes will be guided by ecological health monitoring plans that are developed in consultation with internal and external monitoring experts, make use of existing programs and data, and include cultural knowledge, as appropriate.

The level of scientific monitoring which underpins this initiative is significant — it is likely the largest systematic ecological monitoring program in NPWS history. However, it is not feasible to measure everything. A suite of attributes has initially been chosen for RHG. This list will be amended and expanded over time as the program is further developed and, in particular, as our knowledge about the ecological health of RHG improves, as any new risks emerge and as technology improves our capacity for ecological monitoring.

For RHG, information on population trends will be provided for a range of native species, such as the vulnerable eastern pygmy-possum (*Cercaretus nanus*), the endangered koala (*Phascolarctos cinereus*) and endangered broad-headed snake (*Hoplocephalus bungaroides*). Threatened species are a significant focus of monitoring because they are at greater risk, are a significant focus of management and because there is a high level of public interest in how their populations are faring. However, a range of common species have also been identified for monitoring as data are more readily collected and may be more informative for tracking ecological changes. Threats that have a significant ecological impact, including feral animals such as rusa deer (*Rusa timorensis*), priority weeds such as boneseed (*Chrysanthemoides monilifera)* and changes in fire patterns, are a primary focus for monitoring and reporting. Additional threats may be monitored and reported in the future.

The program's focus is on quantifying the status and change in indicators over time, for example, measuring and reporting changes in the population (or other metric) of key threatened species and the density or activity of feral animals. The program is not structured as a series of research questions to explain why any changes are occurring. In many cases, existing research will already provide information which helps explain why changes are occurring. For example, we know an increase in the fox population may cause a reduction in small to medium-sized mammal populations. Where there are knowledge gaps which impede the ability of management to understand and respond to the ecological health data, a separate research project will be developed to help fill those gaps. A research prospectus will be developed over time to address priority questions and knowledge gaps.

Ecological health data will be considered by park managers as part of regular management reporting which integrates the review of expenditure, management activity and outputs and ecological outcomes. As the Scorecards program is further developed, benchmarks or reference conditions will be included for indicator metrics. This could be, for example, a target abundance or density for a threatened species, a desired 'patchiness' metric for fire, or the target density for a feral animal species such as the red fox (*Vulpes vulpes*). This will strengthen the link to management decisions.

There are 4 key components to the Scorecards program:

1. Park-wide surveillance monitoring using several survey methods at each survey site to monitor multiple species and habitat attributes
2. Targeted monitoring of priority conservation assets (typically threatened species and ecological communities)
3. Measuring the extent of feral animals, weeds and other threats
4. Measuring and reporting of park-wide fire metrics.

The park-wide surveys were completed over 2 financial years 2021–22 and 2022–23 (Table 1). In this report the monitoring results from the park-wide surveillance sites are reported for a single calendar year of survey, 2023 if available, otherwise 2022.

The 2022 and 2023 park-wide surveillance monitoring in RHG generated a significant volume of data highlighting the large scale of this initiative (Table 1). The survey data included:

- 85,304 camera images of animals (2022)
- 261,327 audio files (2023)
- 2,633 bird records (2022)
- 2,395 plant records (2023)
- 200 soil samples (2023)
- 40 water quality samples (2022).

This first scorecard provides a collation, analysis and summary of ecological data attained through on-ground surveys, existing spatial data, threat management efforts, and patterns of fire in time and space. It is a critical first step in better understanding changes in the health of RHG. Analyses have not been extended to assess ecological patterns or relationships, nor to evaluate ecological responses to management interventions. Data collected in subsequent years will provide opportunity for improved analysis of the trajectories and status of native species and ecosystem processes.

Targeted indicators and/or monitoring effort may change over time as data are collected and analysed and will be informed by power analyses to assess the survey design, including determining the optimal number of monitoring sites and survey occasions required to adequately track change in species numbers over time. A consistent but adaptive approach will be the key to monitoring effectiveness and improvements in ecological health outcomes into the future.

Table 1 Park-wide survey effort at the Royal–Heathcote–Garawarra Scorecards site in 2022 and 2023

Survey type	Survey effort	Survey timing	Data output
Camera	2022: 136 cameras at 34 sites for a mean of 36 nights (4,713 total trap nights)	May – June	85,304 animal images (287,083 total images)
	2023: 160 cameras at 40 sites for a mean of 99 nights (15,774 total trap nights)	March – June	Number of animal images pending (890,043 total images)
Audible sound recorder	2022: 20 recorders at 20 sites for a mean of 50 nights (997 total trap nights)	May – June	7,974 sound files
	2023: 40 recorders at 40 sites for a mean of 99 nights (3,849 total trap nights)	March – June	85,175 sound files
Ultrasonic sound recorder	2023: 34 recorders at 34 sites for a mean of 9 nights (311 total trap nights)	March – June	176,152 sound files
Bird	2022: 48 surveys at 23 sites (2 surveys per site on average)	Nov	827 individual records
	2023: 80 surveys at 40 sites (2 surveys per site)	Oct – Nov	1,806 individual records
Vegetation	2023: 40 20 × 20 m floristic plots, 40 50-m point intersect transects, and 40 50 × 20 m tree density plots	June	Floristic plots: 2,395 records Tree density plots: 3,728 records (stems) Point intercept transect: 10,716 records
Soil	2023: 40 soil cores for bulk density and 160 soil cores for composite analysis	June	200 soil cores
Water quality	2022: 40 samples at 20 sites	April – May Oct – Nov (autumn and spring)	40 samples for water quality and invertebrates

Wildlife

In the last 5 years, 42 native mammal species have been recorded in RHG. This tally is 82% of, or 9 species less than, the likely pre-European (circa 1750 CE) mammal assemblage of 51 species, based on records from RHG and the wider Sydney Basin bioregion (Appendix I). Of the 9 mammal species not recorded from RHG in the past 5 years, 6 are expected to have been lost from the area and 3 may still occur. The 6 mammal species suspected to be lost since European settlement consist of 5 medium-sized mammals and one arboreal mammal. While the loss of up to 18% of the pre-European mammal species assemblage is considered a high rate of local extinction by global standards (Woinarksi et al. 2015), compared to many parts of New South Wales, especially west of the Great Dividing Range, RHG retains a relatively high proportion of its pre-European mammals. This may reflect a combination of high rainfall, varied topography and associated vegetation types, an extensive sea boundary and early declaration as Australia's first national park. While 40 mammal species are extinct across Australia (Burbidge 2023), all species suspected to be locally extinct in RHG survive elsewhere in Australia and could potentially be reintroduced. The platypus (*Ornithorhynchus anatinus*) was successfully reintroduced in 2023.

Park-wide surveillance in 2022 recorded 109 species of native fauna. This includes 29 mammal species (5 small ground-dwelling mammals, 3 medium-sized mammals, 5 arboreal mammals and 16 microbats) and 80 bird species (terrestrial species only, of which 41% are woodland-dependant species). Key results from the 2022 park-wide surveillance for mammal species include:

- The first ever detection in RHG of the threatened yellow-bellied sheath-tailed bat (Saccolaimus flaviventris).
- Krefft's glider (Petaurus notatus) was recorded for the first time in RHG. This species of Petaurus has only been recognised since the taxonomic split of the sugar glider (Petaurus breviceps) in 2021 (Cremona et al. 2021). Further investigation is needed to determine if there is more than more one petaurid species in RHG.
- Dusky antechinus (Antechinus mimetes) recorded for only the third time in RHG.
- Native mammals with the highest occupancy and activity levels were swamp wallaby (Wallabia bicolor), antechinus species, eastern pygmy-possum, long-nosed bandicoot (Perameles nasuta) and short-beaked echidna (Tachyglossus aculeatus).
- RHG is an important site for the threatened eastern pygmy-possum.
- RHG supports over half of all microbat species in New South Wales, including over 40% of all threatened microbat species.

Mammal species of concern (and not recorded during these surveys) include the threatened species: southern greater glider (*Petauroides volans*), koala, new holland mouse (*Pseudomys novaehollandiae*) and spotted-tailed quoll (*Dasyurus maculatus*) (not recorded since 2007). While not threatened, the rakali (the Aboriginal name for water rat, *Hydromys chrysogaster*) has not been recorded since 1964.

A total of 234 bird species were recorded in RHG in the last 5 years. This represents 70% of the likely pre-European bird assemblage. There are 4 bird species which were once considered resident that have not been recorded in RHG in the last 5 years: eastern bristlebird (*Dasyornis brachypterus*), eastern ground parrot (*Pezoporus wallicus*), bush stone-curlew (*Burhinus grallarius*) and regent bowerbird (*Sericulus chrysocephalus*) (Goldingay 2012).

Targeted monitoring captures information on RHG species that are not well represented in the park-wide surveillance monitoring. Broad-headed snake surveys suggest the population is stable. Targeted monitoring is to be implemented in the future for koala, southern greater glider, giant burrowing frogs (*Heleioporus australiacus*) and stream-breeding frogs.

Flora and vegetation communities

There are 5 major vegetation formations in RHG: dry sclerophyll forests (shrubby), heathlands, rainforests, wet sclerophyll forests (grassy) and wet sclerophyll forests (shrubby). These comprise 59 plant community types (PCTs). RHG supports over 1,000 plant species, approximately 5% of Australia's total plant species (DPE 2022a; Australian National Botanic Gardens 2009). There are 15 recognised threatened ecological communities (TECs), including the targeted endangered community Littoral Rainforest in the South East Corner, Sydney Basin and NSW North Coast Bioregions.

A total of 488 species of native plants were recorded from floristic surveys at park-wide surveillance monitoring sites across the 5 major vegetation formations. One threatened plant species, *Hibbertia stricta* subspecies *furcatula*, not previously recorded from RHG, was recorded.

Two of the 12 threatened plant species recorded in RHG have targeted monitoring programs: villous mint bush (*Prostanthera densa*) and scrub turpentine (*Rhodamnia rubescens*). Of high concern is the survey findings that the critically endangered scrub turpentine population in RHG is severely impacted by myrtle rust (*Austropuccinia psidii*), with high levels of mortality and canopy loss. As a result of the current survey, new management actions have been proposed to address the threat to this species in RHG. The villous mint bush population is stable.

Vegetation communities away from roads and tracks were found to be mostly free from weeds and containing only small numbers of standing dead trees, although mortality was observed in the scrub turpentine trees severely affected by myrtle rust. Large hollow-bearing trees were found mostly in the wet sclerophyll forests, which provide roosting and nesting habitat for hollow-dependent species.

Ecological processes

The soils in RHG were found to be generally low in nitrogen and phosphorus reflecting the underlying sandstone geology, and higher levels were found in the shale soils of rainforest sites. Higher levels of total organic carbon in rainforest and wet sclerophyll forest are explained by the build-up of organic matter.

The waterways of RHG are generally in very good to good condition, with only a small proportion in fair condition (10%) or poor to very poor condition (20%). Poor conditions were recorded at sites in proximity to the urban interface including at Bundeena, Saville and Wilsons Creeks and immediately upstream of the weir on the Hacking River near Audley visitor area. Despite surveys indicating that the water quality is generally good, there is some indication of habitat degradation within the waterways demonstrated by a low proportion of pollution-sensitive macroinvertebrates.

Feral animals and weeds

The red fox is widespread in RHG, detected at 85% of sites, with high activity levels. High fox occupancy and activity suggests that they are ubiquitous within the RHG landscape and likely to be impacting on populations of native species, particularly small to medium-sized ground-dwelling mammals.

Rusa deer were detected at 44% of monitoring sites, with very high levels of activity. They occur in the north, west and especially the southern parts of RHG, predominantly in rainforest and wet sclerophyll. Of particular concern is their impact on rainforest; 64% of littoral rainforest was found to be impacted by deer. NPWS shot 462 rusa deer in RHG across the 2 financial years of 2021–22 and 2022–23.

The feral cat (*Felis catus*) was not detected in RHG. However, they are likely present but at low densities. Feral pigs (*Sus scrofa*) and feral goats (*Capra hircus*) were also not detected.

There are several significant weeds present in disturbed areas of RHG, including boneseed, holly-leaved senecio (*Senecio glastifolius*), sea spurge (*Euphorbia paralias*) and aquatic weeds. All have targeted control programs. Control of other weed species is targeted within threatened ecological communities. In 2022–23, NPWS staff and volunteers treated 243 ha of weeds. Weeds were detected at only 4 surveillance monitoring sites, where they occurred in very low abundance.

Climate change

The effects of a changing climate have been widely acknowledged as impacting species and ecosystems, either directly (e.g. prolonged drought) or indirectly (e.g. more severe and frequent fires as a result of prolonged drought). Likely interactions between climate change and other factors such as predation and habitat loss compounds and complicates monitoring. Relating short (5 year) to medium (10 year) changes in RHG species and ecosystems to broad-scale climate-related effects only becomes achievable in the long-term (>10 years) and across multiple NPWS sites. As such, possible climate-related factors that may affect species distributions and abundance have not been directly incorporated in the monitoring design but will be addressed analytically as multiple years and sites are completed.

Fire

The highest priority for fire management at RHG is to protect life and property, noting the large urban interface. This is consistent with a broad ecological objective to prevent widespread, severe and frequent fire.

The fire history of RHG has included a period from 1988 to 2001 where fire impacted severely on the ecological health of the park aggregate. In 1994, 95% of Royal National Park was burnt at high severity with most of the canopy burnt in many places across the landscape. In 1988–89 and 2001, bushfires burnt greater than 50% of Royal National Park. These fires impacted significantly on the health of RHG and are likely to have caused a significant decline in southern greater glider populations.

However, in the last 20 years there has been virtually no bushfire (unplanned fire) in RHG. On average, nearly 200 ha has been burnt annually in prescribed burns.

The impact and role of fire varies across vegetation formations. Some general observations include:

- there are few areas of long unburnt (>30 years) dry and wet sclerophyll forest, however, some areas have survived more than 30 years without canopy (severe) fire
- 76% of rainforests have burnt in the last 30 years, although very little (6%) experienced (severe) canopy fire
- spatially, the major vegetation formations are characterised by large stands of similar time-since-fire. Over time, a key challenge will be transitioning this to a stronger mosaic which includes vegetation patches of different time-since-fire age classes spread across the landscape.

The delivery of planned fire in the landscape will assist with the ecological management of RHG while also helping to reduce the risk of broadscale severe fires.

Program design

The NSW NPWS Ecological Health Performance Scorecards program provides information to track long-term trends across the NSW national park estate for ecological indicators, (common, threatened and/or declining native species), ecological processes, and threats to biodiversity and ecological health (feral animals and weeds). In turn, this information can be used to inform on-ground management to help deliver better biodiversity and other ecological health outcomes. Due to the diversity of organisms and ecosystems which occur across NPWS parks, a 2-tiered monitoring approach has been developed for biodiversity indicators: park-wide surveillance and targeted monitoring. In addition, metrics for fire and threatening processes are collected and reported.

The program is composed of 4 components.

1. **Park-wide surveillance monitoring** is broad in scope and covers a large geographic area. Monitoring utilises several survey methods at each site to monitor multiple species and habitat attributes to provide a snapshot of the ecological health of the park.
2. **Targeted monitoring of select biodiversity indicators** will supplement surveillance monitoring to obtain information on priority species (e.g. threatened or declining species) and ecosystems (e.g. rare or threatened ecological communities) not adequately sampled in surveillance monitoring.
3. **Monitoring of threatening processes** including feral animals and weeds.
4. **Measurement and reporting of fire metrics**, noting while fire is a natural process it also represents a threat to ecological health if, for example, fires are too hot, too large, or too frequent.

Tranche 1 of the Scorecards program includes the aggregate of Royal National Park, Heathcote National Park and Garawarra State Conservation Area — collectively called Royal–Heathcote–Garawarra (RHG) and Kosciuszko National Park. The RHG scorecard is the first scorecard to be developed for the program.

The ecological health monitoring approach for RHG follows principles of sound ecological monitoring. The focus is on long-term monitoring to provide a general understanding of changes in biodiversity. The purpose of ecological health monitoring is to quantify, as far as practicable, the status of the distribution, abundance, or other metric of each indicator and to track changes over time. For example, ecological health monitoring is intended to report the population (or similar metric) of both common species, such as antechinus, and threatened species, such as eastern pygmy-possum and koala, and how populations change over time. It is not intended, in isolation, to address the question of why changes occur. In many cases, existing research will help explain why changes are occurring. Where additional information is needed to understand the cause of change, further research may be conducted in addition to this program.

Park-wide surveillance

To effectively monitor the overall ecological health of assets, threats and processes across RHG, survey sites have been stratified by ecosystems and fire history, 2 critical factors that can underpin variations in ecological health metrics. Dry sclerophyll forests and heathlands comprise 86% of the park aggregate and thus more sites were allocated to these vegetation formations than the other formations (Table 2, Figure 2). Geographic representation was considered more important than balanced replication for fire history, as not all vegetation formations are equally represented by the spread of fire history across RHG, fire is actively excluded from some (e.g. rainforests and wet sclerophyll forests), and fire histories will change over time.

Table 2 The number of sites in each vegetation formation selected in Royal–Heathcote–Garawarra (RHG) for the establishment of long-term park-wide monitoring sites

Vegetation formation	Percent area of RHG	No. of sites
Heathlands	30.3%	13
Dry sclerophyll forests (shrubby sub-formation)	55.9%	15
Rainforests	2.4%	4
Wet sclerophyll forests (grassy sub-formation)	1.5%	4
Wet sclerophyll forests (shrubby sub-formation)	7%	4
Totals	**97.1%**	**40**

Monitoring site design

Metrics are calculated for a suite of indicators for conservation assets, threats and processes from a network of 2-ha surveillance monitoring sites across the park aggregate. At each surveillance monitoring site, camera traps and acoustic devices are partnered with bird, vegetation and soil surveys to increase the array of fauna and to provide contextual data on vegetation composition, cover and structure, and habitat value.

Within a 100 × 100 m area of the 2-hectare site, 4 remote cameras were installed in a square or diamond configuration (Figure 3), with 2 infra-red flash and 2 white-flash cameras used. Three cameras were deployed with a lure, a mixture of peanut butter, oats and honey. A fourth camera with no lure was placed on a medium to large animal pathway.

Two passive sound recorders were installed per site. One device recording sound in the audible range to detect bird species such as owls, and the other device a full-spectrum ultrasonic sound recorder to detect microbats.

Diurnal birds were surveyed within a standard 2-ha plot (100 × 200 m) over a 20-minute period. Each site was surveyed 2 times, by different observers on different days, to limit day and observer effects. Climatic variables were also recorded. Surveys were undertaken during the early morning, as close to dawn as possible, but also at dusk to help build a more complete list of bird species for each site.

Each site has a 20 × 20 m vegetation plot positioned within the 2-ha area with the mid-points permanently marked. Species, signs of dieback, percent foliage cover and abundance of all plant species in the plot were recorded. Soil samples were taken randomly from 4 to 5 sites within each vegetation plot using a soil corer (0–10 cm core with a 3.6 cm diameter). Information on tree diameter was recorded from a 20 × 50 m plot that overlaps the floristic plot. Any additional plant species observed in this plot were also recorded. Percentage cover of leaf litter and canopy cover in each stratum was recorded using a 0–50 m point intercept line transect along the marked midpoints (Figure 3).

The park-wide surveys were completed over 2 financial years 2021–22 and 2022–23 (Table 1). In this report the monitoring results from the park-wide surveillance sites are reported for a single calendar year of survey, 2023 if available, otherwise 2022.

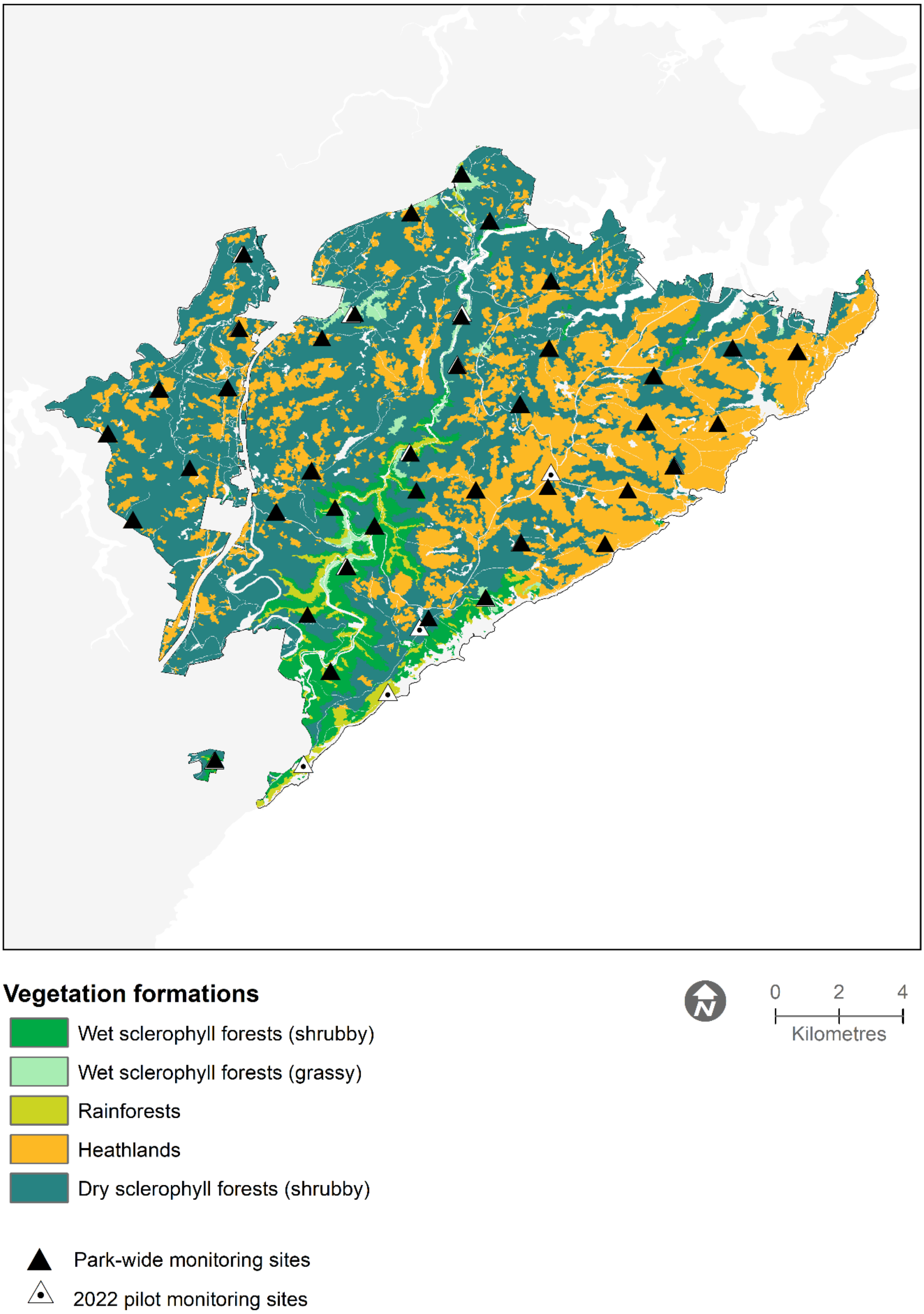


Figure 2 Location of park-wide surveillance monitoring sites across the major vegetation formations in Royal–Heathcote–Garawarra (NSW state vegetation type map, release C1.1M1 [DPE 2022b])

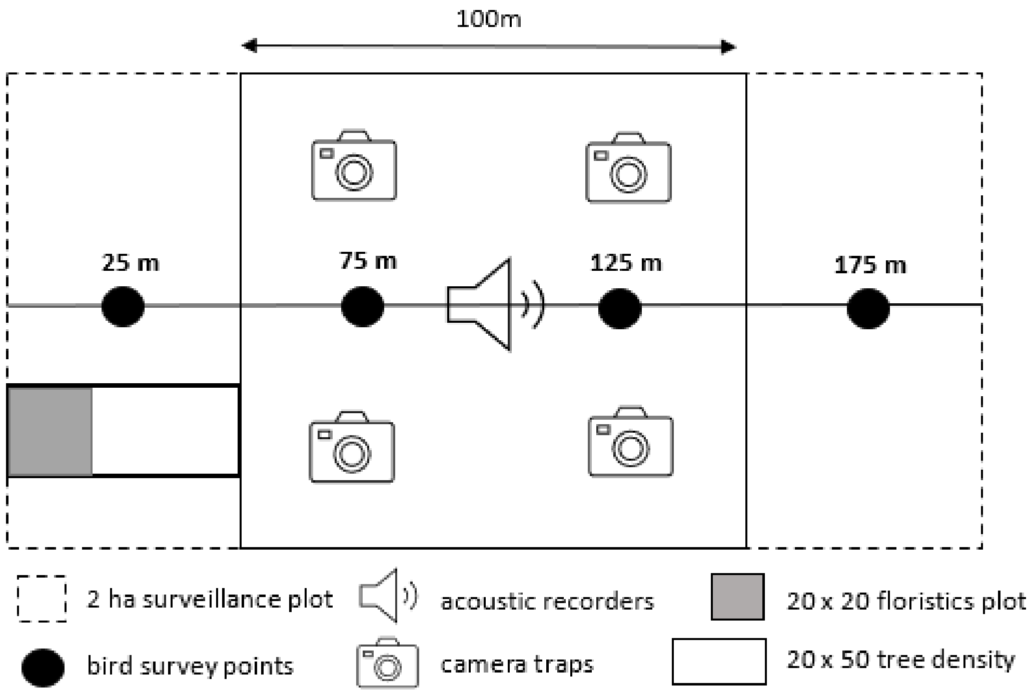


Figure 3 **Survey site layout showing placement of each camera and audio devices, bird point survey transects, and vegetation plots**

Targeted monitoring

While the most representative vegetation communities and fauna species which occur throughout RHG are monitored through the park-wide surveillance approach, additional fauna, flora and vegetation communities are important to monitor for their high conservation status, sensitivity to threatening processes, or endemism, and require specialised monitoring techniques.

Targeted monitoring augments the surveillance monitoring and will provide information on status and population trends at the whole-of-park scale. The frequency and type of monitoring is guided by the ecological dynamics of the target species or ecosystem. Monitoring protocols will be developed where they do not already exist to ensure a consistent approach in monitoring design, sampling approach, and reporting metrics across the park estate.

Some of the targeted species or ecological communities are already monitored as part of existing threatened species or management programs, for example, Saving our Species. However, the monitoring objectives may differ to those of the Scorecards program. Opportunities to leverage, align and supplement existing park monitoring programs will be undertaken following a process of review.

Park-wide surveillance: fauna

Terrestrial and arboreal mammals

Conservation context

Australia has a unique and iconic mammal fauna which has suffered the worst extinction record in the world (40 species) in the 200 years since European colonisation (Burbidge 2023). In New South Wales there are currently 85 of 138 (62%) terrestrial mammal species listed as threatened under the *Biodiversity Conservation Act 2016* (NSW): 26 presumed extinct, 3 critically endangered, 17 endangered and 39 vulnerable. The total number of mammal species that was expected to occur in RHG pre-European colonisation (circa 1750) is 51 (BioNet; Atlas of Living Australia (ALA) records; Woinarski et al. 2015) (Appendix I). Six of these are now considered extinct from RHG and an additional 3 have not been recorded in the last 5 years but may still be present in RHG. A comparison of the present-day fauna assemblage to the expected 1750 assemblage provides an indicator that measures, directly and indirectly, the overall amount of biodiversity that currently exists (OEH 2019).

RHG provides an important conservation refuge for fauna species in the southern area of the Sydney Basin. Two species of mammal recorded in RHG, koala and southern greater glider, are listed as endangered under the Biodiversity Conservation Act and *Environment Protection and Biodiversity Conservation Act 1999* (Cth). The eastern pygmy-possum is listed as vulnerable under the Biodiversity Conservation Act and the New Holland mouse is listed as a vulnerable under the Environment Protection and Biodiversity Conservation Act. Park-wide surveillance and targeted monitoring of mammal fauna is designed to detect changes in species richness (number of species) and occurrence across mammal guilds.

Methods and results

In 2022, 13 species of native mammals were recorded using camera traps deployed for 4 weeks in early May at 34 park-wide surveillance sites. Of the 136 cameras deployed, all except 9 ran the duration of the survey period; 2 failed and 7 stopped working before the end of the survey. Eight ground-dwelling mammals were detected: brown antechinus (*Antechinus stuartii*), dusky antechinus, common dunnart (*Sminthopsis murina*), bush rat (*Rattus fuscipes*), swamp rat (*Rattus lutreolus*), long-nosed bandicoot, swamp wallaby and short-beaked echidna. Five species of arboreal mammals were also detected on camera traps: common ringtail possum (*Pseudicheirus peregrinus*), mountain brushtail possum (*Trichosurus cunninghami*), eastern pygmy-possum, Krefft's glider and koala. Three species of introduced mammals were detected: rusa deer, red fox and black rat (*Rattus rattus*).

Twenty-two species of ground-dwelling and arboreal native mammal species have been recorded in RHG in the last 5 years (30 June 2018 to 30 June 2023), based on records from the current survey, incidental sightings and database records (BioNet and ALA). Ground-dwelling mammal species not captured by the 2022 monitoring were yellow-footed antechinus (*Antechinus flavipes*), eastern grey kangaroo (*Macropus giganteus*), common wallaroo (*Osphranter robustus*), New Holland mouse and bare-nosed wombat (*Vombatus ursinus*). Note that these species are rare and restricted in distribution in RHG and the large kangaroos may have been introductions. Three arboreal mammals not captured by the surveillance monitoring were: southern greater glider (2021 BioNet record SMRF21071400, image taken), feathertail glider (*Acrobates pygmaeus*), and common brushtail possum (*Trichosurus vulpecula*).

Ten platypuses were reintroduced into RHG in May 2023 and at least 9 have survived in the first 12 months since introduction. Historic records (BioNet and ALA) indicate that 3 other terrestrial mammal species have previously been recorded in RHG: the spotted-tailed quoll (last recorded in 2007), the rakali (water rat) (last recorded in 1964) and dingo (*Canis lupus dingo*). The veracity of any records of dingo in RHG is uncertain due to high levels of hybridisation (Cairns et al. 2020).

Summary statistics of the surveillance fauna data have been calculated for species richness, naïve occupancy (i.e. proportion of sites where a species was detected) and activity. Activity has been defined as the number of unique camera detections separated by a 30-minute interval for all camera days recorded standardised to 100 days. The 30-minute detection interval was chosen to over-accommodate the findings of previous studies demonstrating that, for at least 30 species commonly detected on cameras, intervals between 1 and 10 minutes are temporally independent (D. Mills pers. comm. for NPWS Wildcount data; Kays and Parsons 2014).

Species richness

The mean number of mammal species observed at surveillance monitoring sites was 5, with a range of 2 to 8 species per site. More mammal species were detected in dry sclerophyll forest than any other vegetation formation (Figure 4).

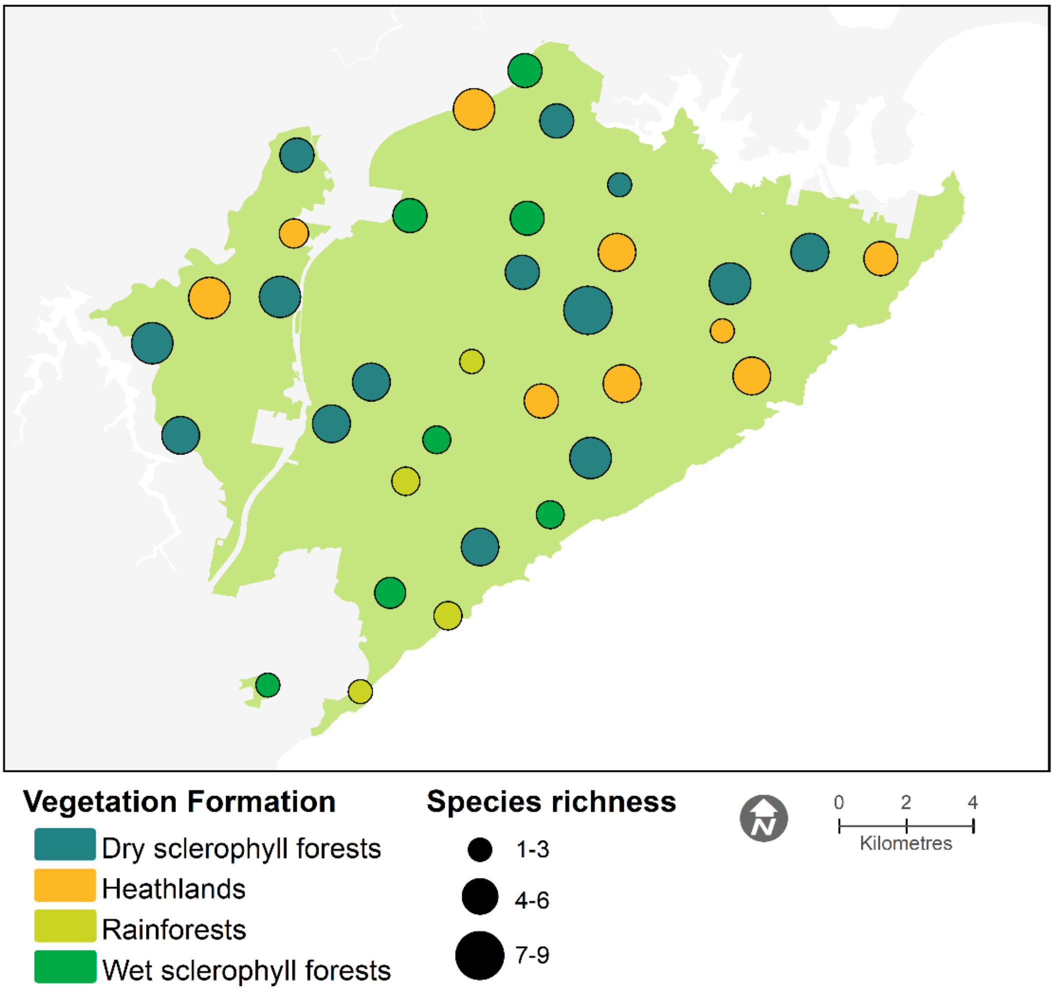


Figure 4 Native mammal species richness detected for each vegetation formation in Royal–Heathcote–Garawarra in 2022

Circles indicate a monitored site coloured by the vegetation type. Size of the circle is proportional to the number of species detected at the site (i.e. species richness, larger circles indicate more species).

An analysis was undertaken to assess difference in mammal species richness between vegetation types (Figure 5). Rarefaction and extrapolation curves were calculated using the *R* package iNEXT (Chao et al. 2014). Rarefaction is a technique to estimate species richness adjusting for differences in sampling effort, in this case the number of mammal species detected at each site within different vegetation formations. The extrapolation component of the curve is the predicted richness if more sites were sampled. Confidence intervals are also reported for each of the vegetation formations.

The sampled and predicted mammal species richness was highest in dry sclerophyll forest and lower, but similar, in the other vegetation formations (Figure 5). The dry sclerophyll forest extrapolation curve suggests more surveys are needed to adequately represent species richness.

Species occupancy and activity

Four ground-dwelling native mammal species occurred at more than 60% of all survey sites (naïve occupancy) in RHG: swamp wallaby (97%), antechinus species (82%), long-nosed bandicoot (62%), eastern pygmy-possum (62%). These 4 species had the highest levels of activity of all native species detected on camera traps (Table 3 and Figures 6 and 7). Bush rats were detected at 56% of sites, but likely occurred at more sites as rats that could only be identified to genus level (*Rattus*) were detected at 88% of sites and could have either been native or introduced species. Short-beaked echidna was detected at 35% of sites. The least commonly occurring ground-dwelling species was the common dunnart, which was recorded only once in the 2022 surveys.

Mammal species were detected at varying rates across the vegetation formations. Collectively, antechinus species were detected more frequently in rainforest and wet sclerophyll forests. Eastern pygmy-possums were detected more frequently in dry sclerophyll forest and heathlands. Long-nosed bandicoots were detected more often in heathland and wet sclerophyll forests. Swamp wallabies were detected commonly in dry sclerophyll forests, heathlands and wet sclerophyll forests and less often in rainforest. Echidnas were detected evenly across all vegetation formations.

Multi-method occupancy modelling using the *R* package RPresence (Mackenzie and Hines 2023) was used to assess species detection probability for 4 commonly detected species (3 mammal and one bird species) for each of the 4 different camera set-ups deployed at each site:

1. infra-red camera 2 m from bait (IR200)
2. unbaited infra-red camera with focus at 4 m (IR400)
3. white-flash camera 1.5 m from bait (WL150)
4. white-flash cameras 2.5 m from bait (WL250) (Mills and Stokeld 2023).

Multi-method occupancy estimates the probability of detection (capture by camera and positive identification) given that a species is present at a site, and accounts for spatial dependency between observations at different cameras within the same sample period (in this case 24 hours).

The mean detection rates of eastern pygmy-possum and eastern yellow robin (*Eopsaltria australis*) suggest that these small species are better detected by white-flash baited cameras traps, however there was considerable variation in the data recorded (Figure 8). Brushtail possum and deer had a much higher detection probability by the unbaited IR400 camera. The IR200 camera was the only camera set-up that did not have the best detection for any species, however it was better than the IR400 for eastern pygmy-possum and better than WL250 for brushtail possum, and very similar to WL150 and WL250 for deer.

Table 3 Occupancy (naïve) and activity (a relative abundance index of number of unique camera detection per site per 100 days) across the park-wide surveillance sites for Royal–Heathcote–Garawarra

Species or guild	Occupancy (naïve)	Activity (mean ± SE unique detections per 100 camera days)
Antechinus species*	82%	8.4 ± 2.1
Eastern pygmy-possum	62%	2.4 ± 0.7
Long-nosed bandicoot	62%	2.4 ± 0.76
Short-beaked echidna	35%	0.5 ± 0.2
Swamp wallaby	97%	13.6 ± 1.9
Small-ground dwelling-mammal guild	94%	12.8 ± 2.5

*Antechinus species were pooled as many animals could not be identified to species level in the camera images.

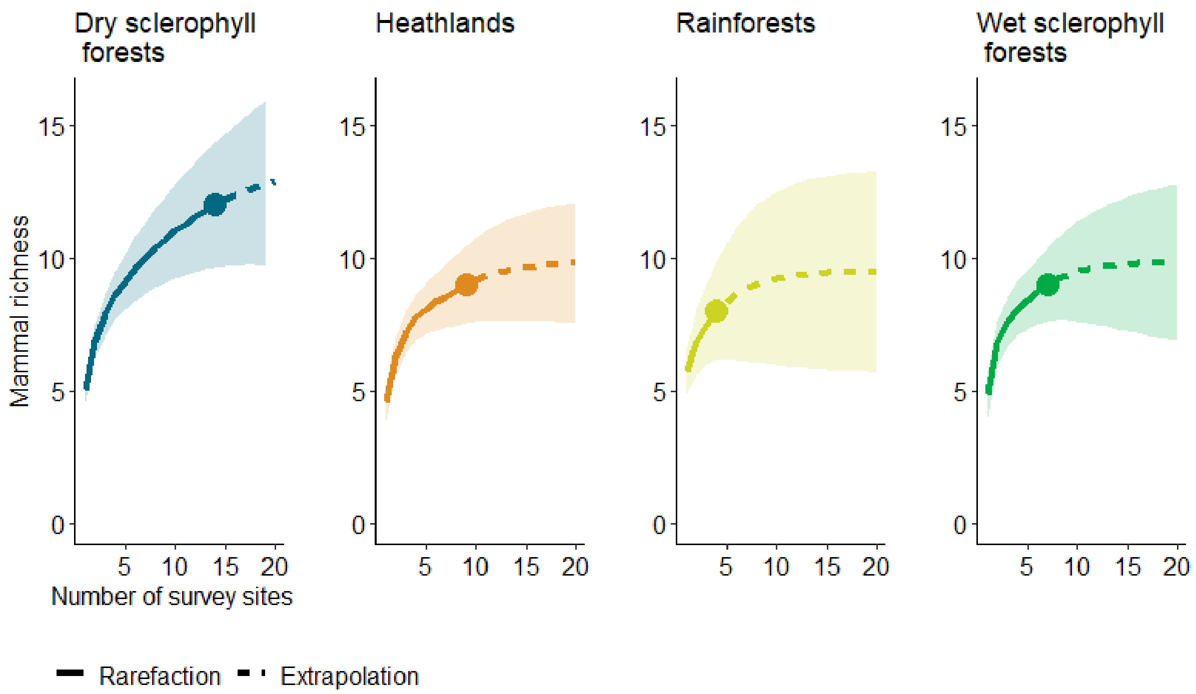


Figure 5 Native mammal species richness detected in the vegetation formations in Royal–Heathcote–Garawarra

Solid lines indicate diversity estimates for surveys completed (rarefaction). Dotted lines indicate projected diversity estimates (extrapolation) with additional surveys. Shaded areas represent variance with a 95% confidence interval.

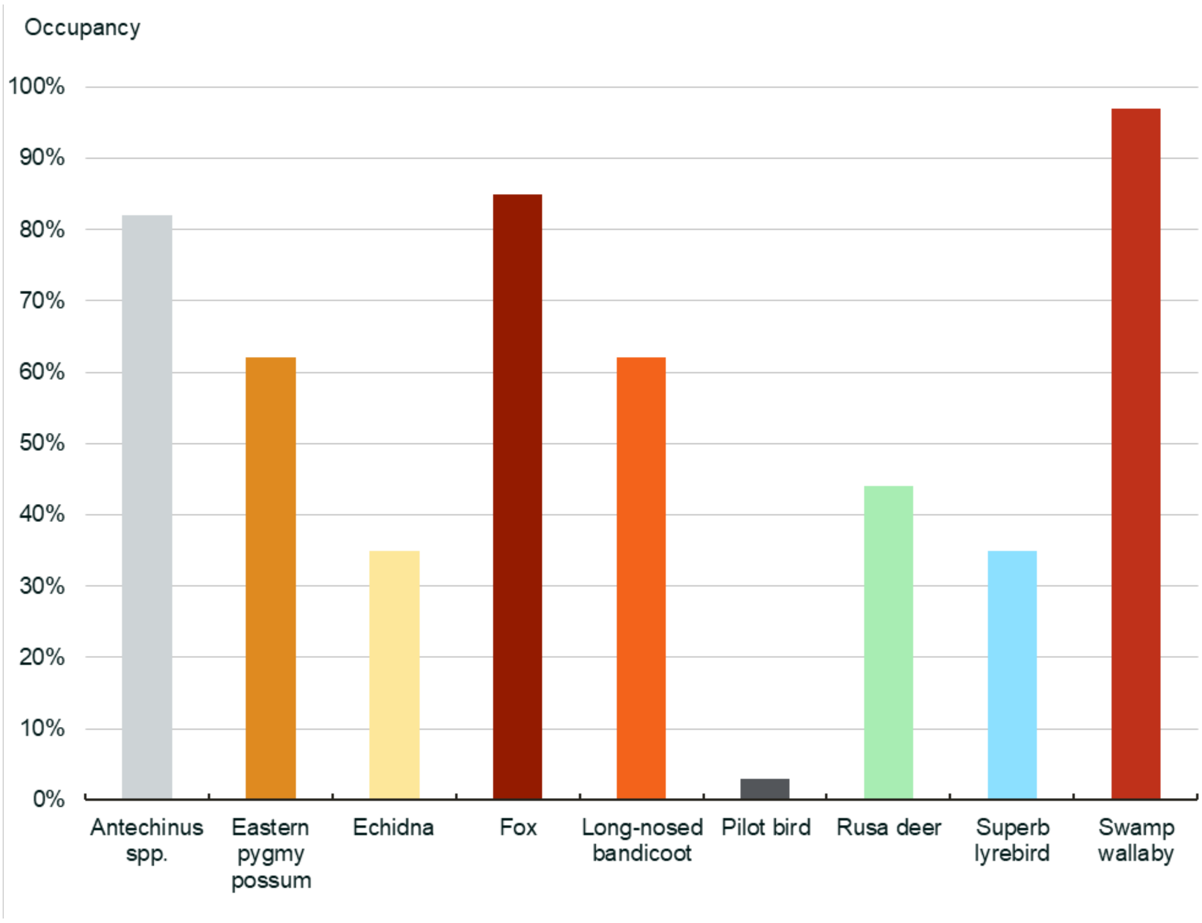


Figure 6 Naïve occupancy of select species at park-wide surveillance sites in Royal–Heathcote–Garawarra between May and June 2022

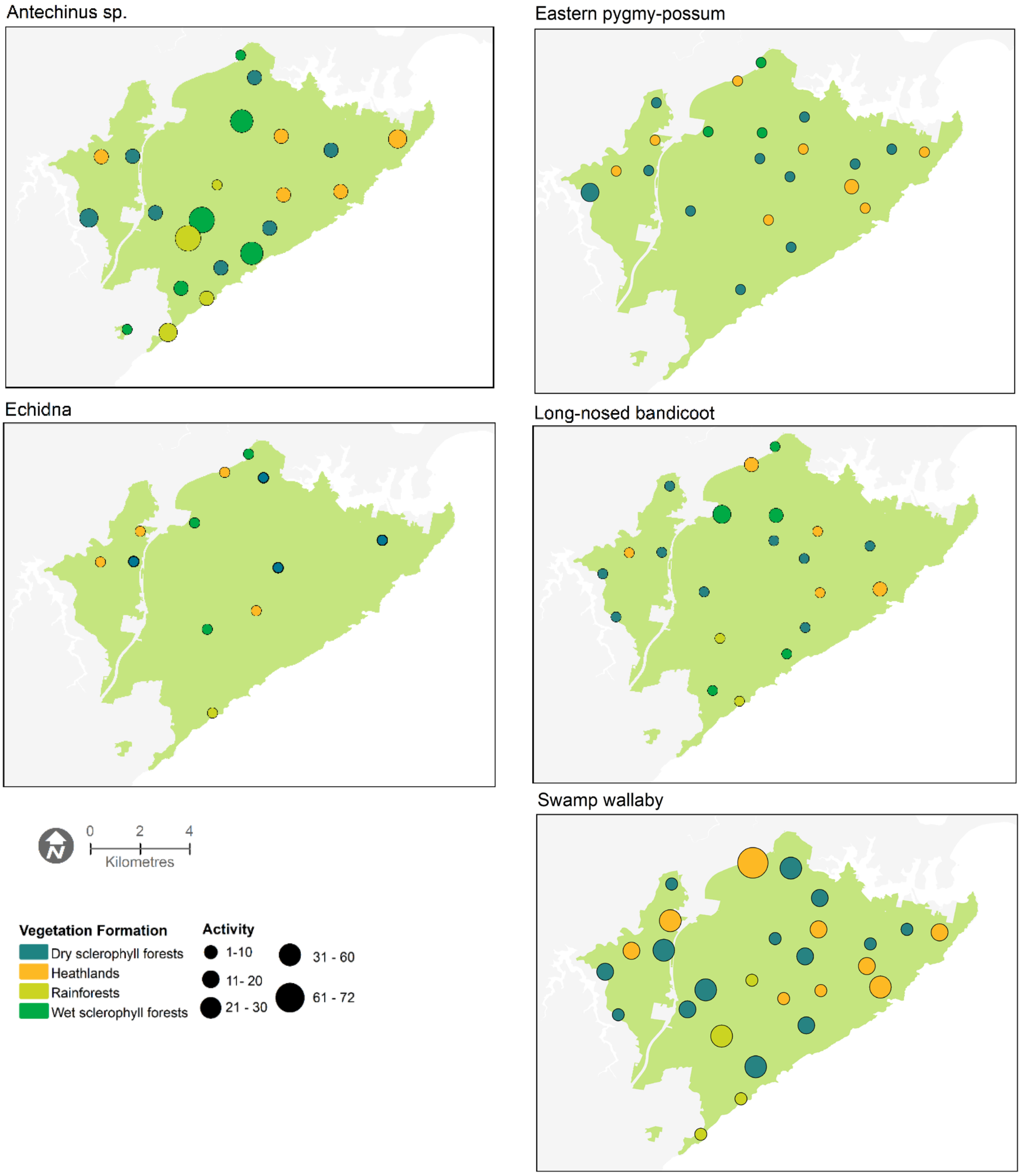


Figure 7 **Naïve occupancy and proportional activity of antechinus species, short-beaked echidna, long-nosed bandicoot, eastern pygmy-possum and swamp wallaby at park-wide surveillance sites in Royal–Heathcote–Garawarra in 2022**

Activity refers to the relative abundance index of unique number of detections per site per 100 camera days. Data from 2022 camera surveys.

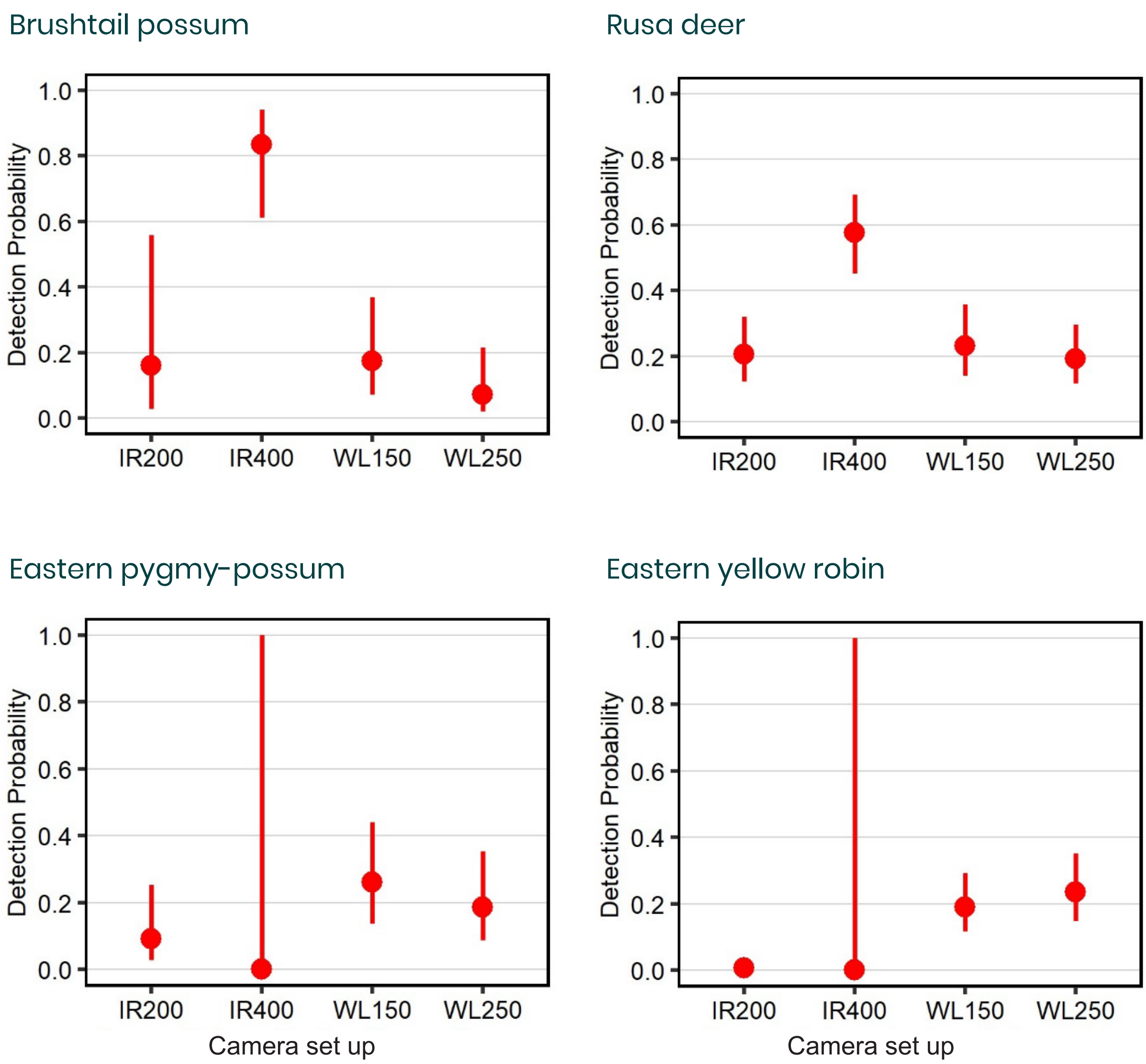


Figure 8 **A comparison of detection probabilities for 4 different camera trap set-ups for 4 species: brushtail possum, eastern pygmy-possum, eastern yellow robin and rusa deer in Royal–Heathcote–Garawarra in 2022**

IR200 = infra-red with bait at 200 cm, IR400 = infra-red no bait focus at 400 cm, WL150 = white flash with bait at 150 cm, WL250= white flash with bait at 250 cm. Red circles represent the mean and the red line 95% confidence intervals.

Discussion

The distribution and activity of ground-dwelling mammals captured on camera traps at the RHG park-wide surveillance survey sites across the major vegetation formations was consistent with the preferred known habitats of each species (Menkhorst and Knight 2010; Woinarski et al. 2014). Many arboreal mammal species were also recorded on the camera traps, however targeted surveys are needed to adequately record the presence and activity of this mammal guild. The exception to this trend was the detection of eastern pygmy-possum activity captured by ground-based camera traps. Widespread detection of eastern pygmy-possum confirms that RHG provides important habitat for the species (Goldingay 2012). Five of the most commonly occurring mammal species detected at park-wide survey sites — swamp wallaby, antechinus species, long-nosed bandicoot, eastern pygmy-possum, and echidna — have been targeted to monitor long-term occupancy trends over the entire park aggregate.

Of note from the park-wide surveillance monitoring are the 2 records of dusky antechinus which is only the third time the species has been recorded from RHG; previous records were in 2014 and 1974. Krefft's gliders were recorded for the first time in RHG. This species of *Petaurus* has only been recognised since the taxonomic split of the sugar glider (*Petaurus breviceps*) in 2021 (Cremona et al. 2021). All previous records of *Petaurus* species from RHG pre-date the taxonomic split and further investigation is needed to determine whether there is more than a single species of *Petaurus* in RHG.

The 3 terrestrial mammal species that have not been recorded at RHG in the last 5 years — dingo, spotted-tail quoll and rakali — are extant elsewhere in New South Wales and either may still be present in RHG, or may be able to recolonise the area in future years. Both spotted-tail quoll and rakali have been recently recorded on the Woronora Plateau, which is a connected forested landscape of which RHG is at the northern end. Rakali was recorded in 2017 near Dharawal National Park, and spotted-tail quoll was recorded in 2017 near Menangle and in 2022 in Upper Nepean State Conservation Area. While dingoes are present throughout eastern New South Wales, and may well occur in RHG, hybridisation of dingos and domestic dogs (*Canis lupus familiaris*) is extensive (Cairns et al. 2020), making the validity of any record questionable.

Future surveys will be modified to improve the likelihood of detecting mammal species with the addition of 6 extra sites. In addition, data analysis of the different camera set-ups suggests future surveys should consider replacing the IR200 camera set-up with an alternate set-up to increase the number of species detected. Targeted surveys using different methods for arboreal mammals will be included in the park-wide surveillance monitoring in future years. Southern greater gliders are part of the targeted monitoring program and would generally not be detected on ground-based cameras.

The diversity of small and medium-sized mammals detected in RHG suggests that ecosystem services that mammal guilds perform are widespread and contributing to the health of RHG. For example, bandicoots play a role in organic matter cycling, soil aggregate formation and stability, microbial and seed distribution; and eastern pygmy-possums assist with pollination (Martin 2003). The mammal diversity detected across RHG reinforces the need for fire management to conduct hazard reduction burns of varying intensities to provide refugia and a variety of habitats.

Bats

Conservation context

As with other mammal groups, bat assemblages are impacted by habitat fragmentation and urbanisation, affecting species diversity, abundance and foraging activity (Hopkins 2015). Most Australian microbat species are insectivorous; one species, southern myotis (*Myotis macropus*), feeds on aquatic vertebrates and invertebrates. The absence of microbats from forests has been linked to measurable increases in defoliation, suggesting microbats influence the health, structure and composition of forests (Bielke and O'Keefe 2023).

Prior to park-wide surveys, 18 species of microbat were known in RHG, representing 51% of all described microbat species currently known to occur in New South Wales (35 species) (Pennay et al. 2004; BioNet 21/11/2023). This includes 7 species listed as threatened under the Biodiversity Conservation Act; 41% of all microbat species listed as threatened in New South Wales (17 species). There have been limited surveys carried out for microbats in RHG. Park-wide surveillance monitoring of bat fauna has been designed to detect changes in species richness, and the occurrence of indicator species which will contribute to a broader understanding of the status of microbats in RHG.

Three species of microbat were chosen as target species for monitoring: eastern horseshoe bat (*Rhinolophus megaphyllus*), large-eared pied bat (*Chalinolobus dwyeri*) and southern myotis. The eastern horseshoe bat is a regionally significant species for the Sydney Basin bioregion as RHG supports one of the few known maternity sites in the bioregion (Schulz and Magarey 2012). The eastern horseshoe bat is an obligate cave-dwelling species, with a preference for roosts with high humidity levels (Van Dyk and Strahan 2008) and is likely to be impacted by climate change. The large-eared pied bat is listed as vulnerable in New South Wales under the Biodiversity Conservation Act. The Sydney Basin bioregion is listed as providing essential habitat for this species, which shows a preference for roosting in caves and overhangs on sandstone outcrops near high-fertility forests or woodland near watercourses (Williams and Thomson 2018). The rainforest and wet sclerophyll forest of RHG are important to the conservation of this species (Schulz and Magarey 2012). The southern myotis is a stream-dependent microbat which is potentially an important indicator of water quality and changes in the flow of streams and watercourses (Schulz and Magarey 2012).

The grey-headed flying fox (*Pteropus poliocephalus*), a megabat listed as vulnerable under the Biodiversity Conservation Act and Environment Protection and Biodiversity Conservation Act, is a common seasonal visitor to the RHG survey area. It is not currently monitored as part of the Scorecards program, as there are no known camps in RHG. Individuals are likely to access the RHG area when key feeding plants are flowering and fruiting (DECCW 2011) from nearby roosting camps, which occur in the Kurnell Peninsula and Kareela areas.

Methods and results

Microbats were surveyed in RHG using Song Meter Mini Bat ultrasonic sound recorders deployed from March to June 2023 at 34 of a proposed 40 park-wide surveillance monitoring sites. Operator error resulted in a high rate of battery failure in ultrasonic devices. The average number of deployment nights was 9 (range: 1–37 deployment nights) at 34 sites and 6 sites had complete device failure. Processing of sound files was undertaken using Anabat Insight (Titley Scientific, version 2.0.7-0-g3e26022).

In 2023, 15 species of microbat were confidently detected on the ultrasonic sound recordings, along with calls from a *Nyctophilus* species which could not be resolved at the species level (Table 4). The yellow-bellied sheath-tailed bat was detected for the first time in RHG. There was also a probable single detection of golden-tipped bat (*Phoniscus papuensis*), which due to uncertainly has not been included in the tally of microbat species recorded in RHG. The average number of microbat species recorded across monitoring sites was 8 (range: 1–12 species), with the highest mean species richness recorded in wet sclerophyll forests (Figure 9).

Naïve occupancy was calculated for each microbat species (Table 4). The eastern horseshoe bat was detected at the greatest number of sites (94% of sites), followed by Gould's wattled bat (*Chalinolobus gouldii*) and eastern free-tailed bat (*Ozimops ridei*), both detected at 91% of sites. The large-eared pied bat was found at just over half of the park-wide surveillance monitoring survey sites with a naïve occupancy of 56%.

The target species, eastern horseshoe bat, had an activity index of 3.1 ± 0.5 detections per site per night (Table 5). Activity was calculated as the number of unique detections (passes separated by at least 30 minutes) per site per night. The highest mean activity for this species was in rainforests. The large-eared pied bat, also a target species, had an activity index of 1.0 ± 0.3 with the greatest mean activity detected in wet sclerophyll forests. Large-eared pied bats were not detected in rainforests.

Nineteen microbat species have been recorded in RHG over the last 5 years (30 June 2018 to 30 June 2023), based on records from the current survey, incidental sightings and database records (BioNet and ALA, see Appendix I). This includes the yellow-bellied sheath-tailed bat but does not include the probable detection of golden-tipped bat. Species recorded in BioNet in the past 5 years in RHG, which were not recorded in the current survey, are eastern broad-nosed bat (*Scotorepens orion*) and eastern coastal free-tailed bat (*Micronomus norfolkensis*). Two species of long-eared bat, *Nyctophilus* species, have previously been recorded in RHG, Gould's long-eared bat (*Nyctophilus gouldi*) and the lesser long-eared bat (*Nyctophilus geoffroyi*). The audio calls recorded for the Scorecards program could not differentiate between long-eared bat species, and as such *Nyctophilus* species have been only counted as a single species in the 2023 survey.

Table 4 Naïve occupancy of microbat species detected on ultrasonic devices deployed at park-wide surveillance sites in Royal–Heathcote–Garawarra in 2023

Scientific name	Common name	Naive occupancy (% of sites)
Austronomus australis	White-striped free-tailed bat	76%
*Chalinolobus dwyeri**	Large-eared pied bat	56%
Chalinolobus gouldii	Gould's wattled bat	91%
Chalinolobus morio	Chocolate wattled bat	56%
*Falsistrellus tasmaniensis**	Eastern false pipistrelle	44%
*Miniopterus australis**	Little bent-wing	21%
*Miniopterus orianae oceanensis**	Large bent-wing	6%
*Myotis macropus**	Southern myotis	n/a
Nyctophilus species	Long-eared bat species	n/a
Ozimops planiceps	Southern free-tailed bat	21%
Ozimops ridei	Eastern free-tailed bat	91%
Rhinolophus megaphyllus	Eastern horseshoe bat	94%
*Saccolaimus flaviventris**	Yellow-bellied sheath-tailed bat	26%
*Scoteanax rueppellii**	Greater broad-nosed bat	29%
Vespadelus darlingtoni	Large forest bat	68%
Vespadelus vulturnus	Little forest bat	29%

*indicates species listed as vulnerable under the Biodiversity Conservation Act.

Table 5 Naïve occupancy and activity of 2 microbat target species at park-wide surveillance monitoring sites in Royal–Heathcote–Garawarra in 2023

Species	Naïve occupancy (% of sites)	Activity (± SE)
Eastern horseshoe bat	94%	3.1 ± 0.5
Large-eared pied bat	56%	1.0 ± 0.3

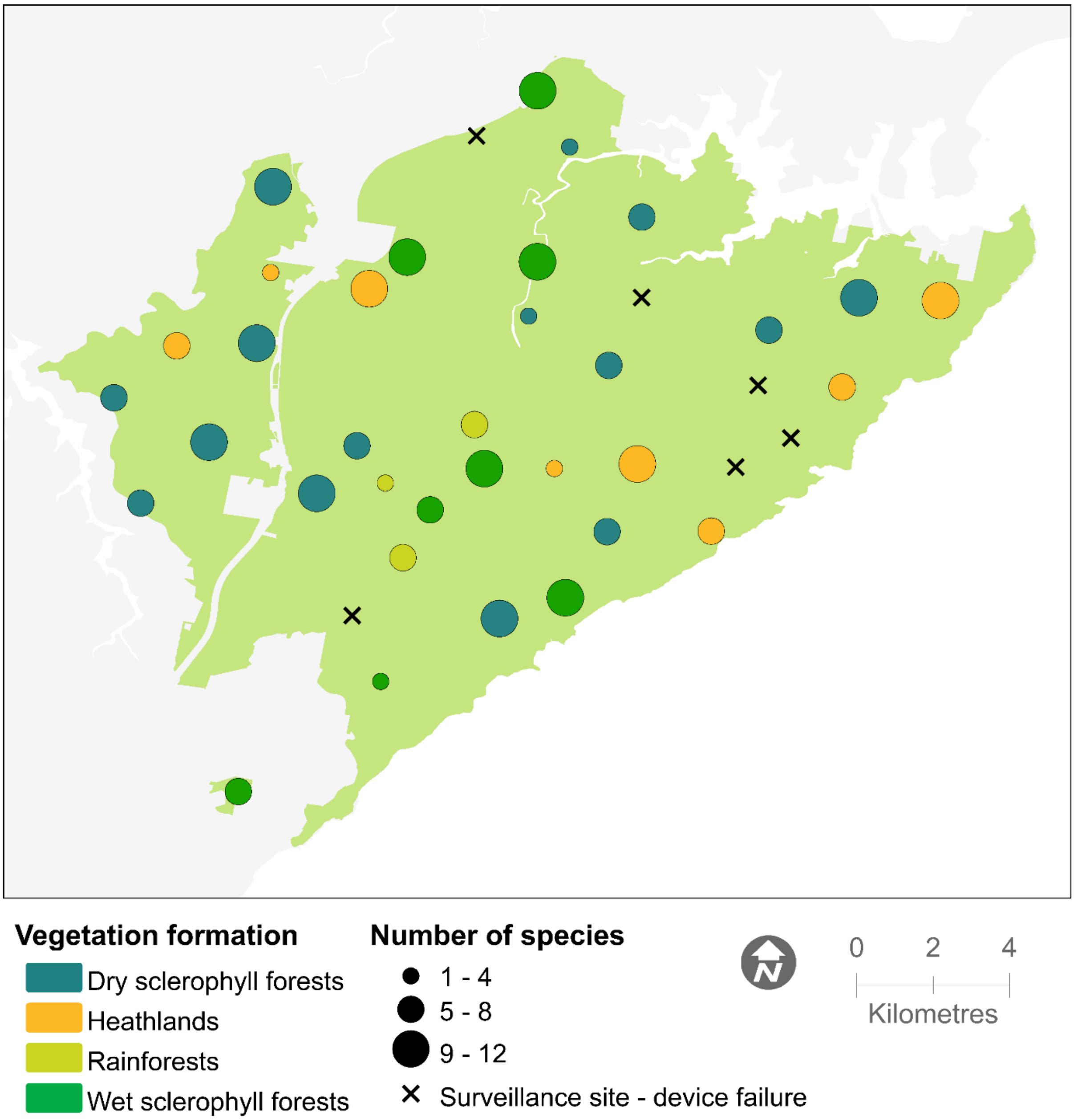


Figure 9 **Number of microbat species recorded at park-wide surveillance monitoring sites in Royal–Heathcote–Garawarra in 2023**

Circles indicate a park-wide monitoring site, coloured by vegetation formation. Larger circles indicate a higher number of species recorded at a site. Number of species recorded by site ranged from 1 to 12 species.

Discussion

The park-wide surveillance monitoring in 2023 recorded the presence of 15 species of microbat in RHG plus at least one *Nyctophilus* species. This included the detection of yellow-bellied sheath-tailed bat, which has not previously been recorded in RHG. The detection of this species in the survey area is significant as it listed as vulnerable under the Biodiversity Conservation Act and the status of this species in the Sydney Basin bioregion is poorly understood. Six other species recorded in the surveys are listed as vulnerable under the Biodiversity Conservation Act: eastern false pipistrelle (*Falsistrellus tasmaniensis*), greater broad-nosed bat (*Scoteanax rueppellii*), large bent-wing bat (*Miniopterus orianae oceanensis),* large-eared pied bat, little bent-wing bat (*Miniopterus australis*) and southern myotis. The large-eared pied bat is also listed as vulnerable under the Environment Protection and Biodiversity Conservation Act.

The 2023 surveys also recorded a probable detection of golden-tipped bat, a species infrequently detected on ultrasonic sound recorders (Reinhold et al. 2001). The golden-tipped bat calls were verified as probable by several experts, however due to the difficulty in identifying their calls, could not be given a definitive identification. Prior to 2023, golden-tipped bats have not been recorded in RHG, with the closest record from an unconfirmed Anabat recording at Helensburgh on the boundary of RHG. Golden-tipped bats occur in rainforests and adjacent wet sclerophyll forests and primarily roost in the suspended nests of yellow-throated scrubwren (*Sericornis citreogularis*). Suitable habitat potentially occurs in the RHG survey area (DECCW 2011). Harp trapping along the Hacking River and tributaries could confirm the definite presence of golden-tipped bats in RHG.

The park-wide surveys have increased the total number of microbats recorded in RHG from 18 to 19. The previous systematic survey of RHG in 2011 (DECCW 2011) recorded 14 species of microbat using ultrasonic devices and harp trapping for low-flying species. Four microbat species — the lesser long-eared bat, Gould's long-eared bat, eastern broad-nosed bat and eastern coastal free-tailed bat — have been previously recorded in RHG, but not detected in 2023. They are likely still present as long-eared bats and the eastern broad-nosed bat cannot be confidently detected on ultrasonic sound recorders as their calls are difficult to distinguish from other species (Pennay et al. 2004). As indicated above, long-eared bat species (*Nyctophilus* species) calls were detected in the 2023 surveys but could not be assigned to species level classification as they are difficult to distinguish from each other (Pennay et al. 2004). Harp trapping in targeted habitat could confirm the current presence of these 4 species in RHG.

Southern myotis have been identified as a target indicator species for RHG, due to their dependence on streams and as a potential indicator of water quality and changes in water flow, however further processing of the data is needed to yield occupancy and activity metrics. Alternatively, as southern myotis roost and forage along waterways (Campbell 2009), harp trapping and targeted acoustic monitoring along the Hacking River and tributaries could provide a more robust measure of activity for this species.

Most microbat species are highly mobile with even the smallest, as well as slow-flying microbats, capable of foraging over 5 km from roost sites. As such, measures of site occupancy will typically be much greater than for terrestrial and arboreal mammals and are unlikely to be a reliable monitoring metric, especially where the distance between sites is less than 5–10 km. Many species are capable of regular forays 10–30 km from roost sites. This means that one of the assumptions of occupancy modelling, independence of observations, is violated. Future analyses will investigate use of activity indices for monitoring long-term trends of this suite of mammals.

Birds

Conservation context

Birds are an integral component of ecosystem function, providing many direct and indirect services including pollination, seed dispersal and as ecosystem engineers. Birds are impacted by environmental disturbance such as altered fire regimes, habitat fragmentation due to urbanisation, habitat degradation particularly by feral herbivores, and predation by feral predators (Garnett 2021).

Superb lyrebird (*Menura movaehollandiae*) and pilotbird (*Pycnoptilus floccosus*) are species sensitive to environmental change. Both species rely on forests with dense leaf litter, so they can forage for insects, which makes them potential indicators of ecosystem recovery post-fire (Garnett 2021; Nugent et al. 2014; Woinarski and Recher 1997). Lyrebird activity is greatly reduced in recently burnt forests, especially those burnt in high-severity fires (Hughes et al. 2023; Maisey et al. 2023; Woinarski and Recher 1997). Lyrebirds are more likely to nest in rainforests, a vegetation type that is likely to be increasingly impacted by climate change–induced fire events of large scale, such as the 2019–20 fires, which burnt 43% of the entire lyrebird range nationally (Hughes et al. 2023). Rainforests also serve as local refuges for species from fire to then recolonise burnt areas at a later stage. Pilotbirds appear sensitive to climate change, becoming rare at lower altitudes (Cth DAWE 2022). Modelling indicates that fire-related mortality just one year following the widespread 2019–20 fires has reduced the pilotbird population across its entire range by 26 to 30%, contributing to the recent listing as vulnerable under the Environment Protection and Biodiversity Conservation Act (Cth DAWE 2022; Legge et al. 2022).

The large forest owls of New South Wales — powerful owl (*Ninox strenua*), masked owl (*Tyto novaehollandiae*) and sooty owl (*Tyto tenebricosa*) — are each listed as vulnerable under the Biodiversity Conservation Act. These 3 species are uncommon residents throughout the Sydney Basin bioregion, including RHG (Schulz and Magarey 2012). As high-order predators, their occurrence throughout RHG provides a good indicator of ecosystem health, as they require a diverse range of prey species as well as mature hollow-bearing trees for nesting (Milledge 2004).

Woodland birds, especially honeyeaters (Meliphagidae), Australian warblers (Acanthizidae) and fairy-wrens (Maluridae) are ubiquitous across varied habitats in RHG and easily identified by sight and sound. As birds are responsive to environmental changes, these 3 families may be useful indicators of changing ecological conditions, including ecological changes due to climate change, across different plant communities in RHG (Bain et al. 2020; Ford et al. 2001).

The total number of native birds recorded since database records began in RHG is 335 species (BioNet, ALA and eBird databases) (Appendix 2). This includes 62 species listed as threatened under the Biodiversity Conservation Act and an additional 6 species listed as threatened under the Environment Protection and Biodiversity Conservation Act. Park-wide surveillance monitoring of bird fauna is designed to detect changes in species richness and occurrence across identified terrestrial bird groups and indicator species.

Methods and results

Native birds in RHG were monitored using multiple methods. Diurnal survey at 2-ha plots is a standard approach to monitoring diurnal bird species. Two surveys, one morning and one evening, were conducted at 23 of the 40 surveillance sites in November 2022, during the spring breeding season for resident birds. Two sites had morning surveys only. Song Meter Mini sound recorders were used to target the nocturnal bird guild. These were deployed in March to June 2022, to capture owl breeding, including powerful owl, sooty owl and masked owl. Camera traps as part of the park-wide surveillance monitoring surveys were used to target superb lyrebird. Detections of all bird species from park-wide monitoring methods and incidental observations have been collated and contribute to total number of species recorded for RHG.

In 2022, 80 species of native birds were recorded across all survey methods (bird surveys, camera surveys and incidental observations) at park-wide surveillance monitoring sites. This included 2 species listed as threatened under the Biodiversity Conservation Act — square-tailed kite (*Lophoictinia isura*) and varied sitella (*Daphoenositta chrysoptera*) — and one species listed as vulnerable under the Environment Protection and Biodiversity Conservation Act, pilotbird.

A total of 827 individual bird records, comprising 50 diurnal bird species, were recorded at the 2-ha monitoring plots alone. The species with the highest naïve occupancy (Table 6) was eastern yellow robin, observed at 64% of sites, followed by grey fantail (*Rhipidura albiscapa*) and rufous whistler (*Pachycephala rufiventris*), both observed at 60% of sites. The species with the highest relative abundance was New Holland honeyeater (*Phylidonyris novaehollandiae*), followed by little wattlebird (*Anthochaera chrysoptera*) and rainbow lorikeet (*Trichoglossus moluccanus*).

Species richness

The mean number of diurnal bird species observed at sites was 11, with a range of 3 to 23 species (Figure 10). Rarefaction and extrapolation curves were calculated for bird species richness by vegetation formation using the *R* package iNEXT (Chao et al. 2014). The sampled and projected species richness was highest in dry sclerophyll forest and lowest in heathlands (Figure 11).

Eleven species of honeyeater were detected during diurnal bird surveys: brown-headed honeyeater (*Melithreptus brevirostris*), eastern spinebill (*Acanthorhynchus tenuirostris*), Lewin's honeyeater (*Meliphaga lewinii*), little wattlebird (*Anthochaera chrysoptera*), New Holland honeyeater, noisy friarbird (*Philemon corniculatus*), red wattlebird (*Anthochaera carunculata*), white-eared honeyeater (*Nesoptilotis leucotis*), white-naped honeyeater (*Melithreptus lunatus*), white-plumed honeyeater (*Ptilotula penicillata*), yellow-faced honeyeater (*Caligavis chrysops*). The highest number of honeyeater species was observed in dry sclerophyll forests.

Four species of Australian warbler were detected during diurnal bird surveys: brown gerygone (*Gerygone mouki*), brown thornbill (*Acanthiza pusilla*), striated thornbill (*Acanthiza lineata*) and white-browed scrubwren (*Sericornis frontalis*). The variegated fairy-wren (*Malurus lamberti*) was the only species of Australian fairy-wren detected during diurnal bird surveys.

Occupancy and activity

Superb lyrebirds were detected at 29% of park-wide surveillance sites from camera trap surveys in 2022 (Figure 6, Figure 12). Mean activity detected of superb lyrebirds on camera at park-wide survey sites was 1.23 ± 0.4 (unique detections per site per 100 days), with the highest mean activity in rainforests.

Pilotbirds were recorded at 3% of sites in the 2022 diurnal bird surveys (Figure 6). Further detections are likely to be obtained from audio recordings which are pending data analysis.

Three species of nocturnal birds were recorded from incidental observations: Australian owlet nightjar (*Aegotheles cristatus*), southern boobook (*Ninox boobook*) and tawny frogmouth (*Podargus strigoides*). Future analysis of acoustic data will provide occupancy estimates for the forest owls of RHG.

Table 6 Naïve occupancy and abundance of diurnal birds at Royal–Heathcote–Garawarra surveillance sites in 2022

Note: Observations inside the 2-ha plot only.

Species	Naïve occupancy (%)	Abundance (individuals per survey)
Eastern yellow robin	64	0.771
Grey fantail	60	0.854
Rufous whistler	60	0.917
Brown thornbill	56	0.667
Eastern spinebill	52	0.688
New Holland honeyeater	52	1.646
Spotted pardalote	52	0.896
White-browed scrubwren	52	0.708
Yellow-faced honeyeater	48	0.750
Eastern whipbird	44	0.708
White-throated treecreeper	40	0.583
Golden whistler	36	0.604
Little wattlebird	36	1.188
Variegated fairy-wren	32	0.688
Australian king-parrot	28	0.271
Lewin’s honeyeater	28	0.271
Pied currawong	28	0.229
Crimson rosella	24	0.500
Striated thornbill	24	0.438
Sulphur-crested cockatoo	24	0.292
Brown gerygone	20	0.750
White-eared honeyeater	20	0.188
Black-faced cuckoo-shrike	16	0.167
Grey shrike-thrush	16	0.146
Rainbow lorikeet	16	1.125
Shining bronze-cuckoo	12	0.063
Australian raven	8	0.063
Black-faced monarch	8	0.042
Channel-billed cuckoo	8	0.063
Cicada bird	8	0.042
Fan-tailed cuckoo	8	0.083
Grey butcherbird	8	0.063
Laughing kookaburra	8	0.042
Noisy friarbird	8	0.042

Species	Naïve occupancy (%)	Abundance (individuals per survey)
Olive-backed oriole	8	0.042
Square-tailed kite	8	0.042
Superb lyrebird	8	0.083
Beautiful firetail	4	0.042
Brown-headed honeyeater	4	0.021
Grey goshawk	4	0.021
Horsfield's bronze-cuckoo	4	0.021
Logrunner	4	0.042
Pilotbird**	4	0.021
Red wattlebird	4	0.104
Rufous fantail	4	0.021
Satin bowerbird	4	0.063
Silvereye	4	0.021
Varied sittella*	4	0.083
White-naped honeyeater	4	0.021
White-plumed honeyeater	4	0.042

*indicates species listed as vulnerable under the Biodiversity Conservation Act.

**indicates species listed as vulnerable under the Environment Protection and Biodiversity Conservation Act.

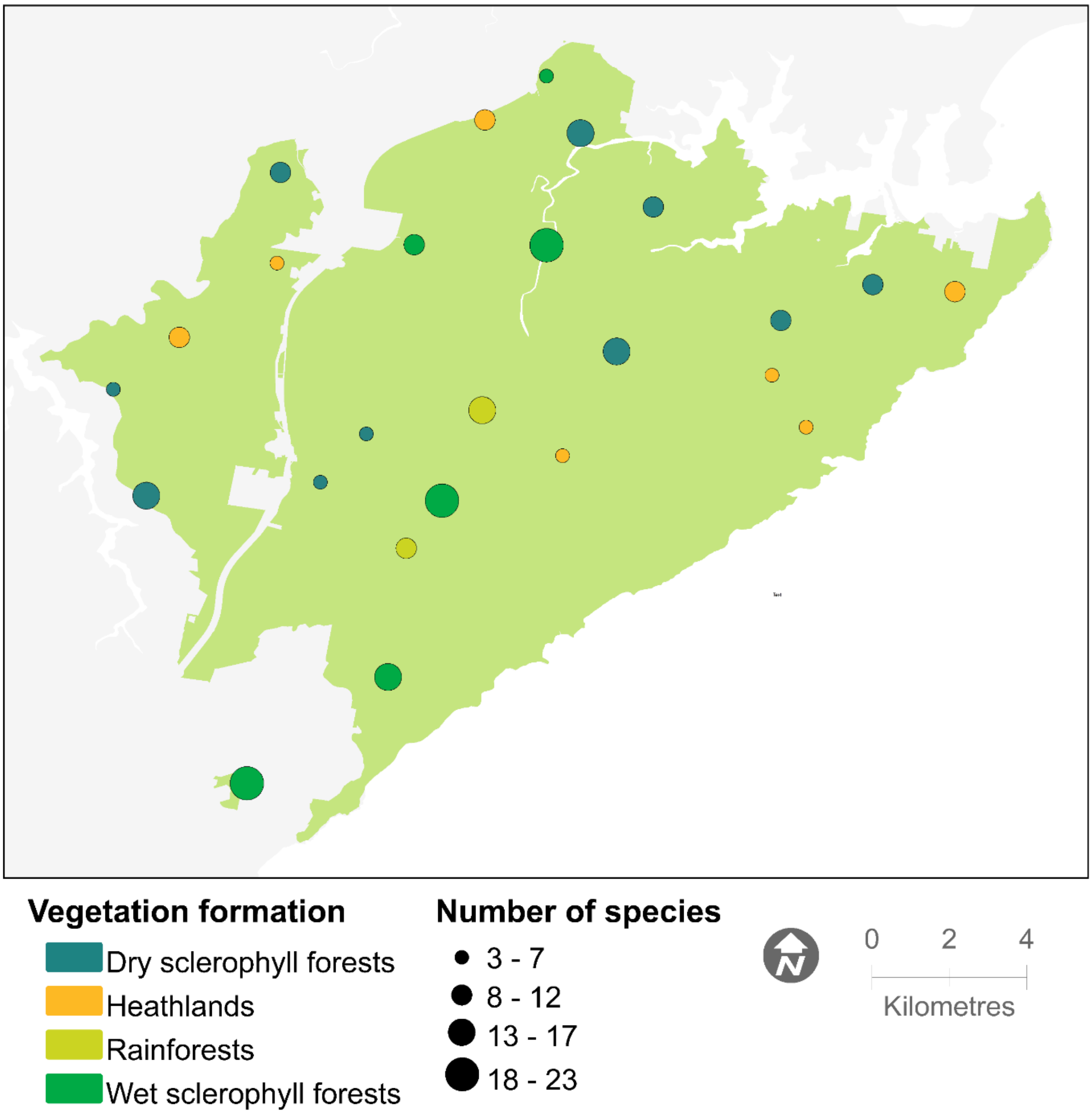


Figure 10 Number of native bird species recorded at park-wide surveillance monitoring sites in Royal–Heathcote–Garawarra in 2022

Circles indicate a park-wide monitoring site, coloured by vegetation formation. Larger circles indicate a higher number of species recorded at a site. Number of species recorded by site ranged from 3 to 23 species. Data from 2022 diurnal bird surveys, including only observations inside the 2-ha plot.

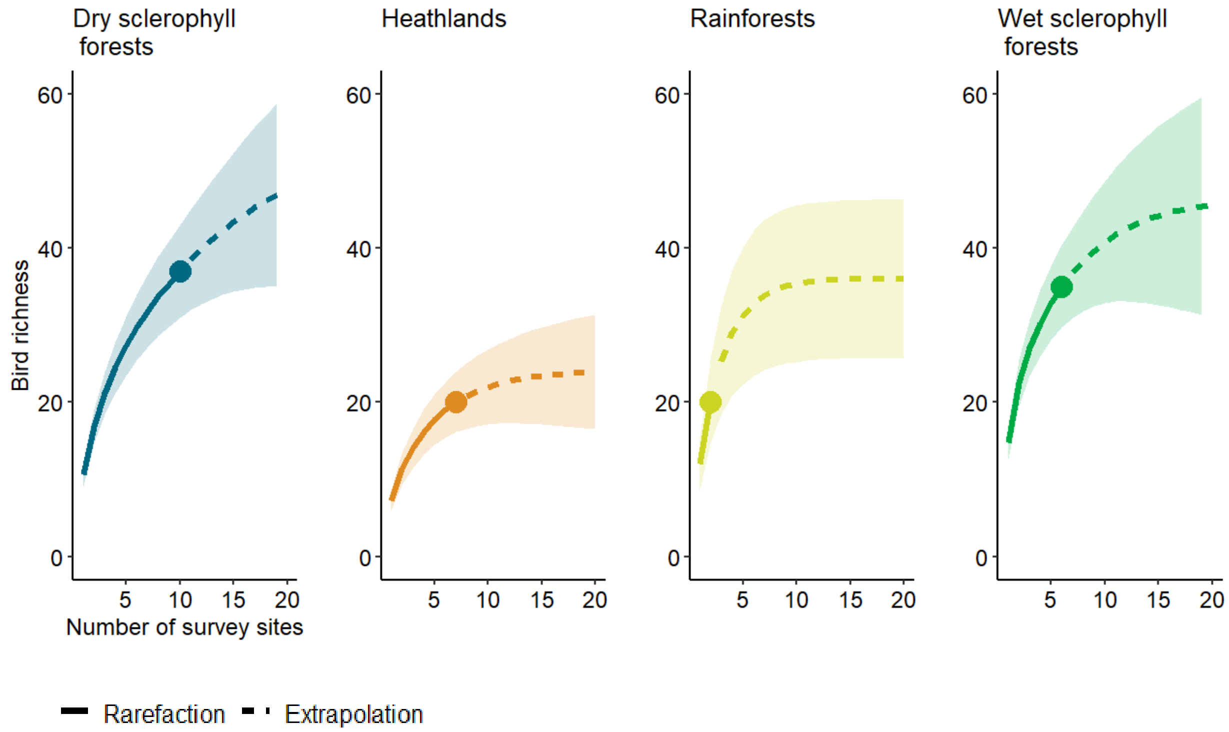


Figure 11 Diurnal bird species richness for each vegetation formation at park-wide surveillance monitoring sites in Royal–Heathcote–Garawarra in 2022

Solid lines indicate diversity estimates for surveys completed (rarefaction). Dotted lines indicate projected diversity estimates (extrapolation), with additional surveys. Shaded areas represent variance with a 95% confidence interval.

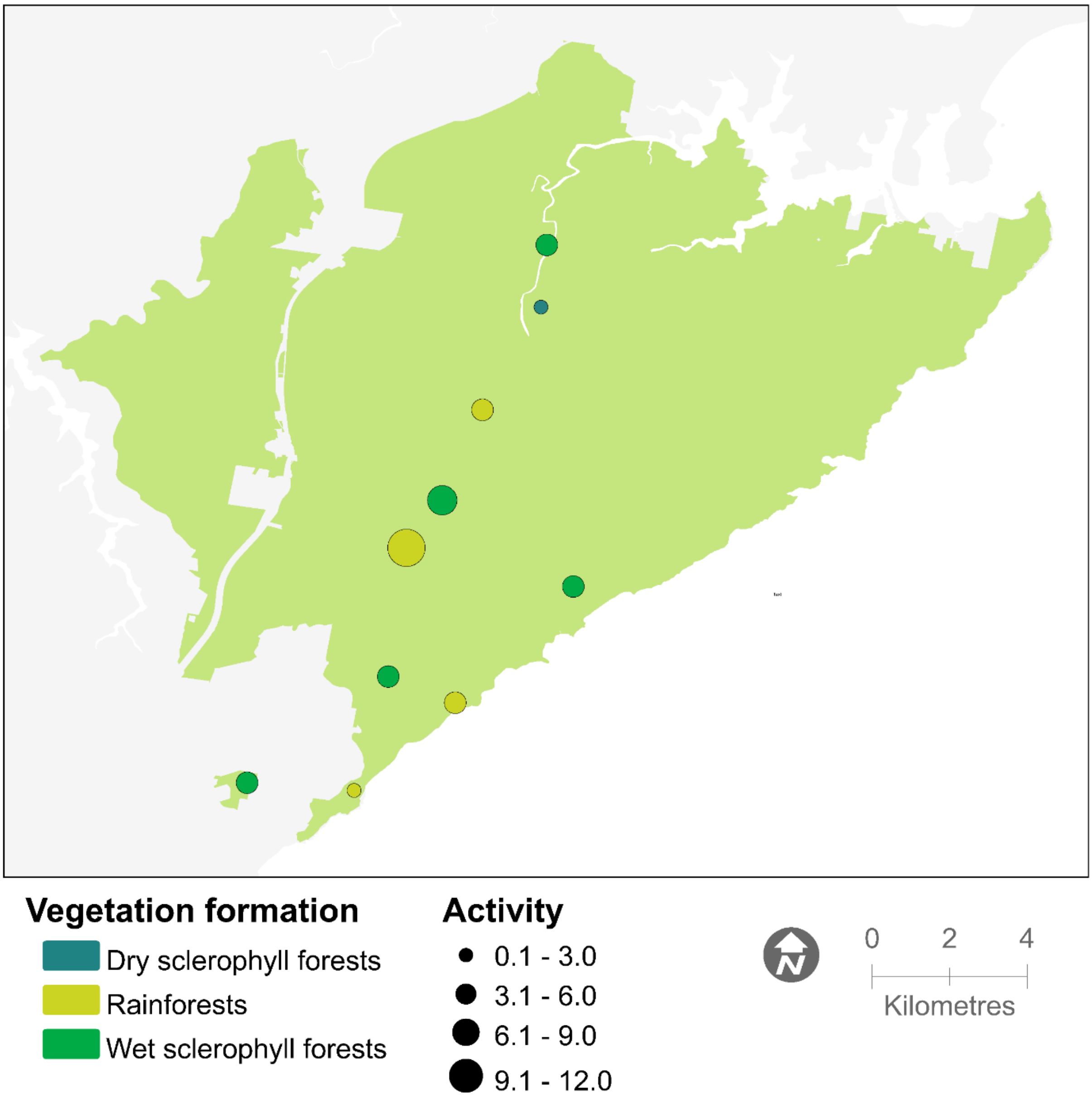


Figure 12 Superb lyrebird naïve occupancy and activity recorded at park-wide monitoring sites in Royal–Heathcote–Garawarra in 2022

Circles indicate a park-wide monitoring site where lyrebird were detected, coloured by vegetation formation. Larger circles indicate a higher value for lyrebird activity. Data from 2022 camera surveys.

Discussion

The diurnal bird surveys conducted in 2022 captured a snapshot of diurnal bird species richness across the major vegetation formations in RHG. The park-wide surveillance monitoring detected 80 bird species, with 41% of these woodland-dependent species (Birdlife Australia 2015). Bird species richness was highest for dry sclerophyll forests and lowest for heathlands. Structurally complex habitats (e.g. forests) support increased bird richness and abundance through the provision of resources and microhabitats, with greater niche space allowing a greater number of species to coexist (Tews et al. 2004; Tay 2019). Conversely, while heathland shrubs provide an excellent nectar resource, low habitat complexity results in reduced shelter and niche availability and therefore a reduced ability to support a high diversity of birds (King 2013; Tay 2019).

The total number of bird species recorded in RHG in the last 5 years (June 2018 to June 2023) is 234 species, based on records from the current survey, incidental sightings and database records from BioNet, ALA and eBird. The number of bird species recorded in RHG from all available records is 335 species, which provides an indication of the assemblage present at the time of European arrival (circa1750). There are 4 species once considered resident in RHG which have not been recorded at the site in the last 5 years: eastern bristlebird, eastern ground parrot, bush stone-curlew and regent bowerbird (Goldingay 2012).

The number of bird species recorded by the park-wide surveys in 2022 is lower than the 234 species recorded in the last 5 years and the 134 species recorded in 2011 systematic park-wide surveys (DCCEW 2011). There are several factors contributing to this:

1. the park-wide surveillance monitoring methodology is designed to capture changes in species richness and occurrence over time, rather than to capture all possible species that might occur in RHG
2. the park-wide surveillance sites were chosen to represent the major vegetation formations, therefore diurnal bird surveys conducted at these sites target woodland birds and do not comprehensively capture other bird groups such as pelagic species, aquatic species, shorebirds or raptors — nevertheless, these groups have been included in the total species lists
3. the 2022 survey was a pilot and only conducted at 23 of the 40 RHG survey sites
4. sound recorders target the nocturnal bird guild and dawn chorus, and should increase the total species richness values once analysis is completed.

Nine of the 11 species of honeyeater detected in the park-wide surveys are either seasonal migrants or are nomadic, moving in response to both insect flushes and local availability of nectar from flowering events (Menkhorst et al. 2017). The potential impacts of broader environmental and climatic trends in New South Wales will be be explored when analysing honeyeater trends over time in RHG.

Species richness extrapolation curves indicate that for all vegetation formations, a greater number of surveys are required to adequately represent the diurnal bird fauna. In 2023, bird surveys have been conducted at all 40 sites with 2 survey replicates in the morning, as evening surveys did not adequately replicate morning surveys nor add to the species detected at each site. The 2023 survey data has yet to be analysed but should provide a more comprehensive representation of bird species richness across park-wide surveillance monitoring sites in RHG. Further, additional surveys may be undertaken at each site in future years to increase species detection.

Park-wide surveillance: vegetation

Vegetation

Conservation context

There are 5 major vegetation formations in RHG classified into 20 vegetation classes and 59 individual plant community types (PCTs). These range from littoral rainforest found on protected headlands and escarpment slopes in Royal National Park, exposed sandstone plateaus covered by a complex mosaic of heaths and mallee, to tall moist eucalypt forest found in deep sheltered gullies (NPWS 2000). Within these vegetation types there are local variations in structure and floristic composition which reflect the complex interactions between soil, moisture availability and fire regimes.

There are 15 threatened ecological communities in RHG listed under the Biodiversity Conservation Act with Eastern Suburbs Banksia Scrub in the Sydney Basin Bioregion listed as critically endangered. Eastern Suburbs Banksia Scrub of the Sydney Region and Littoral Rainforest and Coastal Vine Thickets of Eastern Australia are listed as critically endangered under the Environment Protection and Biodiversity Conservation Act. The littoral rainforests in Royal National Park are the northernmost examples of a once extensive rainforest in the Illawarra region (NPWS 2000).

Methods and results

Vegetation was surveyed at 40 park-wide surveillance monitoring sites between June and July 2023. The 20 × 20 m floristic plots generated 2,395 plant records, the 50-m point intercept transects generated 10,716 records, and the 50 × 20 m tree density plots generated 3,728 tree records.

Species richness

A total of 488 native and 5 weed species were recorded across the 40 park-wide surveillance monitoring sites. A total of 39 plants were unable to be identified to species level. Future surveys during spring, rather than winter, may enable easier identification of species. The total number of native plant species recorded in each vegetation formation ranged from 267 in dry sclerophyll forests (shrubby sub-formation) to 76 in rainforests (Figure 13). Descriptions of the vegetation formations surveyed, and the most common species found is summarised in Table 7. Five weed species, sheep's sorrel (*Acetosella vulgaris)*, crofton weed (*Ageratina adenophora)*, whisky grass (*Andropogon virginicus)*, *Conyza* species and flatweed (*Hypochaeris radicata)* were recorded at 4 sites at low abundance. One species recorded, *Hibbertia stricta* subspecies *furcatula,* is listed as endangered under the Biodiversity Conservation Act and has not been previously recorded in RHG.

Rarefaction and extrapolation curves (Chao et al. 2014) for species richness by vegetation formation at park-wide surveillance show that the observed native plant species richness was greatest in dry sclerophyll forests (shrubby sub-formation) and heathlands (Figure 14). The extrapolation curve predicts that with a greater number of survey sites plant species richness would increase at dry sclerophyll forests and heathland sites. Rainforest and wet sclerophyll forests have lower predicted species richness, however, this may be an artefact of smaller sample sizes (n=4 each) compared to the dry sclerophyll forests (n=15 sites) and heathlands (n=13 sites) as these vegetation formations occupy smaller percentages of the park aggregate (Table 7).

Table 7 Descriptions of the major vegetation formations in Royal–Heathcote–Garawarra including abundant species found at park-wide surveillance monitoring sites

Vegetation formation	Description in Royal–Heathcote–Garawarra
Dry sclerophyll forests (shrubby sub-formation) 10,238 ha (53.5% of RHG)	Dry sclerophyll forests are found on sandstone ridgetops and gullies in RHG. The tree canopy includes red bloodwood (*Corymbia gummifera)*, very frequently in combination with *Angophora costata*, scribbly gums (*Eucalyptus haemastoma*, *E. racemosa)*, narrow-leaved stringybarks (*E. oblonga)*, Sydney peppermint (*E. piperita)* and silvertop ash (*E. sieberi)*. A diverse and dense shrub layer includes multiple species of *Acacia*, *Allocasuarina*, *Banksia*, *Boronia*, *Dillwynia*, *Hakea*, *Hibbertia*, *Grevillea, Isopogon*, *Leptospermum*, *Persoonia*, *Pultenaea* and *Xanthorrhoea*. Other distinctive species include *Allocasuarina*. The ground layer is comprised of a sparse cover of forbs, grasses and sedges that includes *Lomandra longifolia, Entolasia stricta* and *Pteridium esculentum*. The distinctive Gymea lily (*Doryanthes excelsa*) can be found among the ground and lower shrub layers.
Heathlands 5,557 ha (29% of RHG)	Heathlands occupy the broad, exposed sandstone plateau tops of RHG, predominately on the coastal eastern and north-eastern side, but also in a mosaic with dry sclerophyll forest along narrow ridges and rocky outcrops and pavements. Heathlands generally lack trees, but multi-stemmed eucalypts or mallee growth forms are common. Red bloodwood and *Angophora hispida* are very frequent and mallee species include occasional Port Jackson mallee (*Eucalyptus obstans)* and whipstick mallee ash (*E. Multicaulis)*. The shrub canopy has a high cover *of Banksia* species including *B. ericifolia, B. serrata, B. marginata, B. oblongifolia* very frequently with a diverse combination of other shrubs and small trees including *Acacia suaveolens*, *Allocasuarina distyla*, *Boronia ledifolia*, *Dillwynia floribunda*, *Grevillea oleoides, Hakea dactyloides, Hakea teretifolia, Hemigenia purpurea, Isopogon nemonifolius, Leptospermum trinervium, Leptospermum arachnoides, Petrophile pulchella, Persoonia lanceolata* and *Xanthorrhoea resinosa*. The ground layer is a sparse combination of sedges, forbs and grasses including *Actinotus minor*, *Anisopogon avenaceus*, *Cordifex* species, *Cyathochaeta diandra*, *Gonocarpus teucrioides*, *Lepyrodia scariosa*, *Lepidosperma* species, *Lomandra obliqua* and *Ptilothrix deustra*.
Rainforests 435 ha (2.3% of RHG)	On the bottom of the upper Hacking River valley, in the most sheltered and moist parts of the landscape, on rich shale soils, are narrow bands of rainforest. Rainforest occupies and rarely extends beyond the gully bottoms and stream sides of the Hacking and its tributaries. The tall rainforest canopy includes coachwood (*Ceratopetalum apetalum*) with lily pilly (*Acmena smithii*) and sassafrass (*Doryphora sassafras*) in varying proportions. The understory includes occasional shrubs of hairy-leaved doughwood (*Melicope micrococca*), large mock olive (*Notelaea longifolia*) and corkword (*Duboisia myoporoides*) and a diversity of ground ferns including giant maidenhair (*Adiantum formosum*) and creeping shield fern (*Lastreopsis microsora*). The mid-stratum very commonly contains the palm *Livistona australis* and vine *Gynochthodes jasminoides*, with the shrub *Tasmannia insipida* and vines *Palmeria scandens, Pandorea pandorana, Smilax australis, Marsdenia rostrata* and *Parsonsia straminea*. The epiphytic fern *Pyrrosia rupestris* also occurs commonly. Littoral rainforest occurs on the coastal fringe of RHG and is a targeted vegetation community.

Vegetation formation	Description in Royal–Heathcote–Garawarra
Wet sclerophyll forests (grassy sub-formation) 270 ha (1.4% of RHG)	Wet sclerophyll forests (grassy sub-formation) are tall to very tall sclerophyll open forest with a sparse layer of dry sclerophyllous shrubs and a grassy ground cover found on clay-influenced (shale) sandstone crest in the northwest of RHG. The tree canopy includes red bloodwood with *Angophora costata*, species from the stringybark eucalypt group (*Eucalyptus globoidea, E. capitellata, E. sparsifolia*), blackbutt (*E. pilularis*), Sydney peppermint and species from the mahogany eucalypt group (*E. botroides, E. resinifera*). The mid-stratum is multi-layered, commonly with a tall sparse layer of black she-oak (*Allocasuarina littoralis)* and a sparse cover of low dry shrubs. The shrub layer very frequently includes multiple species of *Acacia, Banksia, Hakea, Hibbertia* and *Persoonia*. It has a grassy ground layer with *Entolasia stricta* very frequent, often with different species of *Lepidosperma, Lomandra, Microlaena, Oplismenus* and *Poa*.
Wet sclerophyll forests (shrubby sub-formation) 1,287 ha (6.7% of RHG)	Wet sclerophyll forests (shrubby sub-formation) are tall to very tall sclerophyll open forest with a sparse mesophyll shrub layer including scattered palms and a ground layer of ferns, graminoids and climbers. It is found on the west-facing or intermediate gully slopes and shale-capped crests slopes between the rainforest that borders the valleys of the upper Hacking River and tributaries and the dry sclerophyll forests of the upper slopes and ridge tops. The tree canopy is variable, however commonly includes a high cover of blackbutt, turpentine (*Syncarpia glomulifera*) and *Angophora costata*. The mid-stratum is layered and very frequently includes a sparse cover of cabbage-tree palm (*Livistona australis*). A lower shrub layer commonly includes multiple species of *Acacia*, *Hibbertia*, *Persoonia* and *Pultenaea* and *Leucopogon lanceolatus*. The mid-dense ground layer includes *Dianella caerulea*, *Entolasia stricta*, *Lomandra longifolia* and *Pteridium esculentum*. Vines include *Clematis aristate*, *Eustrephus latifolius*, *Hibbertia scandens*, *Smilax gylciphylla* and *Tylophora barbata.*

(Sources: DPE 2022a, 2023; King 2013).

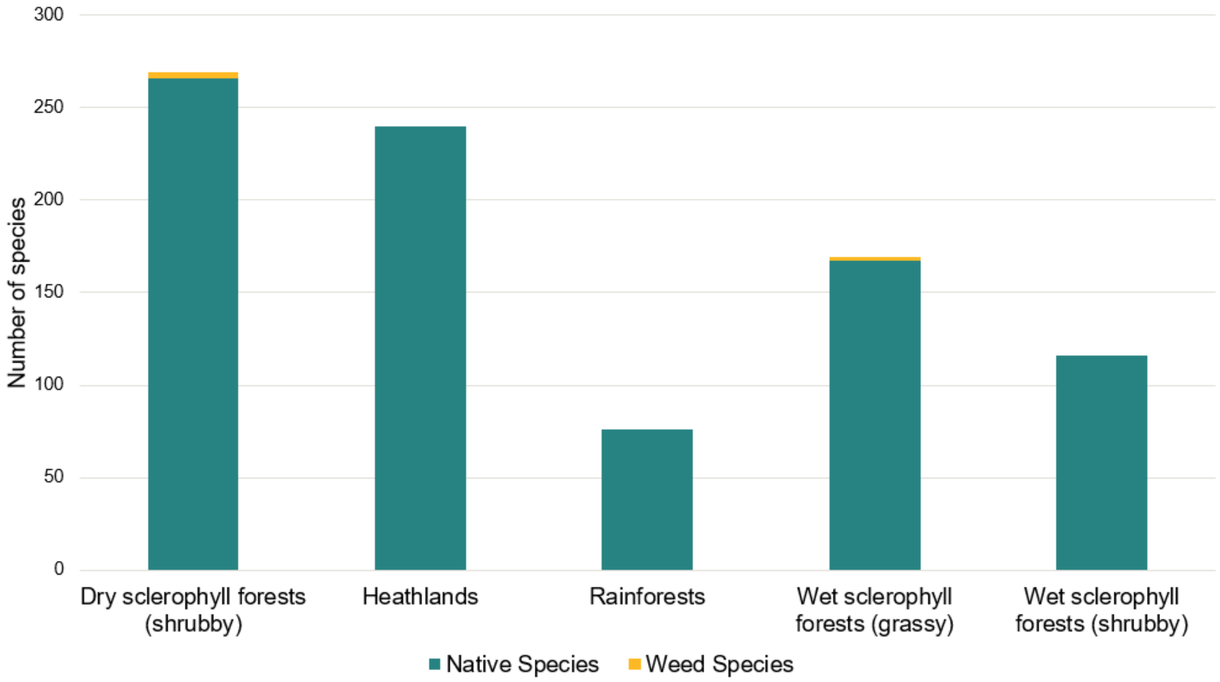


Figure 13 Total number of native and weed species recorded in each vegetation formation in RHG in 2023

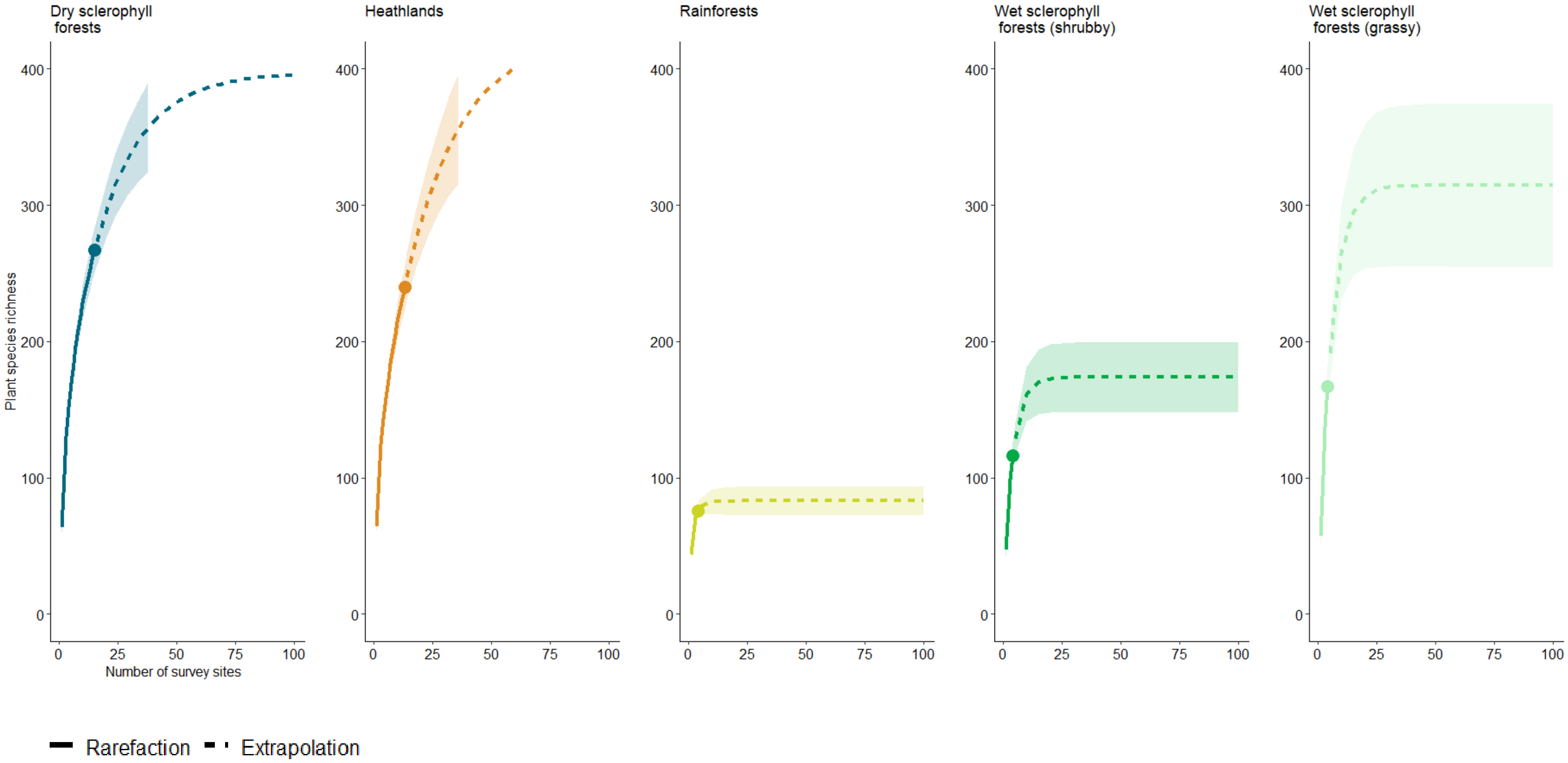


Figure 14 Native plant species richness in the major vegetation formations in Royal–Heathcote–Garawarra in 2023

Curves are based on the number of species recorded at each monitoring site and predicted richness if more sites were sampled. This approach adjusts for the difference in number of sites sampled in different vegetation formations. Shaded areas represent the 95% confidence interval for each vegetation formation.

Native vegetation cover

The percentage of native vegetation cover measured at different heights above the ground provides a measure of vegetation structure. Over time these measures can be used to observe changes in the vegetation community through age, or environmental events like fire and drought, or long-term climate change.

Native vegetation cover at different heights varied between sites within a vegetation formation and between vegetation formations (Figure 15), however the average values were generally consistent with what is expected for the vegetation formations with a range of fire histories (from recently burnt to long unburnt). Rainforests and wet sclerophyll forests had the tallest vegetation, with wet sclerophyll forest (grassy sub-formation) having less mid-story vegetation than either rainforest or the wet sclerophylly forest (shrubby sub-formation). Wet sclerophyll forests (shrubby sub-formation) had the most vegetation (37%) within the 3 to 5 m stratum. Dry sclerophyll forests had the most vegetation (41%) within the 1 to 3 m stratum. Dry sclerophyll forests (67%) and heathlands (75%) had most vegetation in the ground stratum (under 1 m). Litter cover was highest in rainforests (94%) and lowest in heathlands (58%).

Foliage projective cover (FPC) has been used as a canopy cover index and measures the percentage of ground area occupied by the vertical projection of the foliage of woody vegetation calculated from a Landsat image (taken 29/10/2022). The highest FPC values were found in wet sclerophyll forests (shrubby sub-formation) (67%) and rainforests (64%) and the lowest in heathlands (41%). Data quality was not considered accurate for the >5 m height class due to the data collection methods not being repeatable and this data has been omitted from this report.

Tree size and density

Wet sclerophyll forests (grassy sub-formation), followed by dry sclerophyll forests, had the overall highest density of trees, however, most of these trees were small, <20 cm diameter at breast height (DBH) (Table 8). Wet sclerophyll forests (grassy sub-formation) sites had the highest density of large trees (>50 cm DBH), followed by wet sclerophyll forests (shrubby sub-formation) and rainforests. Wet sclerophyll forests and rainforests also had the highest densities of medium-sized trees (20–49 cm). Dry sclerophyll forest had a low number of large trees. The number of standing dead trees was highest in the <20 cm size class and very low in the medium and large size classes. Wet sclerophyll forests had the highest number of standing large dead trees.

In dry sclerophyll forests the most common tress were *Banksia serrata*, *Corymbia gummifera, Eucalyptus sieberi, E. racemosa* and *Angophora costata* (Table 9). In heathlands the most common trees were *Angophora hispida*, *B. serrata*, and *Ceratopetalum gummifera*. In rainforest the most common trees were *Guioa semiglauca*, *Cryptocarya glaucescens*, *Doryphora sassafrass*, *Acmena smithii* and *Ceratopetalum apetalum*. In wet sclerophyll forests (grassy sub-formation) the most common trees were *Allocasuarina littoralis*, *Syncarpia glomulifera*, *Livistona australis* and a mixture of *Eucalypt* species. In wet sclerophyll forest (shrubby sub-formation) the most common trees were *Syncarpia glomulifera*, *Ceratopetalum gummiferum*, *E. pilularis* and *Angophora costata.* Tree numbers were based on the total number of stems recorded across all plots in each vegetation formation.

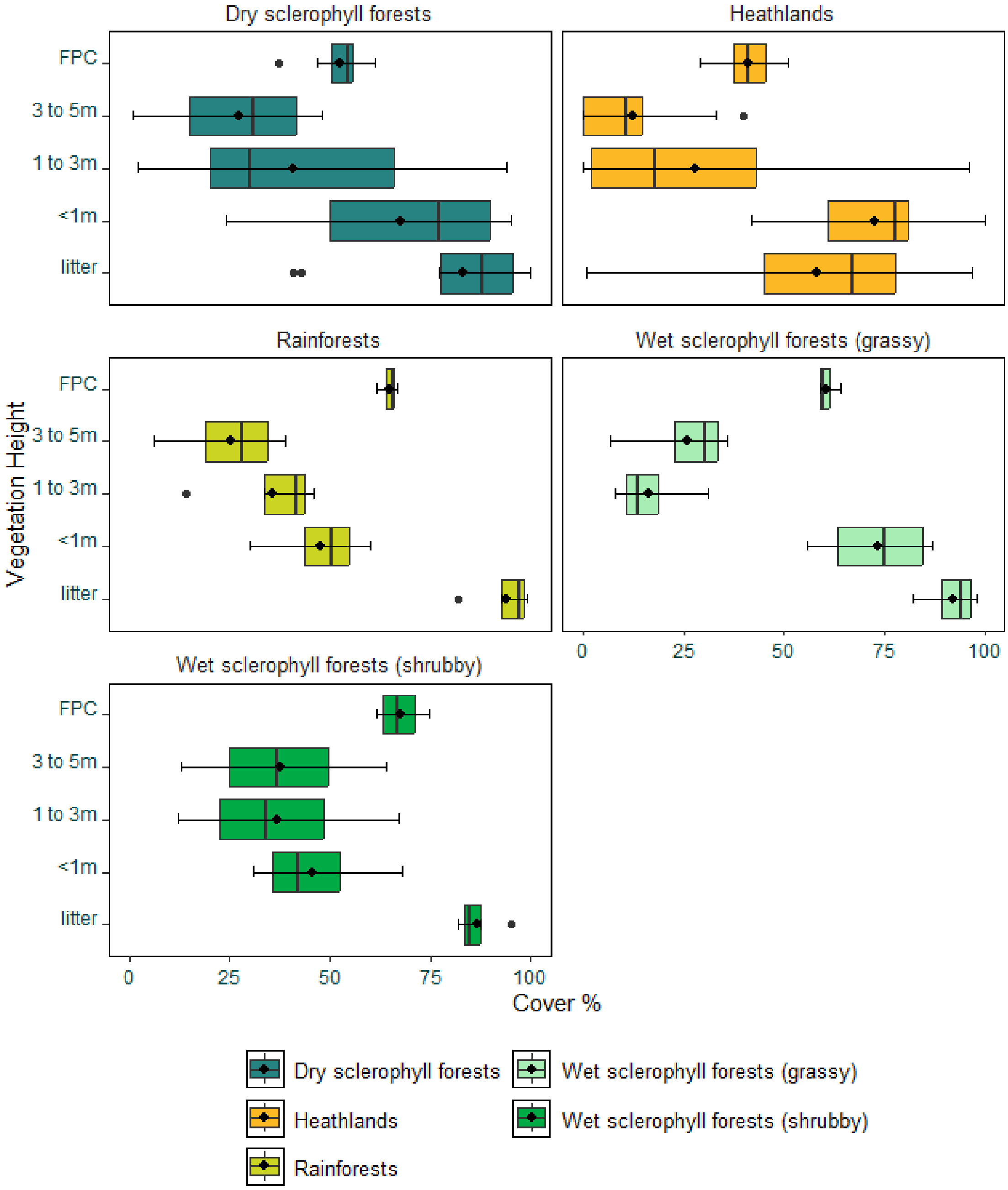


Figure 15 Boxplots showing native vegetation cover in each major vegetation formation in Royal–Heathcote–Garawarra in 2023

Point intersect transects at each surveillance monitoring sites were used to calculate the percentage cover (%) at 3 height strata (<1 m, 1–3 m and 3–5 m high) and litter cover (%). Foliage projection cover (FPC) (a canopy cover index) was calculated from satellite imagery. Lower and upper bounds of each coloured boxes represent the 25th and 75th percentile respectively (the interquartile range), the thick horizontal line within the coloured box indicates the median value and the black circle within the coloured box indicates the mean. Error bars represent the largest and smallest value within 1.5 times the 75th and 25th interquartile respectively. Black circles outside of the coloured box are outliers >1.5 and <3 times the interquartile range.

Table 8 **Tree diameter and density at Royal–Heathcote–Garawarra park-wide surveillance sites**

Vegetation formation		Stem density per hectare: mean (range) <20 cm	20–49 cm	>50 cm	Total
Dry sclerophyll forests (shrubby)	Alive	831 (60–1,750)	115 (20–200)	27 (0–70)	1,060 (150–1,880)
	Dead	35 (0–280)	5 (0–30)	1 (0–10)	41 (0–28)
Heathlands	Alive	780 (90–1,320)	32 (0–170)	0	812 (140–1,350)
	Dead	17 (0–70)	1 (0–10)	0	18 (0–70)
Rainforests	Alive	540 (0–1,470)	220 (110–880)	48 (20–90)	807 (260–1,670)
	Dead	0	0	0	0
Wet sclerophyll forests (grassy)	Alive	900 (740–1,160)	188 (50–290)	48 (0–90)	1114 (1,000–1,450)
	Dead	143 (10–240)	8 (0–20)	3 (0–10)	153 (20–260)
Wet sclerophyll forests (shrubby)	Alive	485 (340–650)	118 (30–240)	85 (40–110)	688 (470–860)
	Dead	28 (0–100)	5 (0–20)	3 (0–10)	35 (0–111)

Table 9 **Mean number of stems per hectare of the most frequently recorded tree species in 50 × 20 m plots in each major vegetation formation of Royal–Heathcote–Garawarra**

Species	Dry sclerophyll forests	Heathlands	Rainforests	Wet sclerophyll forests (grassy)	Wet sclerophyll forests (shrubby)
Acmena smithii	0	0	70	3	0
Allocasuarina littoralis	33	2	0	430	0
Angophora costata	58	7	0	83	60
Angophora hispida	0	394	0	0	0
Banksia serrata	210	111	0	0	23
Ceratopetalum apetalum	0	0	68	0	0
Ceratopetalum gummiferum	51	0	33	0	83
Corymbia gummifera	359	195	0	10	3
Cryptocarya glaucescens	0	0	73	0	0
Doryphora sassafras	0	0	130	0	0
Eucalyptus oblonga	33	30	0	0	0

Species	Dry sclerophyll forests	Heathlands	Rainforests	Wet sclerophyll forests (grassy)	Wet sclerophyll forests (shrubby)
Eucalyptus pilularis	0	0	0	3	108
Eucalyptus piperita	39	0	0	18	0
Eucalyptus racemosa	67	35	0	0	0
Eucalyptus sieberi	73	1	0	3	0
Guioa semiglauca	0	0	225	0	0
Livistona australis	0	0	0	203	0
Syncarpia glomulifera	0	0	3	235	255
Other *Eucalyptus spp.*	33	37	3	65	15
Other *tree spp.*	2	2	205	8	140

Discussion

The park-wide surveillance monitoring sites indicate that RHG has a diverse range of flora which, away from disturbance areas, were found to be mostly free from weeds and contain only small numbers of standing dead trees. Large standing trees are mostly found in wet sclerophyll forests, which provide habitat for tree-hollow dependent species. Future analysis of vegetation data may provide an indication of community health by comparison with benchmark values from the BioNet Vegetation Classification system (NSW Government 2024).

Targeted monitoring

A selection of species and vegetation communities have been identified for targeted monitoring based on their conservation status, susceptibility to key threatening processes and/or ability to indicate changes in the environment. These assets require specialised monitoring techniques which are beyond the scope of the park-wide monitoring surveys. Therefore, each has a bespoke monitoring program with the objective to monitor changes in their status and population trends over time across RHG.

Most of these conservation assets are already monitored as part of existing threatened species or management programs, for example, Saving our Species. While the monitoring objectives for some of these species may differ to those of the Scorecards program, the data are presented below as an interim reporting. A review and optimisation of each monitoring program will be implemented to ensure a high level of rigor to produce information on population trends over time. Additional targeted species and communities may be added to the program over time.

Broad-headed snake

Conservation context

The broad-headed snake (*Hoplocephalus bungaroides)* is a cryptic, venomous, nocturnal ambush predator with a highly restricted geographic range, occurring on sandstone rock outcrops and adjacent habitat within 100 km north and 250 km south of Sydney (Cogger 2014). The species is listed as endangered under the Biodiversity Conservation Act and the Environment Protection and Biodiversity Conservation Act. Key risks to this species include impacts from direct anthropogenic disturbance to habitat, in particular the removal of bush rock (listed as a key threatening process, Biodiversity Conservation Act) and the illegal collection of this species from the wild. Royal National Park is recognised as one of several hotspots for the broad-headed snake, although it occurs at relatively low densities (Newell and Goldingay 2005). Its distribution is limited by its highly specific diurnal retreat sites which is driven by thermoregulation (Pringle et al. 2003). In winter, the broad-headed snake shelters under sun-exposed, flat sandstone rocks and rock crevices during the day, but prefers sheltering in tree hollows in the summer (Webb and Shine 1997). Climate change modelling suggest that the species' distribution will contract to higher altitude areas with increasing temperatures (Penman et al. 2010).

Methods and results

Targeted surveys were carried out at 26 sites to estimate and monitor the area of occupancy of broad-headed snakes across Royal National Park (Schulz and Goldingay 2022). The current 26 broad-headed snake monitoring survey sites were selected from a wider survey of 64 sites conducted in 2017 (Goldingay and Newell 2017). This subset of survey sites was selected to be:

- representative of the broad-headed snake habitat in Royal National Park
- logistically feasible for a single person to survey within survey parameters of dry weather, 3 visits 2 weeks apart, from late July to mid-September
- large enough rock platforms with adequate loose rock shelter for broad-headed snake
- rock platforms >500 m from road which are less disturbed and have higher broad-headed snake occupancy.

A 250 × 20 m (0.5 ha) transect was surveyed for one hour, on 3 separate days, turning and examining rocks (both on rock and soil) for sheltering reptiles, which are then replaced. Rock crevices and spaces under large rocks, or boulders, were investigated by shining a torch beam into them to locate any reptiles. All other reptile species encountered were also recorded.

In 2022, 24 individual broad-headed snakes (7 adults, 4 subadults and 13 juveniles) were detected at 13 of 26 monitoring sites over the 3 visits. Broad-headed snake density was 1.85/ha, calculated as the number of individuals detected per hectare across the surveyed sites.

Occupancy analysis

Single-season occupancy analysis was completed using *R* package Unmarked for 4 years (2017, 2018, 2020, 2022) of broad-headed snake surveys conducted in Royal National Park. In each year, surveys were conducted at 26 sites, with 3 visits per site. Detection and occupancy estimates were calculated for each survey year (Table 10).

A cumulative detection probability curve, calculated using the mean detection probability for the 4 years of surveys, indicates that with 3 site visits, broad-headed snake will be detected on average 85% of the time, however it could be as low as 60% due to large confidence intervals (Figure 16). If the number of visits was increased to 4 or 5 per site, there would be greater confidence in detecting the species at a site at least once during a survey.

Table 10 Broad-headed snake detection and occupancy estimates per survey year with standard error (SE) and 95% confidence intervals (CI) in Royal National Park

Year	Detection probability (+/- SE)	Occupancy (+/- SE)
2017	0.465 (0.121)	0.456 (0.134), 95% CI: 0.225 - 0.708
2018	0.335 (0.111)	0.658 (0.208), 95% CI: 0.240 – 0.922
2020	0.520 (0.118)	0.401 (0.115), 95% CI: 0.207 – 0.632
2022	0.528 (0.097)	0.560 (0.117), 95% CI: 0.333 – 0.762

Note: large confidence intervals (CI) result in reduced ability to detect change.

Rock-plate heath reptiles

Incidental detections of sympatric rock-plate heath reptiles were recorded during the broad-headed snake monitoring surveys. In the 2022 surveys, 22 reptile species of rock-plate heath reptiles were recorded (Table 11).

Table 11 Rock-plate reptiles recorded during 2022 broad-headed snake surveys in Royal National Park

Common name	Scientific name
Blackish blind snake	*Anilios nigrescens*
Broad-tailed gecko	*Phyllurus platurus*
Carpet / diamond python	*Morelia spilota*
Common scaly-foot	*Pygopus lepidopodus*
Common tree snake	*Dendrelaphis punctulatus*
Copper-tailed skink	*Ctenotus taeniolatus*

Common name	Scientific name
Cream-striped shining-skink	*Anilios nigrescens*
Dark-flecked garden sunskink	*Lampropholis delicata*
Eastern brown snake	*Pseudonaja textilis*
Eastern small-eyed snake	*Cryptophis nigrescens*
Eastern water-skink	*Eulamprus quoyii*
Golden-crowned snake	*Cacophis squamulosus*
Jacky lizard	*Amphibolurus muricatus*
Lace monitor	*Varanus varius*
Lesueur's velvet gecko	*Amalosia lesueurii*
Red-throated skink	*Acritoscincus platynotus*
Three-toed skink	*Saiphos equalis*
Tiger snake	*Notechis scutatus*
White's skink	*Liopholis whitii*
Wood gecko	*Diplodactylus vittatus*
Yellow-faced whip snake	*Demansia psammophis*

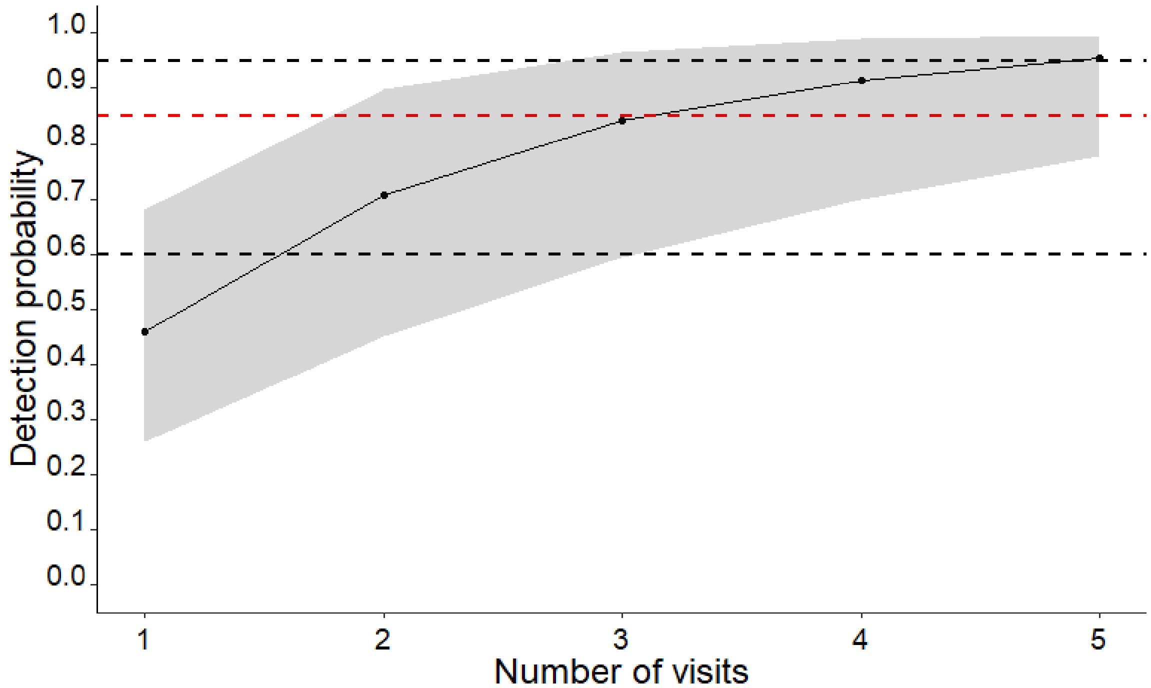


Figure 16 Broad-headed snake cumulative detection probability with 95% confidence intervals

Red dashed line indicates detection probability of 0.85 and black dashed lines indicate 0.95 and 0.60.

Discussion

Despite monitoring data collected between 2017 and 2022 suggesting that the broad-headed snake population in Royal National Park is stable; the confidence in the estimates is somewhat low. This indicates that the current survey design and methodology should be reviewed and updated to increase confidence in the species occurrence and persistence in the park. Future surveys will be expanded to include survey sites in suitable habitat in Heathcote National Park, to obtain a more representative sample for the status of broad-headed snake in RHG. Heathcote National Park provides habitat connectivity between the Woronora Plateau and Royal National Park and contains areas of potentially suitable habitat for the broad-headed snake (DECCW 2011).

Villous mint bush

Conservation context

The villous mint bush is a NSW endemic species listed as vulnerable under the Biodiversity Conservation Act. In RHG it is only known from 3 sites: Marley, Nioka Ridge and Garawarra (Clarke 2022). The total population size of villous mint bush in RHG is unknown but estimated, from plot counts and wandering surveys, to be between 1,000 to 1,500 mature individuals (Clarke 2022). Monitoring conducted between 2019 and 2021 observed an overall stable population with an increase in seedlings in 2020 due to post-fire recruitment at one site (Garawarra) following a hazard reduction fire in 2018 (Clarke 2021). Villous mint bush is a fire-sensitive obligate seeder with a soil-stored seed bank that is both threatened by too frequent fire or too long between fires.

Methods and results

Villous mint bush individuals were recorded from 8 permanent monitoring plots located at the 3 known populations: Marley (2 plots), Garawarra (3 plots) and Nioka Ridge (3 plots) (Clarke 2022) (Figure 17). Plot size varies from 20 × 10 m, 25 × 10 m, 15 × 10 m or 22 × 10 m and each has been positioned to include at least 30 mint bushes. In 2022, a total of 355 individuals (326 mature, 29 seedlings) were recorded from monitoring plots, and a total of 359 individuals (348 mature, 11 seedlings) were recorded in 2023 (Figure 18).

The overall population trend of the villous mint bush in RHG, measured as plot density, was stable between 2022 and 2023. In both 2022 and 2023 surveys, the average density of plants per plot, over all sites, was one mature plant per 5 m^2 (range of one mature plant per 3 to 9 m^2). In 2023 surveys, on average 87% of individuals were recorded as healthy. The recruitment rate (number of seedlings) was 9% in 2022 and 3% in 2023 (Figure 18). A small amount of plant mortality was observed in 2022 and 2023 and was attributed to prolonged above average rainfall (Clarke 2022).

Marley: The population is considered stable and relatively consistent with what has been observed in previous surveys (Clarke 2022, 2023). In 2023 some plants were observed to be stressed or senescing, which may be due to the prolonged rainfall periods of 2020 to 2022. However, surveys at Marley since 2016 have consistently detected dying or dead plants, as well as a low level of recruitment. The last fire at this site was 20 years ago.

Garawarra: The population at this site comprised many small plants that sprouted in 2020 after a controlled burn in 2018 (Clarke 2022, 2023). At one of the monitoring plots, there was only a single plant before the fire and subsequent monitoring has indicated that seedling survivorship has been high. The young plants are now competing with a dense native ground layer and there will likely be natural thinning over time.

Nioka Ridge: The population at this site is considered stable (Clarke 2022, 2023) with a healthy population of over 1,000 plants spread over a linear 1 km. Targeted surveys in 2022 and 2023 expanded the known distribution of this species at Nioka Ridge with plants found along, and extending north, beyond Nioka Brook. Like the other sites in RHG, recent heavy rainfall in 2022 may have resulted in some plant loss, however, most plants appear to be healthy.

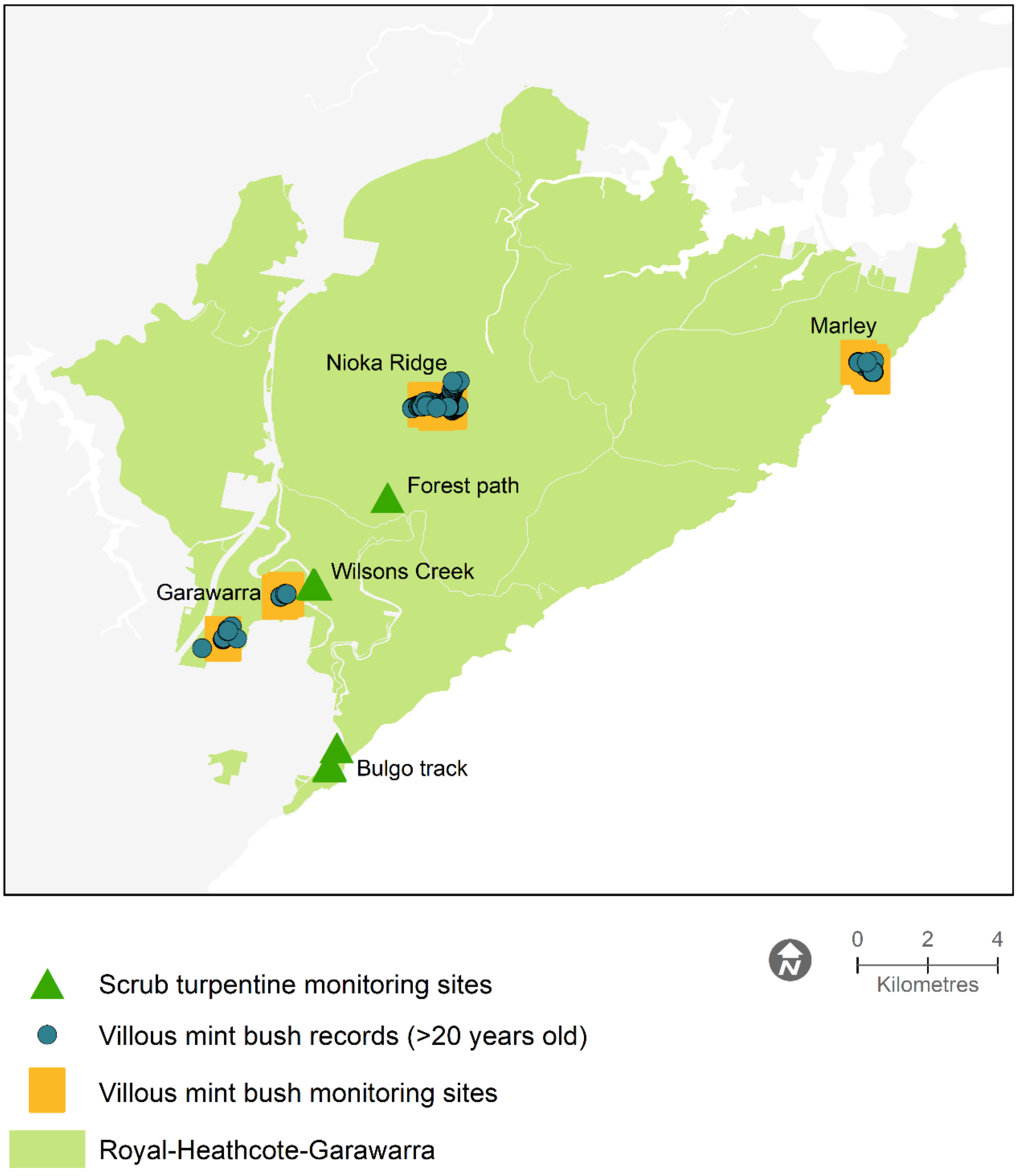


Figure 17 **Map of targeted flora monitoring sites for villous mint bush and scrub turpentine in Royal–Heathcote–Garawarra**

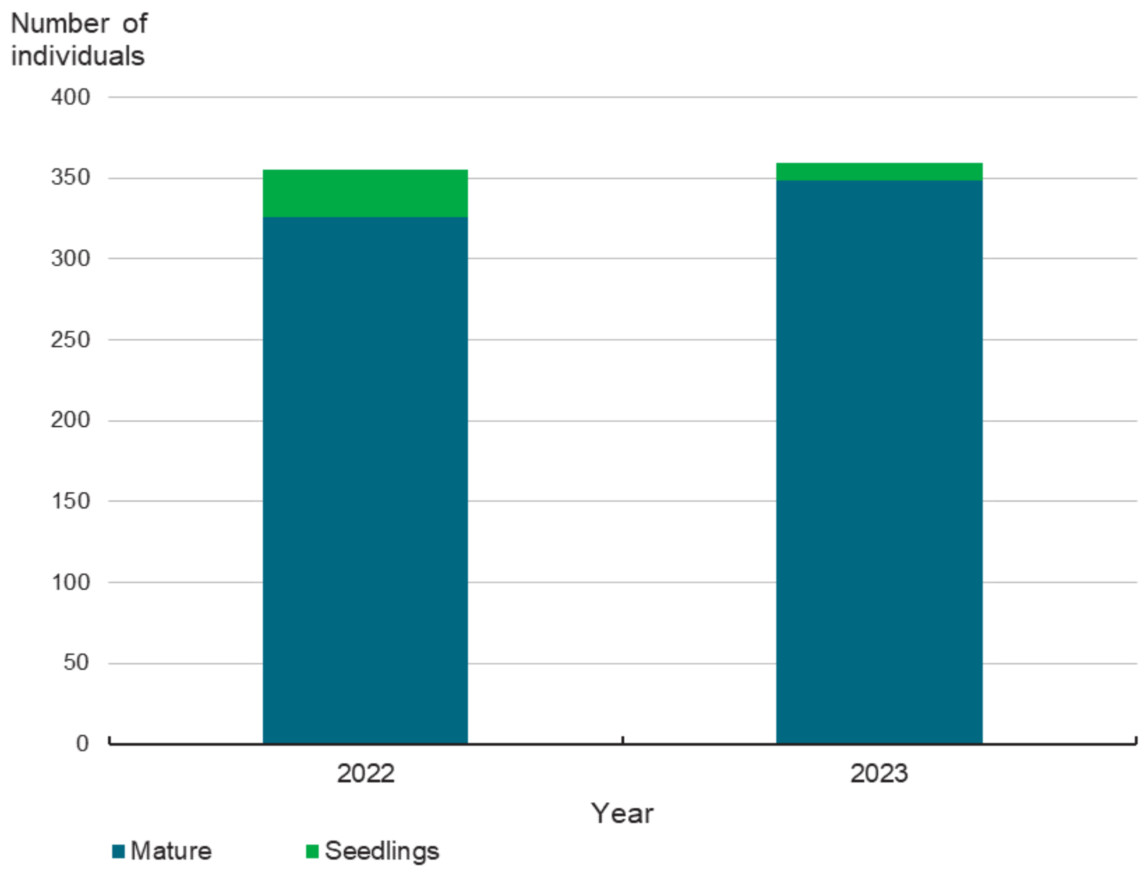


Figure 18 **Population counts of villous mint bush (mature and seedlings) from monitoring plots in Royal–Heathcote–Garawarra in 2022 and 2023 (Clarke 2023)**

Discussion

An appropriate fire regime is important in the ongoing persistence of a healthy villous mint bush population in RHG. The current recommended minimum fire interval is no more than once every 7 years (NSW RFS 2013). Short time intervals between fires in obligate seeders can disrupt the replenishment of seed banks, which are essential to post-fire recruitment and population persistence (Enright et al. 2015; Gallagher et al. 2021). Conversely, too long between fires can lead to population decline as individuals naturally senesce and die or are outcompeted by other larger shrubs, as is likely the case at Marley.

Long-term absence of fire in the Sydney Basin bushland is likely a relatively recent phenomenon because of fragmentation and isolation of remnants from increasing urbanisation. Traditional Owners used fire to manage the landscape of the Sydney Basin for thousands of years and are likely responsible for an elevated fire frequency in this landscape (Black et al. 2007; Mooney et al. 2007). In Sydney peri-urban bushland remnants, plant species diversity has been found to increase with fire frequency (Pendall et al. 2022). A trial ecological burn in the Marley area, which has not burnt for 20 years, would provide information on recruitment and survivorship for villous mint bush.

Scrub turpentine

Conservation context

Scrub turpentine is a coastal species often found in wet sclerophyll forests in rainforest transition zones (Benson and McDougall 1988). A few small stands and most trees are suffering from myrtle rust infection, as they are in many parts of New South Wales. Repeated, severe infection by myrtle rust results in a reduction in foliage production, severely affects crown health and can lead to tree death (Carnegie et al. 2016). Scrub turpentine was listed as critically endangered in 2020 under the Biodiversity Conservation Act and Environment Protection and Biodiversity Conservation Act based on a projected population decline from myrtle rust (TSSC 2020). Scrub turpentine distribution in RHG is restricted to isolated stands.

Methods and results

A total of 90 mature scrub turpentine plants were surveyed from 3 sites in RHG: Bulgo track, Forest path and Wilson Creek (Figures 17 and 19). The 2022 survey included all scrub turpentine individuals at each site.

Scorecards surveys in 2022 found that 30% of standing scrub turpentine trees in RHG are dead (Figure 19). Most of the scrub turpentine individuals in RHG are not healthy with only 3% of trees having >75% of branches with healthy green foliage (Figure 20). The average percentage of alive leaves in the canopy of surveyed trees was 21% (range: 2–90%). Bulgo track was the worst affected site, with the highest proportion of standing dead trees (72%) and the lowest percentage of alive leaves in the canopy of living trees. No data are available on recruitment rate.

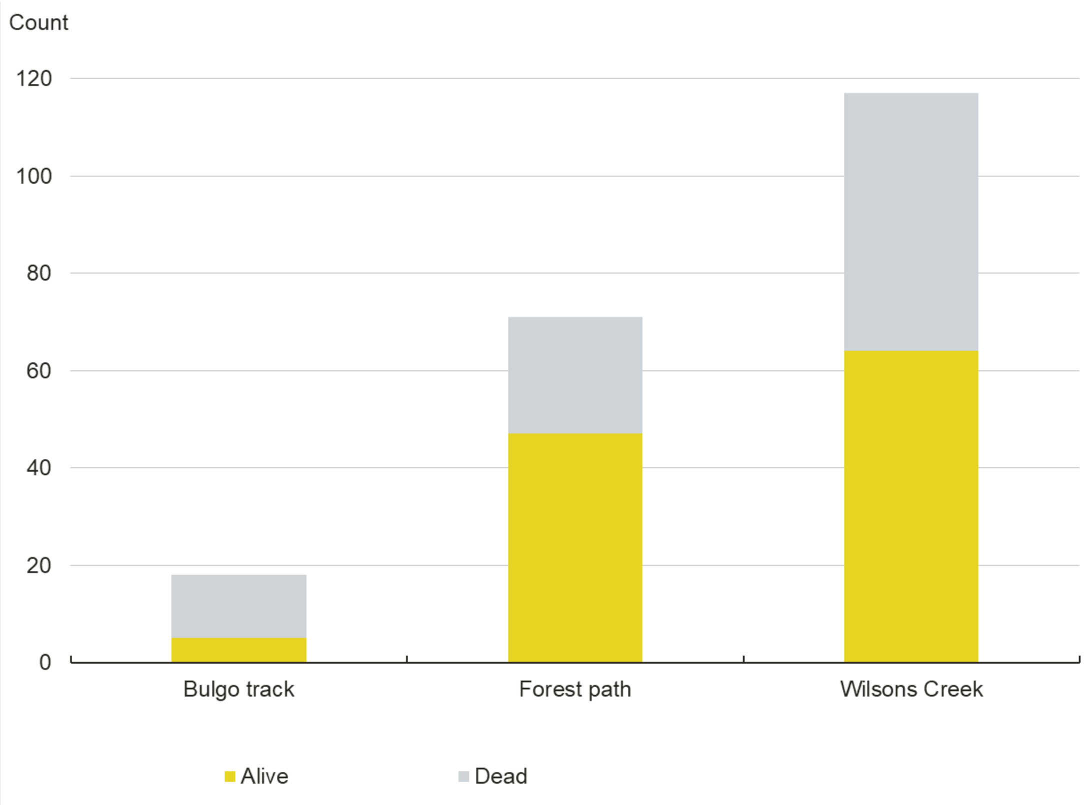


Figure 19 Survey of scrub turpentine trees (alive and dead) from 3 sites in Royal–Heathcote–Garawarra in 2022

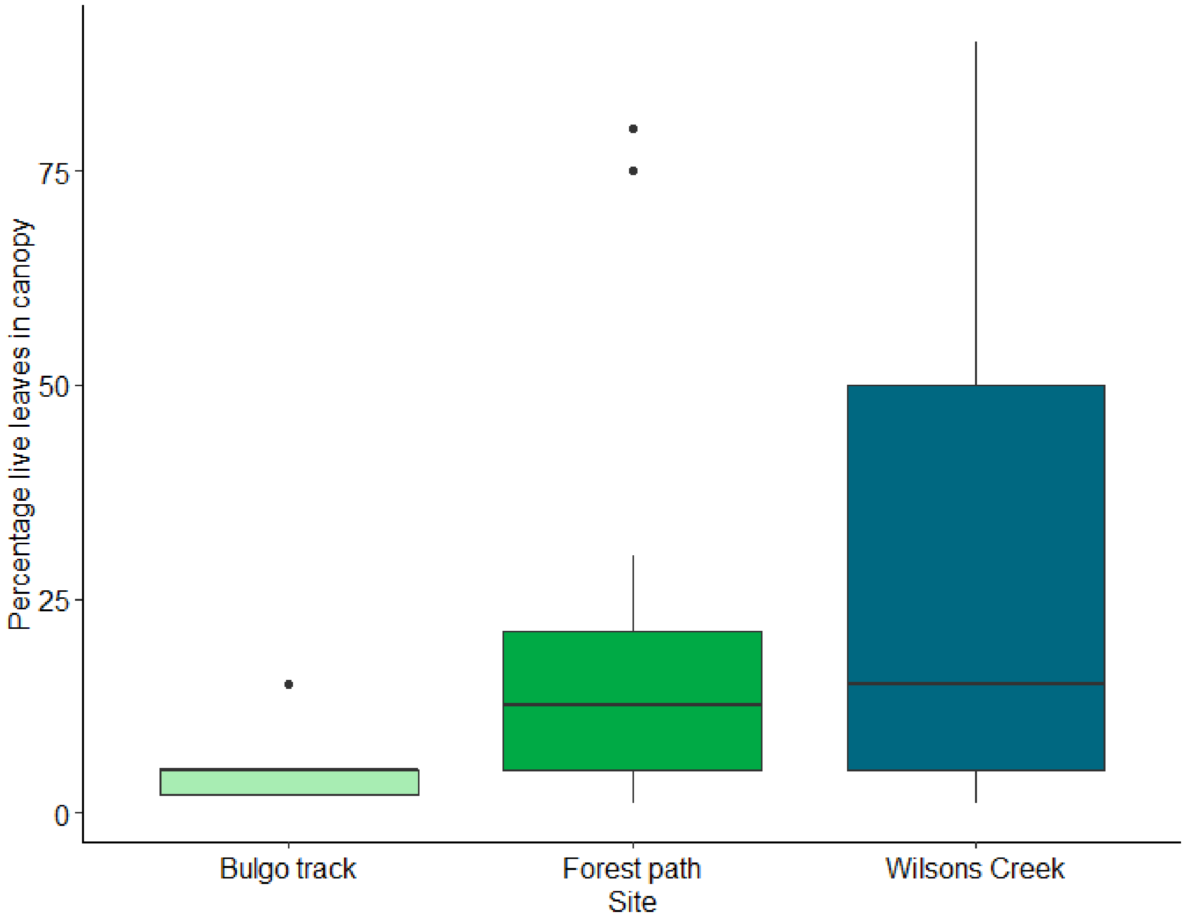


Figure 20 **Percent of live leaves on scrub turpentine trees at 3 sites in Royal–Heathcote–Garawarra in 2022**

Discussion

The Forest path site is the only one of the 3 monitoring sites with historic data on scrub turpentine trees (Carnegie et al. 2016). A comparison over time of the number of standing dead trees at Forest path suggests that the percent of standing dead trees increased in the 6 years between 2016 and 2022, from 23% to 47%, representing a 104% increase.

The decline of scrub turpentine in RHG has resulted in the development of new management actions for the species:

- collection and storage of the germplasm of RHG scrub turpentine
- additional survey that has found a previously unknown stand of the species along Garie Road
- investigation into options to treat and/or limit disease spread.

Scrub turpentine can reproduce both clonally and from seed and a genomics study of the local stands would provide a census of the number of unique individuals.

Littoral rainforest

Conservation context

Littoral rainforest is very rare and only occurs on the NSW coast in many small stands, in total comprising less than 1% of the total area of rainforest in the state. Littoral Rainforest in the NSW North Coast, Sydney Basin and South East Corner Bioregions is listed as an endangered ecological community under the Biodiversity Conservation Act and is part of the critically endangered ecological community Littoral Rainforest and Coastal Vine Thickets of Eastern Australia listed under the Environment Protection and Biodiversity Conservation Act. Approximately 140 ha of littoral rainforest occurs at Jibbon Beach, in the north-east, and along the southern coastal area of Royal National Park. It is threatened by the invasion and establishment of weeds and deer which collectively change the structure and floristics of the ecological community. Increasing fire frequency and severe weather events from climate change may also threatened littoral rainforests (Cth Department of the Environment 2015).

Methods and results

Full floristic data was recorded for 11 monitoring plots (10 × 20 m) randomly selected from accessible areas of littoral rainforest (Figure 21). A total of 321 native species were recorded. Mean native species richness was 28 (range: 19 to 46). A small number (2 to 9) of seedlings, of all species, were recorded at each site. Three weed species were recorded in low abundance: *Senna pendula* var. *glabrata*, *Zantedeschia aethiopica* and *Conyza sumatrensis*. Deer damage was recorded at 7 of the 11 (64%) monitoring sites. Fire impact was recorded at 2 of the 11 (18%) sites (suspected to be from 2018), one which is regenerating strongly and the other only had mild fire impacts.

Discussion

Littoral rainforest sites in RHG are generally in good condition with low levels of weed incursion and low impacts from fire. Browsing and stem rubbing by deer impacts was observed at around 50% of monitoring sites and additional control measures should be considered to reduce deer impacts on this vegetation community. Management should continue to exclude fire from rainforest patches.

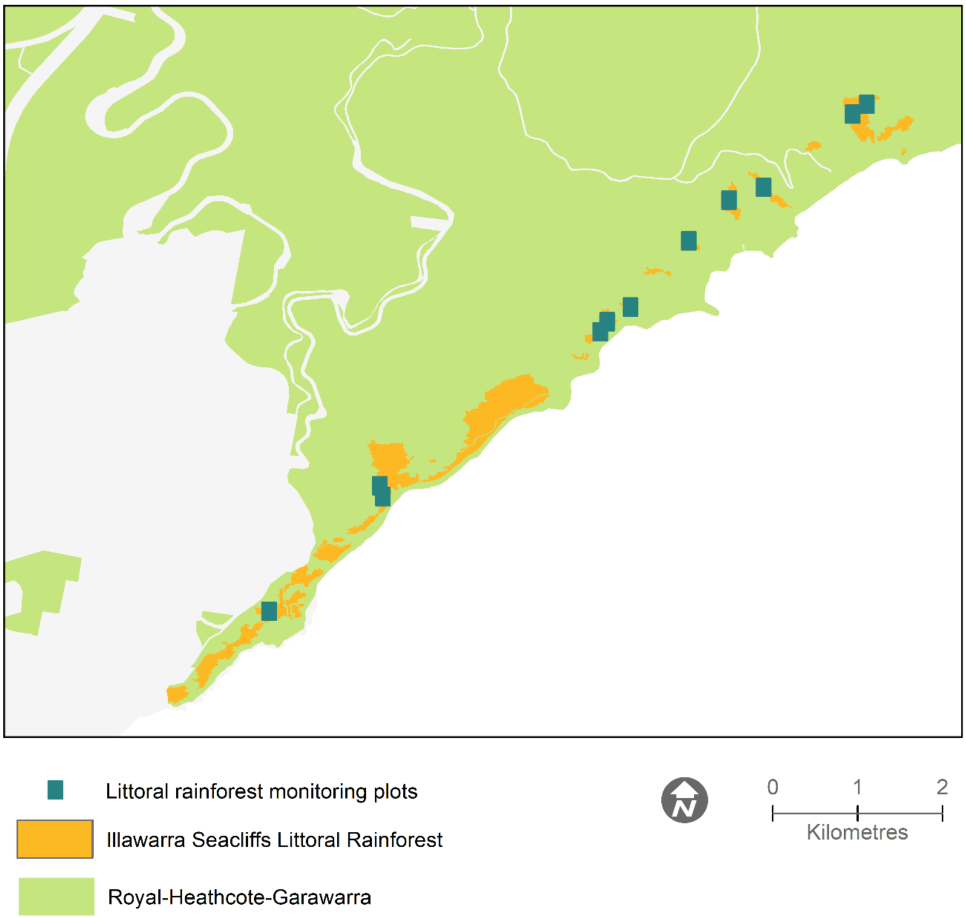


Figure 21 Littoral rainforest monitoring sites in Royal National Park

Coastal upland swamp

Conservation context

Coastal upland swamp is a restricted ecology community generally only occurring when mean average rainfall exceeds 950 mm. RHG has over 100 coastal upland swamps occupying an estimated 80–180 ha or 1 % of the area of RHG (State Government of NSW and Department of Planning and Environment 2015). Coastal Upland Swamp in the Sydney Basin Bioregion is listed as an endangered ecological community on the Biodiversity Conservation Act and Environment Protection and Biodiversity Conservation Act.

Coastal upland swamps in RHG are threatened by a complex picture of possible effects from climate change. Rainfall is expected to become more variable over a range of different time scales from years to decades, with longer duration droughts punctuated by more intense rainfall and flooding. This suggests that highest water levels will increase in the future, but that the swamps will tend to be drier for longer, with lower water levels, as a result of increased evapotranspiration events (Bureau of Meteorology 2022; Cowley et al. 2019; UNSW 2022). Coastal upland swamps are threatened by the consumption of peat by fires during times of severe drought (Fryirs et al. 2019; NSW Scientific Committee 2012) and too frequent fires can lead to tree loss and hydrological change (Keith et al. 2006). Changes in the boundaries between swamps and adjoining woodlands over decadal time scales has been correlated with annual average rainfall (Keith et al. 2010). Methodology will be developed to track changes in swamps over time.

Aquatic and biological indicators

Soil health

Conservation context

RHG is a Hawkesbury sandstone plateau that rises from the ocean to 200 m in elevation (NPWS 2000). The Hawkesbury sandstone forms rugged terrain resulting in a landscape characterised by steep valleys and ridges, rocky outcrops, streams and waterfalls. This varied landscape creates habitat which supports a diversity of plant communities.

Monitoring of a diverse range of above-ground and below-ground indicators is important to provide information of ecosystem health (Dorrough et al. 2023). Information on soil composition can provide an assessment of nutrient cycling and organic matter turnover, can be used as predictors of ecosystem health, or may explain differences in ecosystem functioning.

Method and results

Soil samples were taken randomly in June 2023 from within each of the 40 vegetation plots surveyed using a soil corer (0–10 cm core with a 3.6 cm diameter). Four 3.6 × 10 cm cores were taken at each site to measure soil composition (total nitrogen, phosphorus, pH, total organic carbon) and one core sample for bulk density (to calculate tonnes of carbon per hectare). Samples were analysed by the department's Soil and Water Monitoring Laboratory, Yanco.

Soils from dry sclerophyll forest and heathland sites were low in nitrogen and phosphorus, reflecting the underlying sandstone geology (Figures 22 and 23). Rainforest soils recorded higher levels of nitrogen, phosphorus and total soil carbon compared with the other vegetation formations.

Discussion

Results from the soil sampling reflect the underlying parent geology of RHG, that is, low-nutrient sandstone soils. Rainforest sites recorded higher levels of nitrogen and phosphorus than other vegetation formations which is expected as they occur on higher nutrient, deep shale soils with an accumulation of organic matter on wetter soils. The build-up of organic matter, which occurs in rainforest and wet sclerophyll forest, explains higher levels of total organic carbon in these soils.

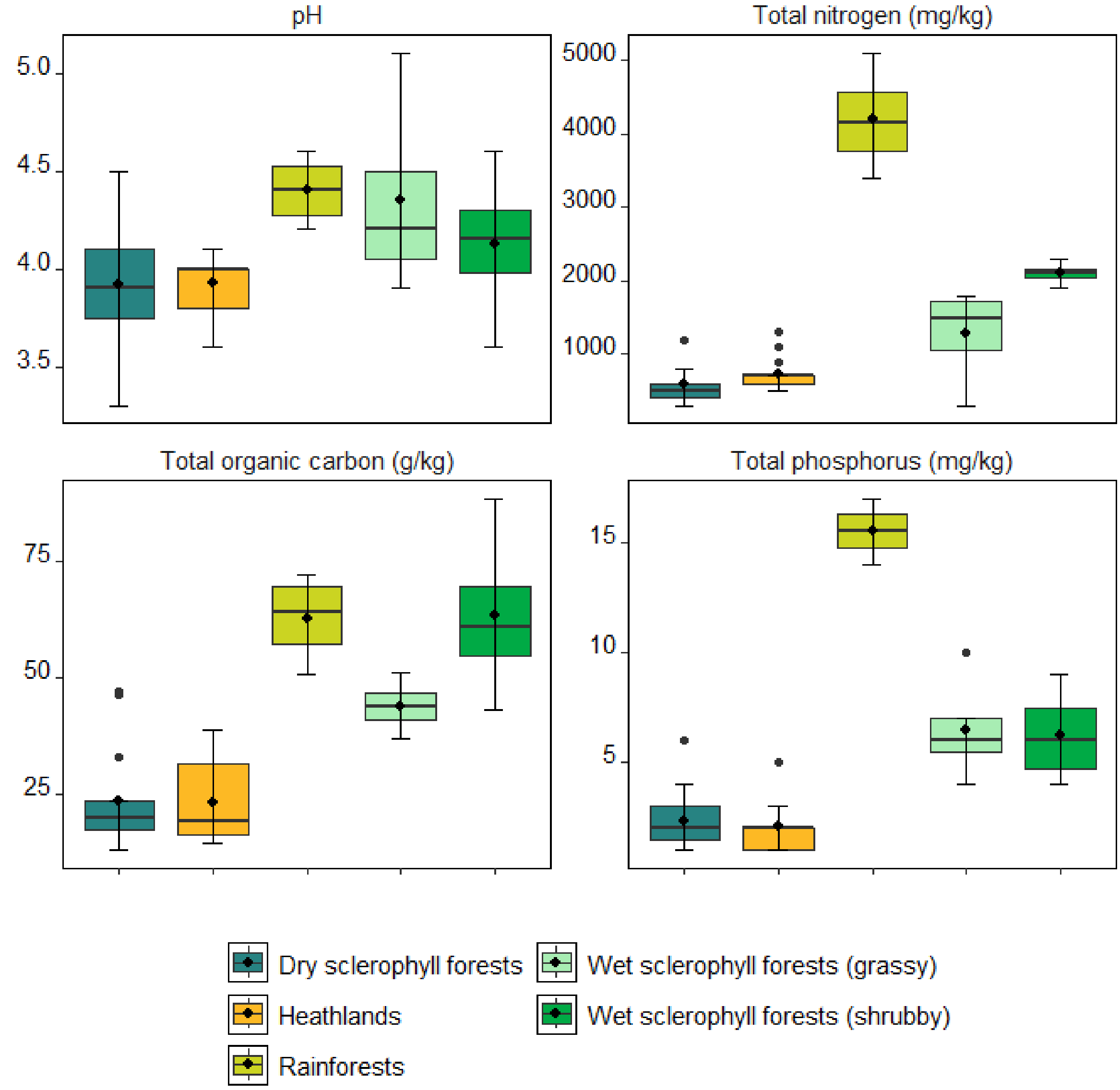


Figure 22 Boxplots summarising soil properties (phosphorous, PH, total organic carbon and total nitrogen) by each major vegetation formation in Royal–Heathcote–Garawarra in 2023

Lower and upper bounds of each coloured boxes represent the 25th and 75th percentile respectively (the interquartile range), the thick horizontal line within the coloured box indicates the median value and the black circle within the coloured box indicates the mean. Error bars represent the largest and smallest value within 1.5 times the 75th and 25th interquartile respectively. Black circles outside of the coloured box are outliers >1.5 and <3 times the interquartile range.

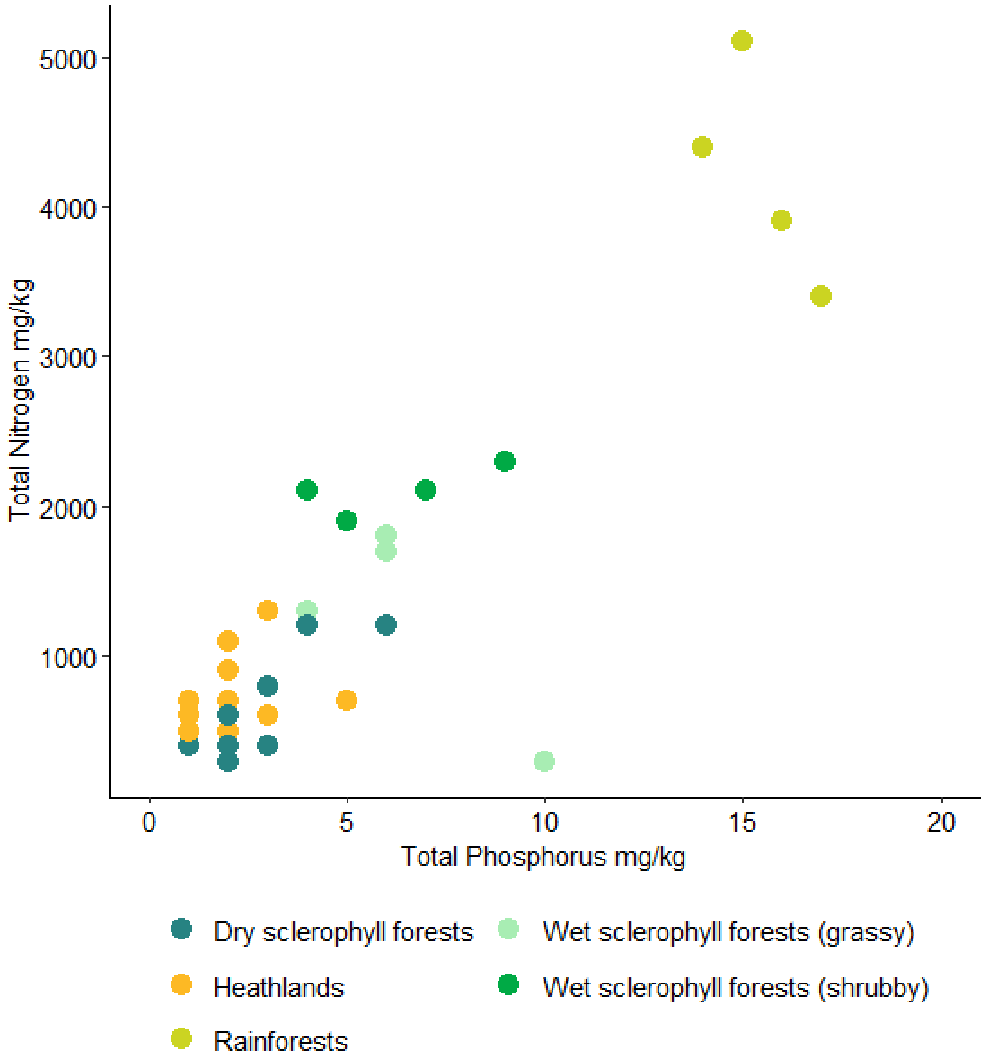


Figure 23 Soil nitrogen and phosphorus levels at each monitoring site by vegetation formation in Royal–Heathcote–Garawarra in 2023

Water quality

Conservation context

The ecosystems of RHG are supported by the major catchments of the Hacking and Woronora rivers. Both rivers originate outside of RHG, the Woronora from the south-west and the Hacking to the south-east. Both rivers are influenced by residential and rural-residential developments outside the park boundaries. Both river flows to the north before flowing into the Tasman Sea. The southern extent of the Hacking River valley in combination with moist, rich shale soils creates the microclimate that supports the relic ancient rainforest community and adjacent ecotone of wet sclerophyll forests. Several creeks along the eastern extent of Royal National Park have their catchments entirely within the park boundary and drain directly into the Tasman Sea.

Waterway monitoring is designed to understand the health of flowing streams and how they are impacted by human activity within their catchment as well as changes in the environment, such as fire, floods and climate change. Clean waterways with natural flows are essential to both aquatic and terrestrial biodiversity and ecosystem processes (Legge et al. 2023). The waterways in RHG are impacted by urban runoff from the surrounding residential areas and transport infrastructure, including roads and rail corridors, as well as localised activity within the park boundary. The Hacking River is also impacted by upstream coalmine discharges and spills.

Methods and results

In autumn and spring 2022, 20 sites on the Hacking River and smaller tributaries in the RHG catchment were sampled for water quality and stream macroinvertebrates (Figure 24). Survey methods were based on a river health stressor-response model developed and implemented by the department's Estuaries and Catchments Science Team and built on existing industry standards and practices where possible.

Site selection considered both administrative and physical boundaries, a review of historic monitoring sites, and water monitoring sites undertaken as part of the platypus introduction program, to create some program overlap. Twenty sites were selected to provide representative park-wide coverage of the RHG waterways based on spatial analysis of catchment and subcatchment boundaries, terrain, vegetation, roads, tracks, human habitation, national park infrastructure and satellite imagery. Sampling sites were at permanent streams, at a stream order of 3 or greater.

Overall site grade was assessed using water quality variables (dissolved oxygen, electrical conductivity, pH, filterable reactive phosphorus, ammonia, nitrogen oxides, total dissolved phosphorus, total nitrogen and turbidity), aquatic macroinvertebrates (Ephemeroptera, Plecoptera and Tricoptera [EPT] ratio, EPT richness, SIGNAL2-family average, taxa richness, AUSRIVAS OE50 (Chessman 2003; Lydy et al. 2000; Turak and Wardell 2002), and riparian and geomorphic condition data that is collected through a field monitoring program. The grading also considered land-use information derived from freely available spatial data. Where applicable, scores were derived via a comparison to *Default guideline values* (Australian Government 2023), derived from historic data available for NSW coastal catchments.

Spatial data was assessed by reclassification of multiple land-use categories into more broad categories that consider the potential for land use to influence aquatic ecosystem condition. This assessment method provided summary scores for water quality, riparian and geomorphic condition, land-use and reach disturbance, macroinvertebrate indices, including diversity, which were then summarised to derive an overall score and grade for each site and at subcatchment and catchment spatial scales.

The majority (70%) of waterways in RHG had very good and good water quality (Figures 24 and 25). Bundeena Gully, Saville Creek and Wilsons Creek and one site on the Hacking River (upstream from the weir in the visitor precinct near Audley) had poor and very poor water quality (20% of sites). These sites recorded at least one sample with water quality values outside the *Australian and New Zealand guidelines for fresh and marine water quality* guidelines (Australian Government 2018; referred to here as the ANZ guidelines') for nitrogen and phosphorus and very poor macroinvertebrate community diversity (Figures 26 to 28). Two waterways, Curracurrong Creek and a site on the Hacking River at the southern end of Lady Carrington Drive, had fair water quality. Levels of turbidity above ANZ guidelines were recorded from Kellys Creek, Wilsons Creek and at the Hacking River near Lady Wakehurst Drive (Figure 29). Elevated levels of electrical conductivity were found at in the upper Hacking River catchment near Lady Wakehurst Drive, Kelly Creek and Wilsons Creek (Figure 30).

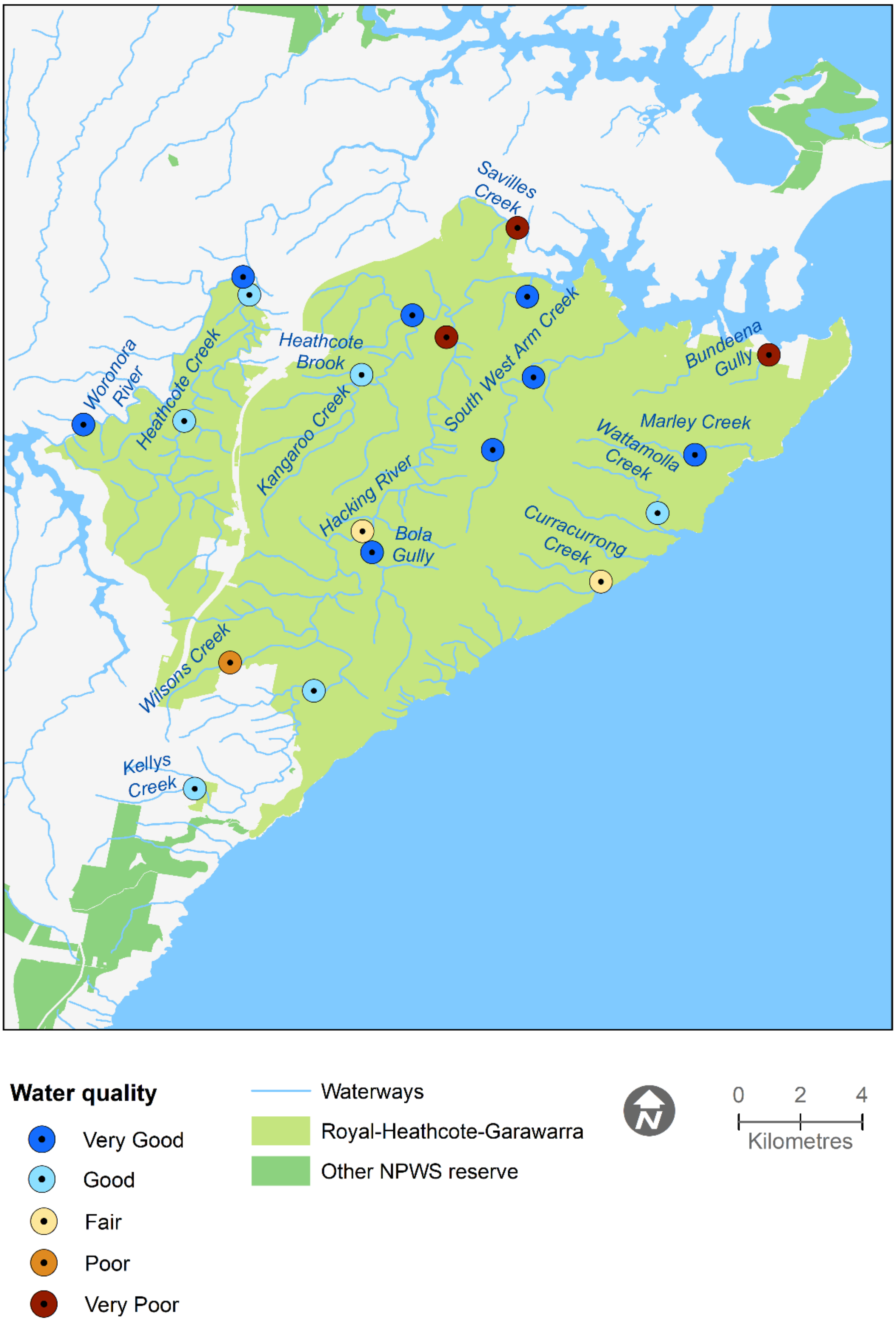


Figure 24 Ecological health of waterways in Royal–Heathcote–Garawarra in 2022

Results are based on testing that uses water quality chemical and physical stressors and macroinvertebrates as biological indicators of waterway health.

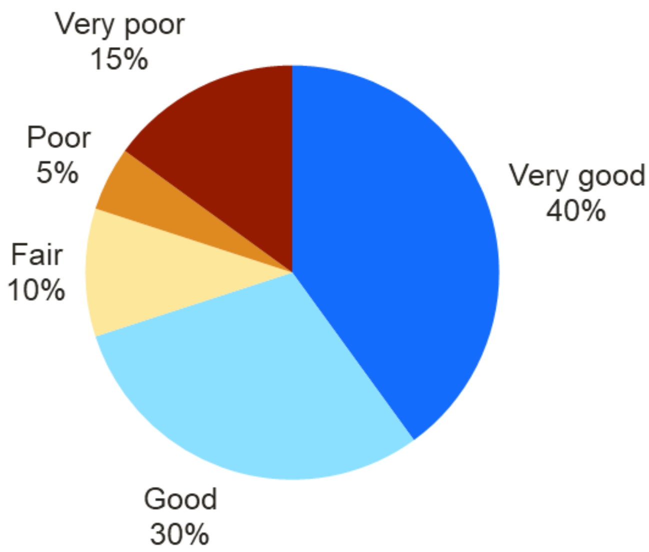


Figure 25 **Proportion of sampled waterways in Royal–Heathcote–Garawarra in each ecological health category in 2022**

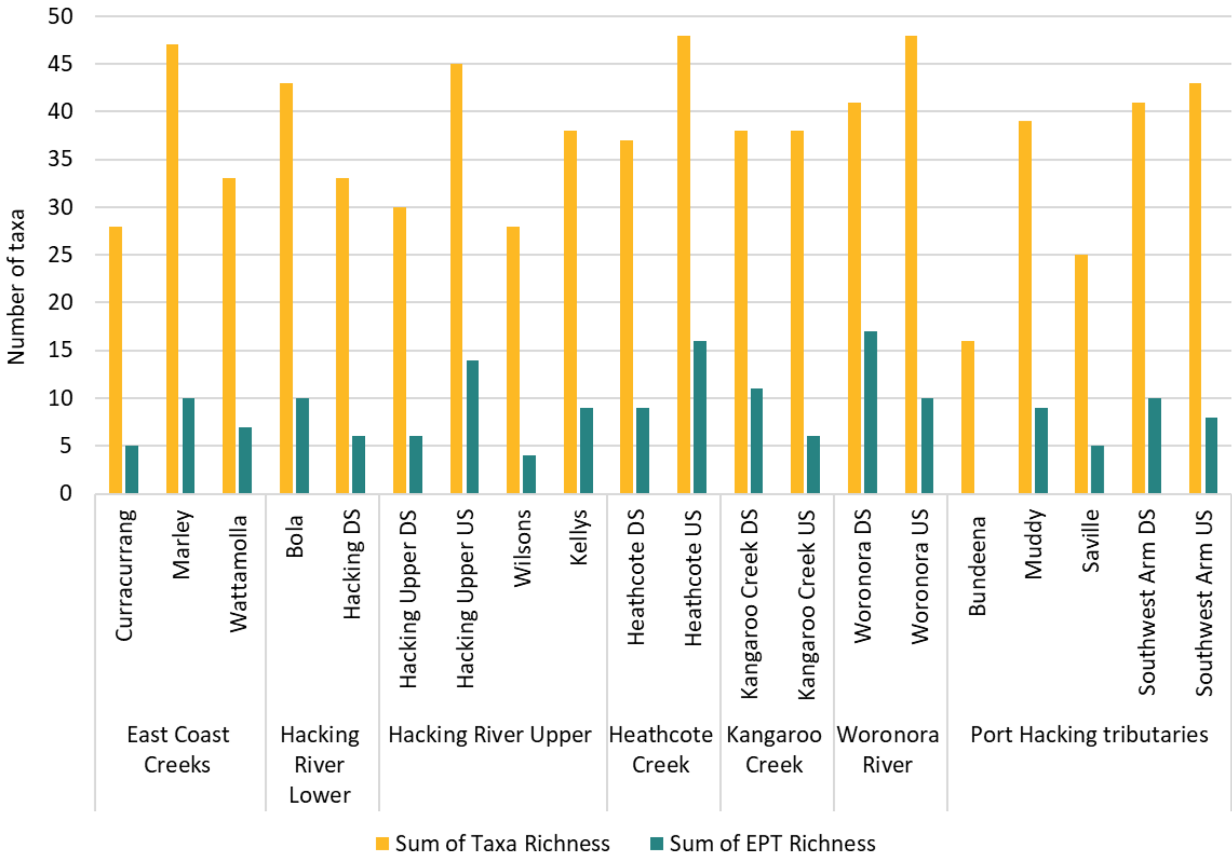


Figure 26 **Sum of macroinvertebrate taxa and Ephemeroptera, Plecoptera and Tricoptera (EPT) richness in Royal–Heathcote–Garawarra waterways sampled in autumn and spring 2022**

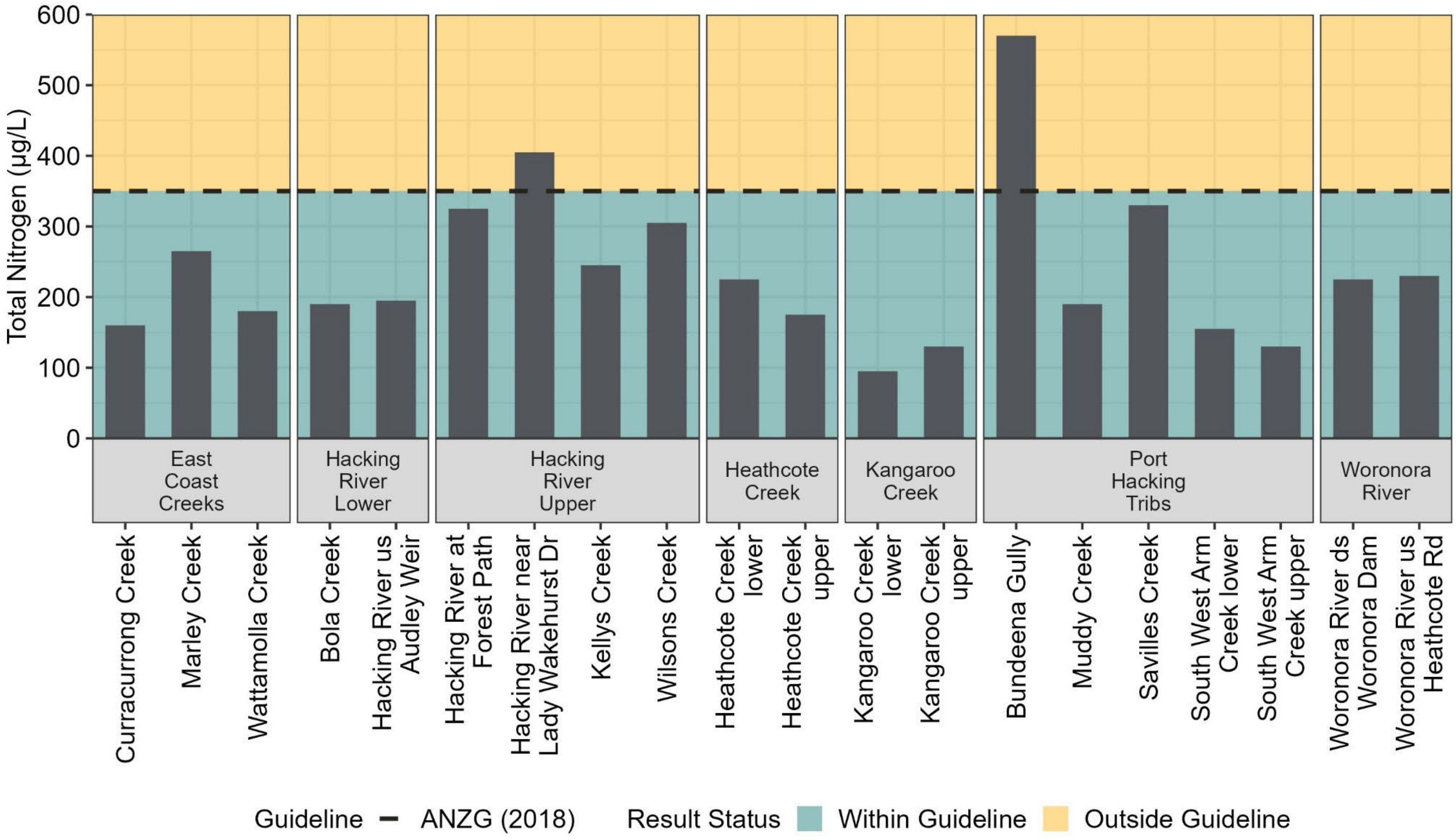


Figure 27 Average total nitrogen for Royal–Heathcote–Garawarra waterways sampled in autumn and spring 2022, showing relationship with ANZ guidelines (Australian Government 2018)

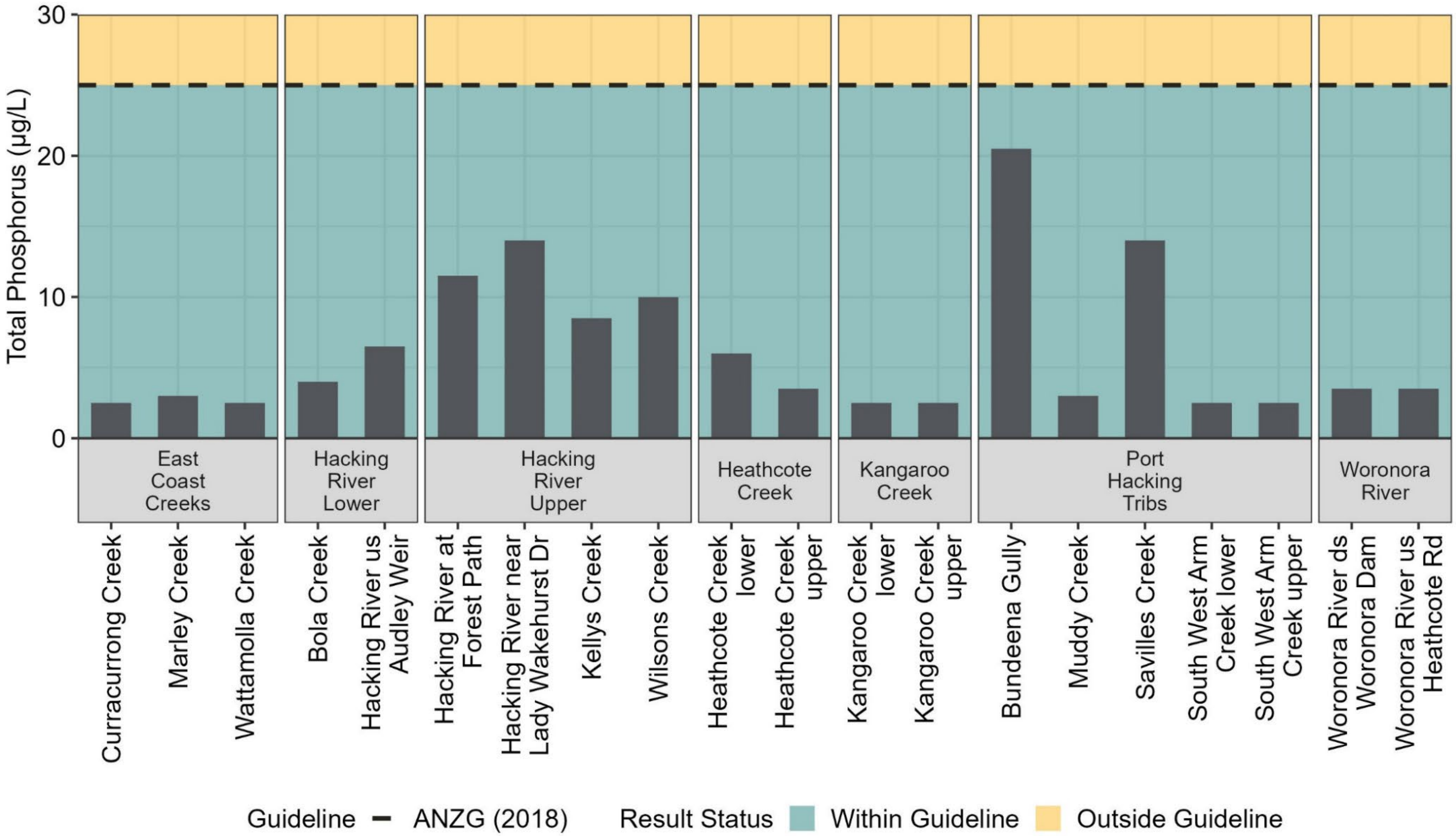


Figure 28 **Average total phosphorus for RHG waterways sampled in autumn and spring 2022, showing relationship with ANZ guidelines (Australian Government 2018)**

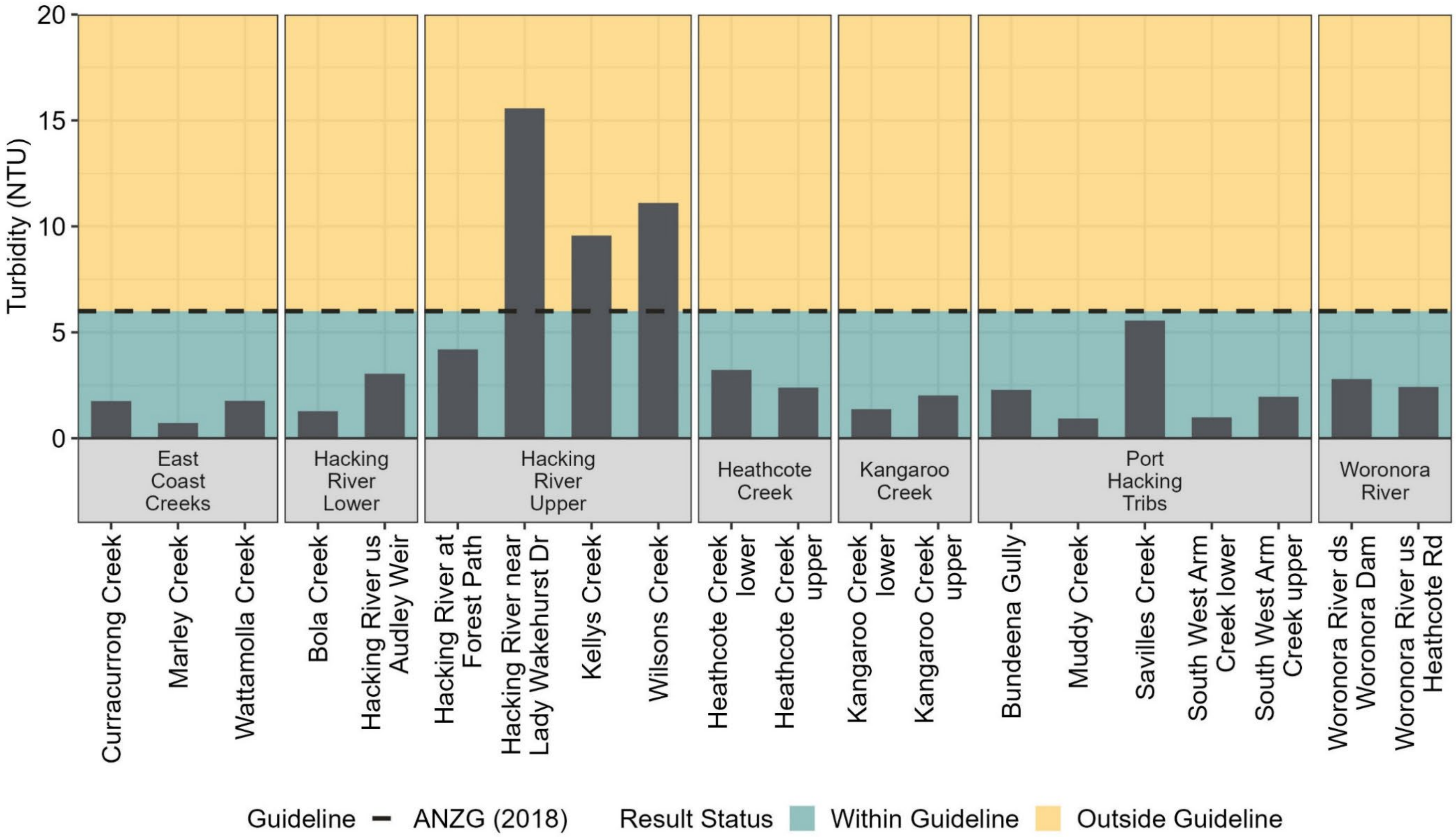


Figure 29 Average turbidity for RHG waterways sampled in autumn and spring 2022, showing relationship with ANZ guidelines (Australian Government 2018)

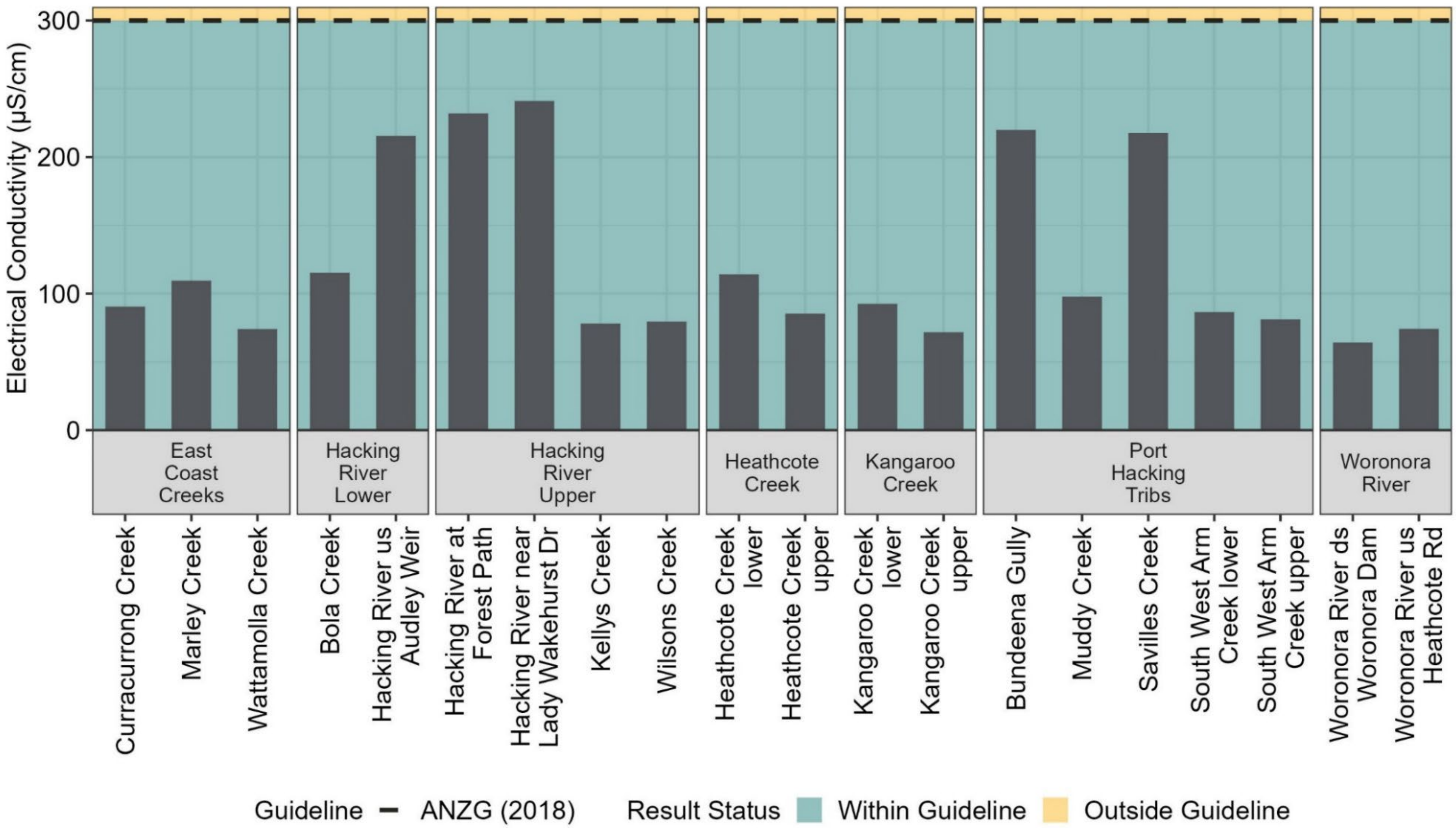


Figure 30 **Average electrical conductivity for RHG waterways sampled in autumn and spring 2022, showing relationship with ANZ guidelines (Australian Government 2018)**

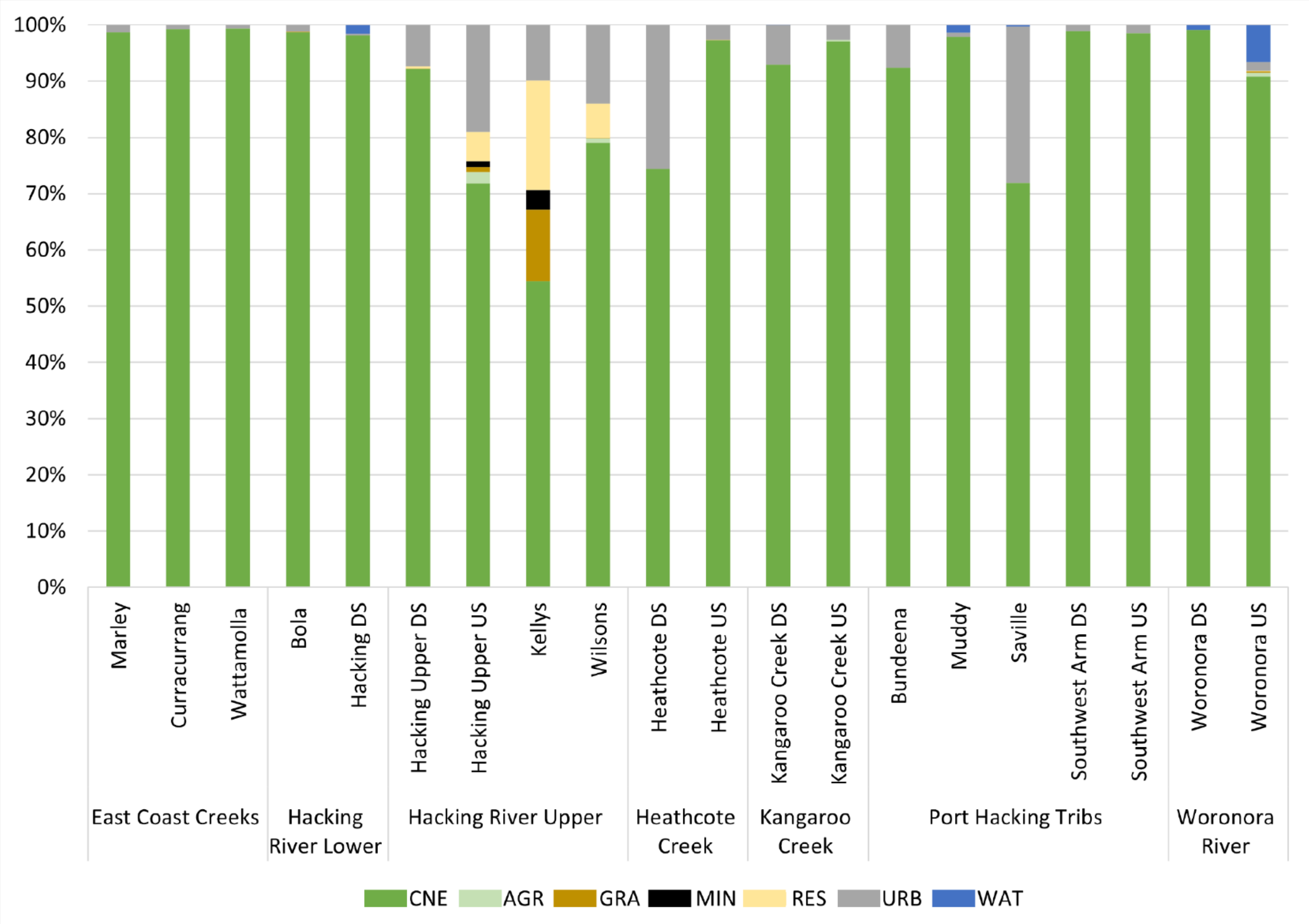


Figure 31 Subcatchment land use (%) in Royal–Heathcote–Garawarra by waterway and catchment of Scorecards water quality monitoring sites.

US = upstream, DS = downstream, CNE = conservation and environment, AGR = agriculture, GRA = grazing, MIN = mining, RES = residential, URB = urban, WAT = other.

Discussion

The park-wide water quality analysis for RHG found that most waterways are in good condition with 70% having very good and good water quality. Three of the 4 water quality sampling sites that were found to be in very poor or poor condition are located near to a park boundary and adjacent to residential areas (Figure 31). The fourth site is located on the Hacking River immediately upstream of the weir at the visitor precinct at Audley. Fair water quality was recorded on the Hacking River near the southern end of Lady Carrington Drive and in Curracurrang Creek.

Mine operation discharges, including several spills in autumn 2022 following record breaking rainfall events, likely contributed to the poor water quality and physical stressor values, leading to lower diversity of pollution-sensitive macroinvertebrates in the lower Hacking River monitoring sites.

The water quality sampling site upstream of the Audley weir suffers from water quality issues as it is at the end of the catchment and receives the cumulative impacts of the catchment upstream. It can also have issues during periods of low rainfall as water and sediment are trapped behind the weir resulting in a concentration of pollutants. Rainfall resulting in higher streamflow flushes the trapped water and, depending on flow discharge, volumes and velocities, the sediment carrying with it the pollution built up from behind the weir into Port Hacking downstream.

The east coast Curracurrang Creek was found to have fair water quality, despite its catchment being located entirely within the park bushland. However, a fair water quality result could be considered normal for this creek as it has a small catchment and a bedrock dominated streambed, such that high rainfall can result in scouring of the stream bed, producing a lowered diversity of macroinvertebrate taxa. This is likely a natural process, which identifies a need to establish site-specific, or ecotype-specific, target values for water quality and macroinvertebrate indices to better understand the health of this and similar waterways.

Park-wide threats

Feral animals and weeds are important threats to both manage and monitor across NPWS parks. Monitoring of feral animals will be guided by protocols developed for each feral animal species to ensure a standard approach in survey design and reportable metrics across NPWS.

Due to the sheer number of weed species and reserve sizes, a consistent approach will be developed to focus weed monitoring efforts on a selection of priority weeds. As much as is practicable, all weed species that are likely to have a significant ecological impact will be monitored. The approach will be based on ecological risk and will be developed in consultation and collaboration with experts to ensure a rigorous approach. Subsequent protocols will be developed for each species to ensure a standard approach in survey design and reportable metrics.

Feral cat

Conservation context

Feral cats (*Felis catus*) are widely regarded as a key driver of mammal extinction and decline in Australia (Woinarski et al. 2015). Predation by feral cats has been listed as a key threatening process under the Biodiversity Conservation Act and Environment Protection and Biodiversity Conservation Act.

Methods and results

In 2022, no cats were detected on park-wide surveillance monitoring cameras at any of the 34 monitoring sites.

Discussion

Cats are a mobile species that use a focal area for short periods of time and then foray more broadly within the area of their long-term home range. As such, they have low levels of detections on camera traps (Stokeld et al. 2015). The absence of cat detections from the park-wide surveillance monitoring sites does not categorically indicate that they are not present in RHG. Feral cats are known from RHG but likely present in low densities. Dedicated surveys to better understand occurrence and density will be established in 2024–25 financial year.

Red fox

Conservation context

Foxes (*Vulpes vulpes*) are regarded as a driver of mammal extinction and decline in Australia (Woinarski et al. 2015). Predation by the European red fox has been listed as a key threatening process under the Biodiversity Conservation Act and Environment Protection and Biodiversity Conservation Act.

Methods and results

In 2022, park-wide surveillance monitoring cameras at 34 sites were used to detect foxes in RHG. Foxes were detected at 85% of sites and an overall activity measure of 3.5 ± 0.7 detections per 100 camera days (Figure 32, Table 12). Site occupancy by foxes was the second highest of all species detected (after swamp wallaby) and the activity was the fourth highest of all species detected (behind swamp wallaby, antechinus species and rusa deer). Foxes were detected more frequently in rainforest than other vegetation formations.

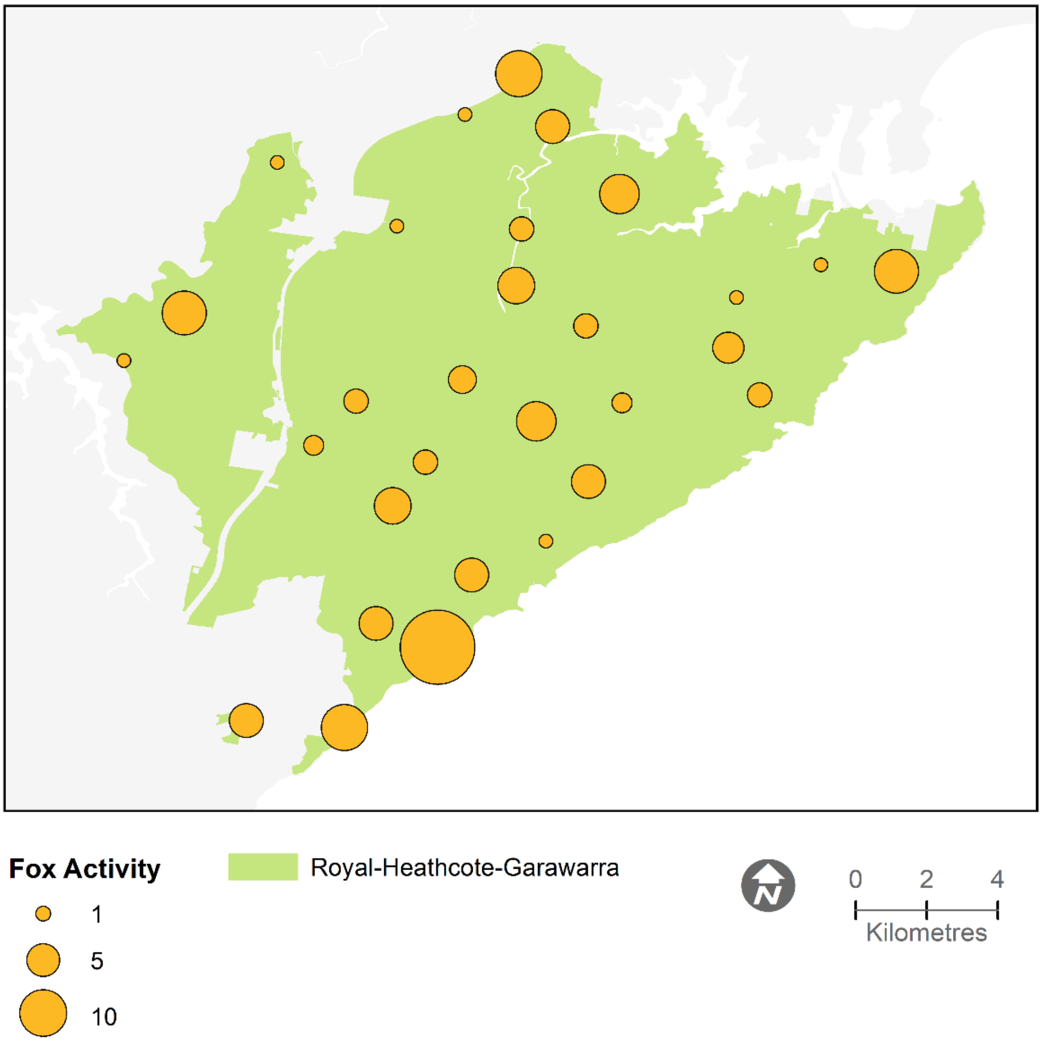


Figure 32 Proportional fox activity at Royal–Heathcote–Garawarra park-wide surveillance monitoring sites

Activity is a relative abundance index of unique detections per 100 camera days.

Table 12 Feral animal occupancy and activity in Royal–Heathcote–Garawarra, 2022

Species	Occupancy (naïve)	Activity*	Density
Feral cat	0	0	–
Red fox	85%	3.5 ± 0.7	–
Rusa deer	44%	6.5 ± 3.5	–

* (mean ± standard error, unique detections per 100 camera days)

Management summary

In March 2023, $9,637 was spent on an aerial baiting control operation for foxes in Royal National Park. The control operation deployed 820 meat baits, each containing 3 mg of 1080, over 80 km of aerial transect at a rate of 10 baits per kilometre. The aerial baiting consisted of 20 transects.

Discussion

The very high level of occupancy and activity of foxes in RHG is expected for parks located adjacent to an urban area, which historically has not had an ongoing park-wide fox control program. A park-wide aerial baiting program for foxes commenced in Royal National Park in 2023. It is important to note that the park-wide surveillance monitoring cameras are not placed on formed walking tracks, trails and roads, as is often the case in camera trap monitoring programs for foxes. As such, the activity index value may be orders of magnitude less than observed on formed trail-based programs, but it provides an unbiased estimate of relative activity (Sollmann et al. 2013; Raiter et al. 2018; Wysong et al. 2020).

Rusa deer

Conservation context

Rusa deer have been an invasive species in RHG for over a century (Keith and Pellow 2005). Trampling and herbivory by deer negatively impact on vegetation cover (resulting in sparse cover), and cause soil erosion. Herbivory and environmental degradation caused by feral deer is listed as a key threatening process under the Biodiversity Conservation Act.

Survey results

In 2022, park-wide surveillance monitoring detected rusa deer at 44% of monitoring sites and an activity measure of 6.5 ± 3.5 detections per 100 camera days (Figure 33). Rusa deer were detected in the north, west and southern parts of RHG, predominantly in rainforests and wet sclerophyll forests. Deer were not detected in the centre of RHG nor on the outer north, west and southern edges of Heathcote National Park. Minimal activity was detected in heathland. Rusa deer activity was the third highest of all species detected (behind swamp wallaby and antechinus). The southernmost site in RHG had the highest activity rate of 115 detections per 100 camera days, 18 times the average activity rate for all species.

Management summary

In 2022–23 financial year, a total of 164 rusa deer were shot in 8 days of aerial shooting (35 hours). The 2022–23 deer control program cost $32,422 and took 489 staff hours. In 2021–22, a total of 312 rusa deer were shot, 123 in 13 days of ground shooting and 189 in 4 days of aerial shooting. The 2021–22 deer control program cost $85,831 ($7,549 ground, $78,282 aerial) and took 1,182 staff hours (195 ground, 987 aerial).

Discussion

Rusa deer remain an ongoing threat to biodiversity values in RHG, despite annual ground and aerial control programs. Ongoing monitoring is needed to measure the long-term effectiveness of current control programs. Of most concern, is the southern end of RHG where very high deer activity was detected (Figure 33). This section of RHG poses challenges for deer control because of proximity to privately owned huts. The southern end of RHG has a continuous bushland connection with the Illawarra escarpment which provides an ongoing source for deer incursion. Control techniques that may be suitable for the southern boundary of Royal National Park and areas in Heathcote National Park should be investigated.

Methods for estimating and monitoring the density of rusa deer are to be developed. Aerial survey methods using infra-red cameras are less effective in RHG due to the large areas of closed canopy vegetation.

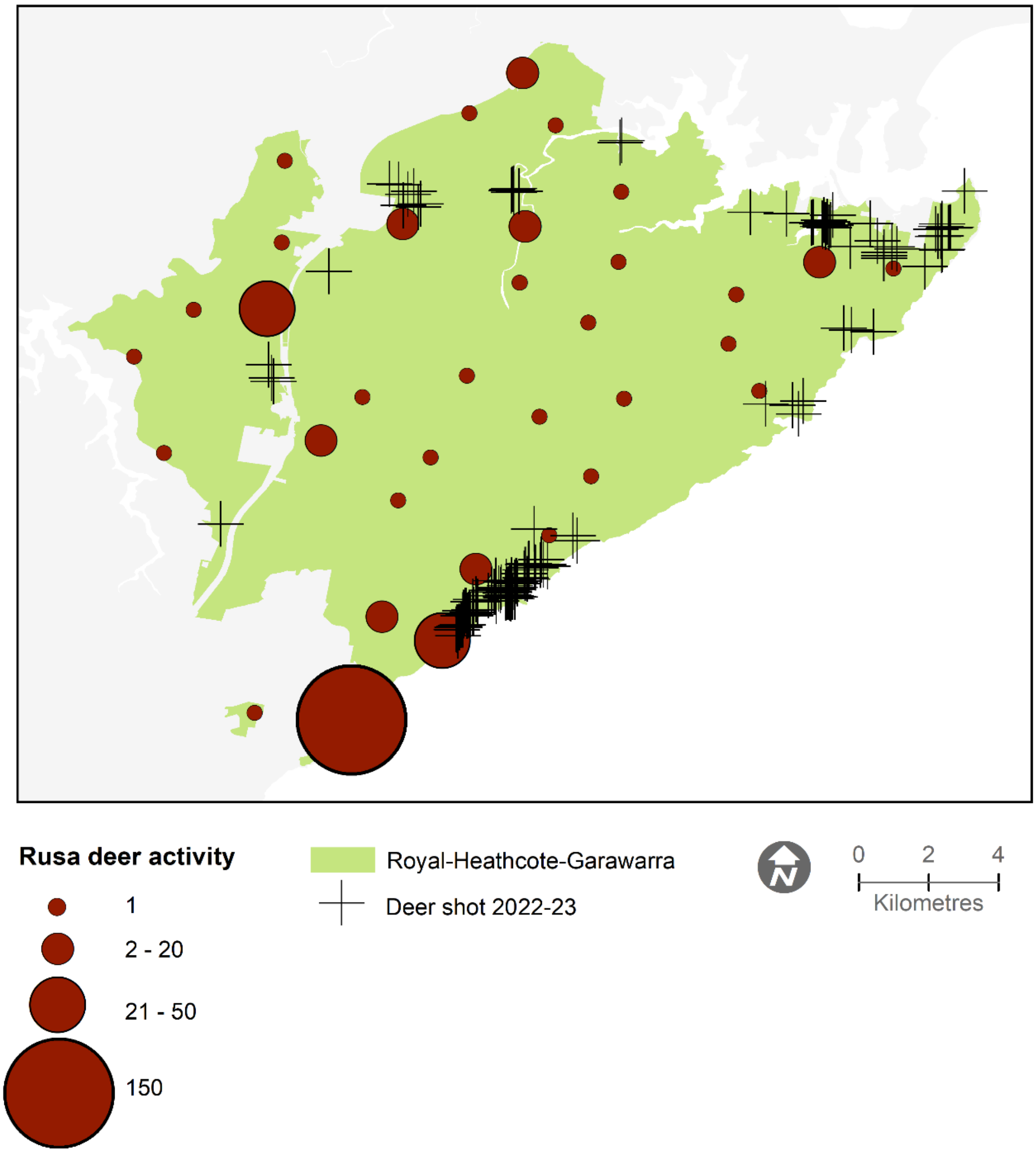


Figure 33 Proportional deer activity at Royal–Heathcote–Garawarra park-wide surveillance monitoring sites in 2022

Activity is a relative abundance index of unique detections per 100 camera days.

Weeds

Conservation context

Despite ongoing management, weeds persist and continue to impact on ecological assets and processes in RHG. Management actions for weeds are most often focused on regional priority species (prevention, eradication and containment) and conservation asset protection, with the intent of assigning available resources to best effect (Local Land Services 2022).

A current list of priority control species in RHG, based on existing NPWS management programs, includes boneseed (*Chrysanthemoides monilifera*), holly-leaved senecio (*Senecio glastifolius*), sea spurge (*Euphorbia paralias*) and aquatic weeds. Priority assets for weed treatment are littoral rainforest, Marley freshwater wetlands and threatened ecological communities in the following areas: Bonnie Vale, Heathcote, Hacking River, Jibbon and Loftus Heights/Garners.

Weed management programs include several techniques such as physical removal of weeds, and targeted herbicide application using backpack or vehicle-mounted spray units. Weed control activities are reported as part of the NPWS Pest and Weed Information System (PWIS). The recording of this information improves ongoing planning and ensures appropriate follow-up is undertaken. Weed control may remove living weeds, however, some weed species may have viable seed for 50 or more years, for example, scotch broom (*Cytisus scoparius)*. Surveillance for re-emergent weeds is important for long-term success and is an important component of weed management programs.

Methods and results

Weeds were only detected at 4 surveillance monitoring sites and at low abundance. These weeds were sheep's sorrel, crofton weed, whisky grass, *Conyza* species, and flatweed.

Management summary

Weed control by NPWS staff, contractors and volunteers is recorded with the Field Manager smart phone app and reported in PWIS. Weed records are recorded by species either as a point record, line transect or polygon. Line transects and polygons often have more than one species reported as treated. For the purposes of reporting area treated and program costs, the primary weed species recorded was used to assign a weed record to either a target species or functional weed group. Therefore, weed metrics may be overstated for some species or weed groups and understated for others. In addition, point records, unlike the line and polygon records, have no recorded area and have been assumed to occupy 0.0001 ha (1 m^2), in line with other NPWS weed reporting.

In 2022–23 financial year, NPWS invested 2,798 hours (staff and volunteer) in weed control programs that treated 243 ha of weeds at a cost of $123,419 (Table 13, Figure 34). Most of the time invested in weed control was by volunteers along the Hacking River corridor, where they helped control a variety of species including exotic perennial grasses, vines and scramblers, woody weeds and other widespread weeds. Boneseed control, a regional priority eradication species, was the largest targeted single species program, with 124 hours and $20,711 spent searching for and controlling this weed over 47 ha. Sea spurge and holly-leaved senecio programs treated 39 ha and 5 ha, respectively. In 2022–23, outbreaks of aquatic weeds, Senegal tea (*Gymnocoronis spilanthoides*), yellow water poppy (*Hydrocleys nymphoides*) and *Ludwigia peruviana*, were controlled.

Discussion

The current NPWS approach to weed management is guided by Branch pest management strategies, weed control priorities plans, and weed priorities from Local Land Services' regional strategic weed management strategies (Local Land Services 2023). Except for a few priority species, NPWS does not have park-wide monitoring established for weeds. Monitoring is usually based on comparing changes in the area of weed control between time periods, which may not reflect changes in the total area occupied by weeds in a reserve.

NPWS is currently revising its overall approach to weed control and monitoring. The revised approach will, to the extent practicable and subject to resources, seek to ensure all weed species that are having an ecologically significant impact are monitored and managed. Consistent with this approach, the weeds relevant to each Scorecards reserve will be ranked using a bespoke, semi-quantitative methodology focused on weed impact on biodiversity including threatened species, environmental health and distribution. The final number of weeds monitored in each Scorecards reserve will be determined by available resources. Monitoring will capture area occupied by these weed species and guide future control efforts. Future Scorecards will report on change in area occupied by these weed species over time.

Table 13 Weed control programs in Royal–Heathcote–Garawarra in 2022–23 financial year

Indicator	Expenditure ($)	Management activity	Input (staff and volunteer)	Output (area treated)
All weed species	$123,419	Foliar spraying, cut and paint, hand pulling	2,798 hrs	243 ha
Boneseed	$20,711	Searching, hand pulling and foliar spray	124 hrs	47 ha
Sea spurge	$5,188	Hand pulling	58 hrs	39 ha
Holly-leaved senecio	$1,088	Hand pulling	12 hrs	5 ha
Aquatic weeds	$8,502	Foliar spray, aquatic tablet	104 hrs	28 ha
Exotic perennial grasses	$87,930	Foliar spray, cut and paint, stem injection, hand pulling	2,500 hrs	6 ha+
Vines and scramblers				17 ha+
Woody weeds				74 ha+
Other widespread weeds				27 ha+

Note: +ha of control based on the primary weed reported in the NPWS Pest and Weed Information System (PWIS) and therefore weed metrics may be overstated for some species and understated for others.

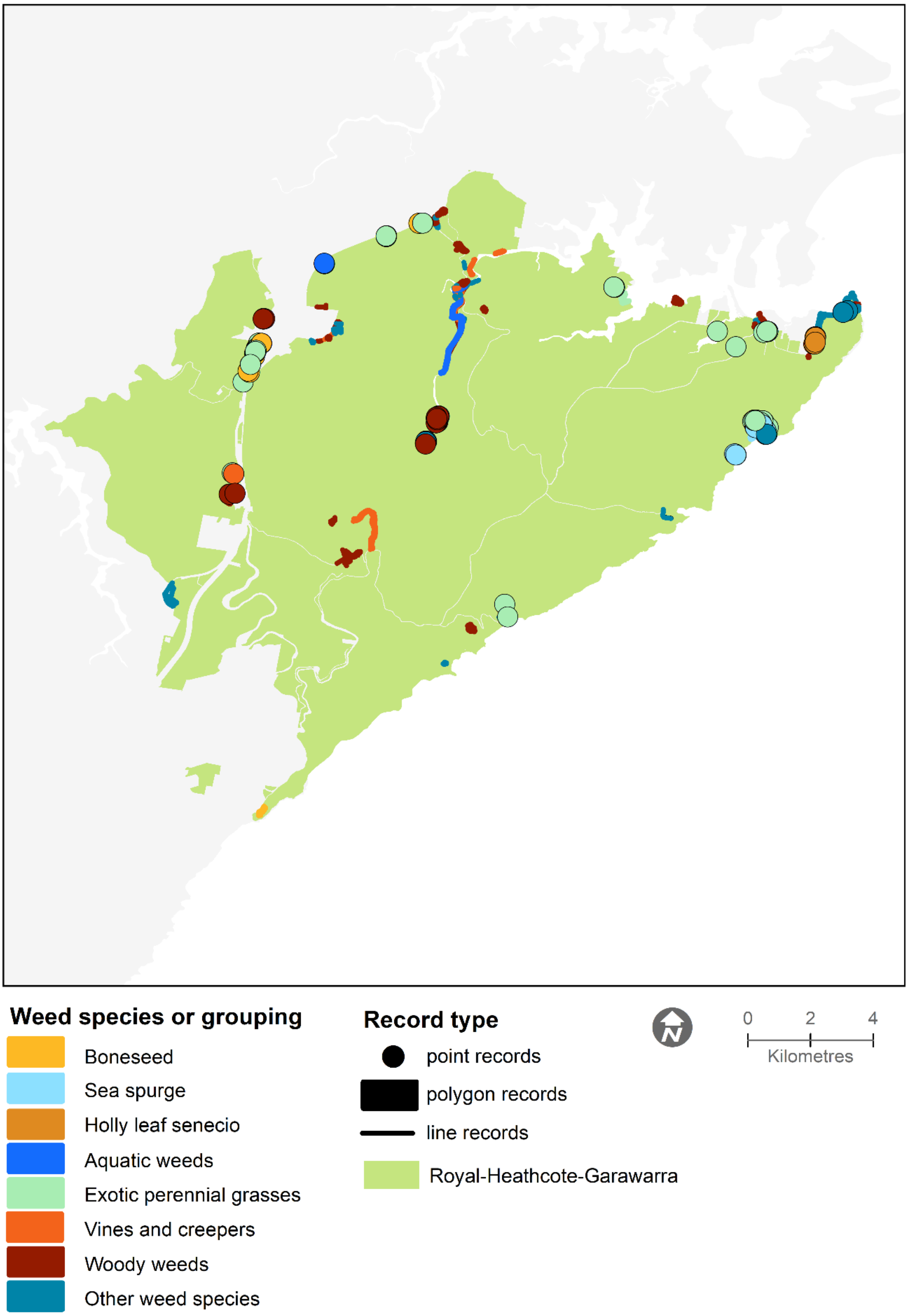


Figure 34 Locations of weed control in Royal–Heathcote–Garawarra in 2022–23 financial year

Climate change

RHG has a mean annual maximum day time temperature of 23.3°C and annual minimum temperature of 11.2°C (Figure 35, Holsworthy Aerodrome AWS, located 13.4 km away). The average rainfall recorded in RHG between 2005 and 2023 was 1,157 mm (Figure 36). While rainfall in 2021 and 2023 were relatively consistent with the long-term average, a higher-than-average rainfall occurred in 2022 (Figure 36), especially in the months between February and May and again in July (Figure 37), due to a La Niña weather system.

The NSW Government *Interactive climate change projections map* provides information on climate across New South Wales (AdaptNSW 2024) and the Australian Government Bureau of Meteorology's *State of the climate 2022* report provides a synthesis of climate projections across Australia (Bureau of Meteorology 2022). Based on these 2 sources, RHG is projected to experience continued increase in air temperature of around 0.6°C by 2040 and 2°C by 2060 and 2079, more heat extremes, and an increase in the number of high fire danger days. Overall rainfall is predicted to increase by 7–10% by 2060 to 2079, however, a decrease in cool season rainfall is likely to lead to more time in drought. Ongoing climate variability will give rise to short-duration heavy rainfall events at a range of time scales.

Impacts of climate change on our biodiversity and ecosystem health are wide-ranging but there is a large degree of uncertainty around future timelines of impacts. Heat extremes will threaten southern greater gliders (Wagner et al. 2020) and longer time in drought may impact some frog and plant species and leave upland swamps more vulnerable to bushfire (Cowley et al. 2019). Climate change projections of larger, more frequent fires may threaten slow-maturing, fire-sensitive plant species, such as the villous mint bush, and vegetation communities such as rainforest and upland swamps (Abatzoglou et al. 2019; AdaptNSW 2024; Enright et al. 2015; Gallagher et al. 2021; Jones et al. 2022).

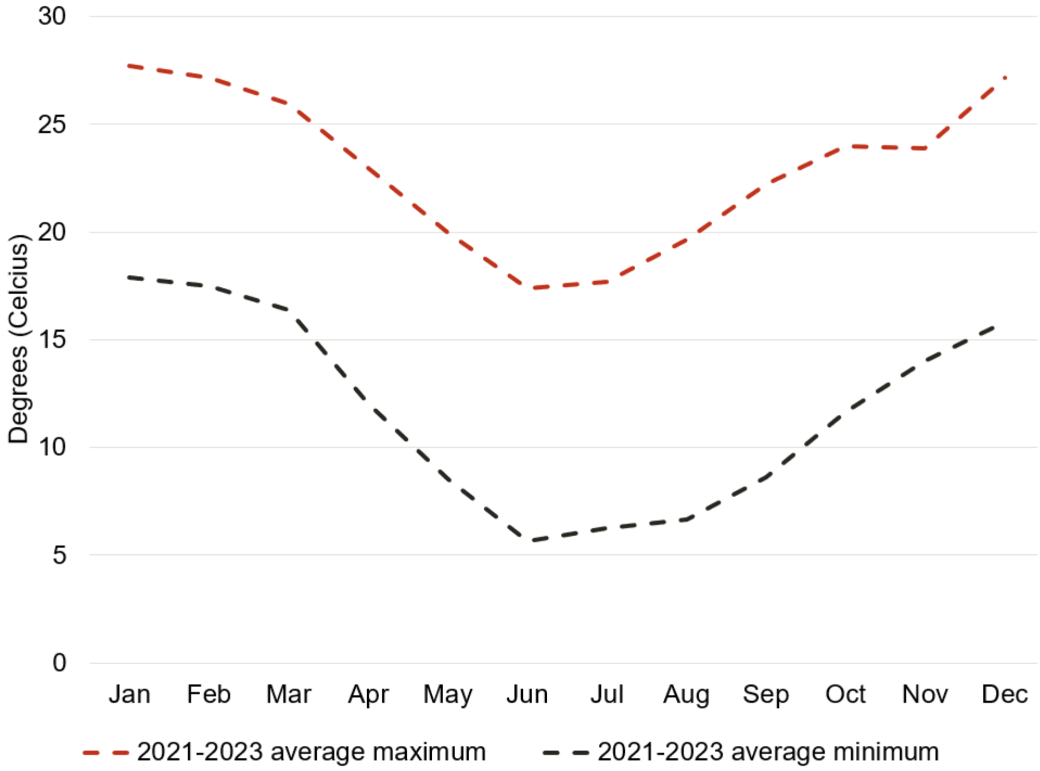


Figure 35 Monthly average maximum and minimum temperatures for 2021 to 2023

Source: Holsworthy Aerodrome AWS station number 66161 (Bureau of Meteorology 2024)

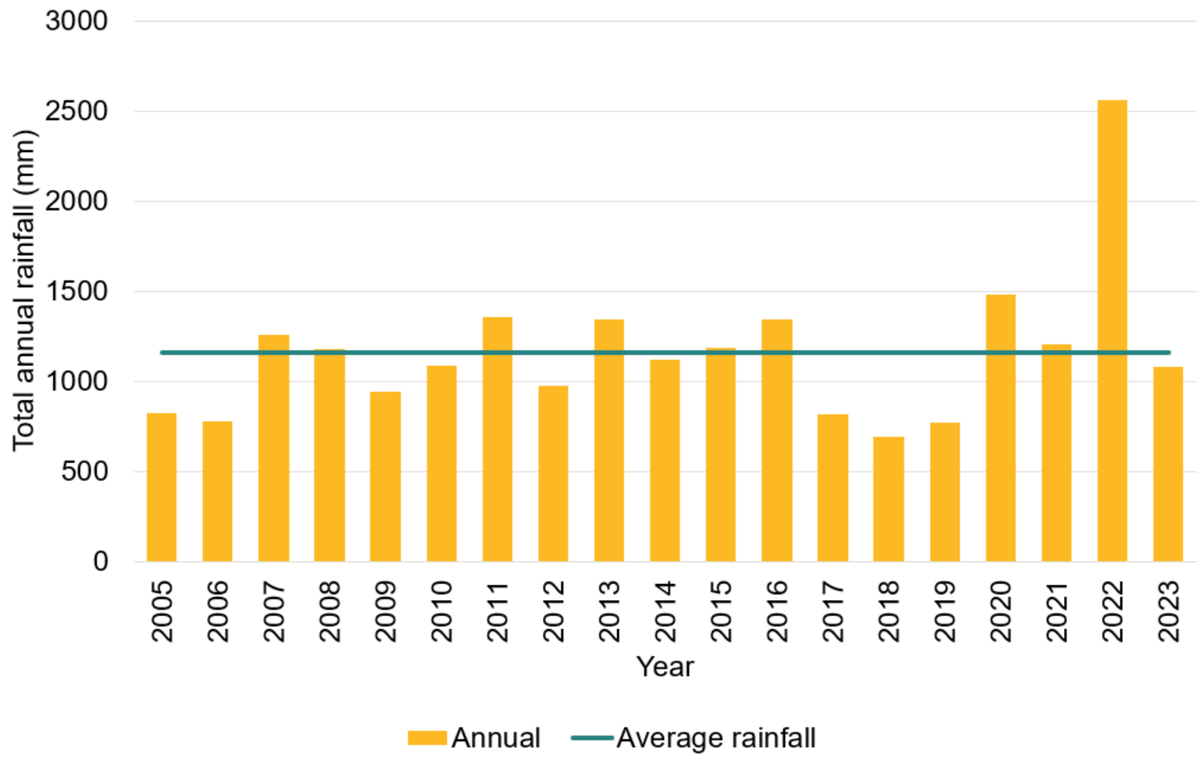


Figure 36 **Annual rainfall (and average rainfall) from 2005 to 2023 at Audley station number 066176 (Royal National Park)**

Total annual rainfall shown as bars and average annual rainfall shown as a solid line. (Bureau of Meteorology 2024)

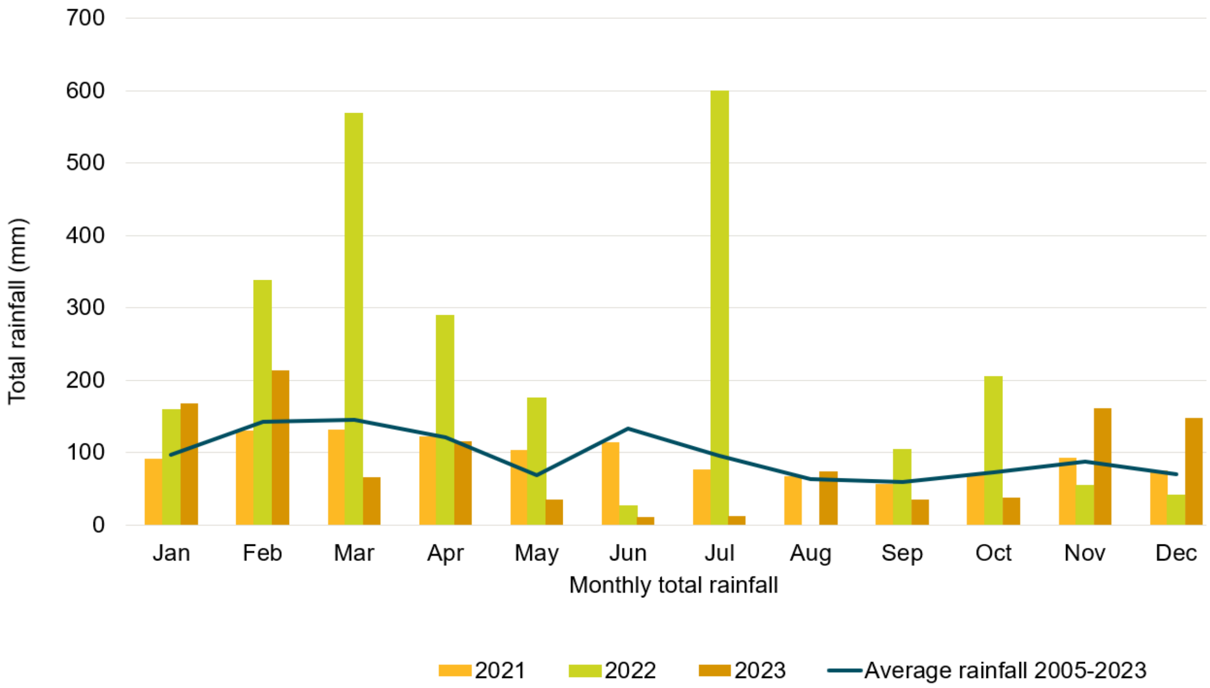


Figure 37 **Monthly rainfall (and average rainfall) from 2021 to 2023 – Audley station number 066176 (Royal National Park)**

Total rainfall per month shown as bars and average monthly rainfall shown as a solid line. (Bureau of Meteorology 2024)

Park-wide fire metrics

Conservation context

Fire metrics provide a high-level overview of fire regimes across the scorecard site, including changes over time in the absolute and relative extent of prescribed burns and bushfires.

Recent fire history of RHG has seen widespread frequent fires from 1988 to 2001, followed by a decade with very little fire, and a mosaic of hazard reduction burns this decade (Table 14, Table 15, Figure 38). Bushfires burnt >50% of Royal National Park in each of the years: 1988–89, 1994 and 2001. The 1994 fire burnt 95% of the park at high intensity, with most of the canopy burnt in many places across the landscape. The intervals between these 3 large bush fires were too short for many plant species to reach maturity and replenish seed banks (Enright et al. 2015) and is likely to have caused biodiversity changes, most notably the collapse of the population of the southern greater glider in Royal National Park (Goldingay 2012). The ability for wildlife to persist following a large bushfire will depend on their ability to immediately survive the fire, the availability of unburnt habitat and the resources to sustain species (food and shelter), and the availability of a source population to recolonise the recovering landscape.

The highest priority for fire management at RHG is to protect life and property, given the large urban interface. This is consistent with a broad ecological objective to support ecological processes within vegetation communities while avoiding a fire regime that is characterised by widespread, severe and frequent fire.

Table 14 Area burnt in Royal–Heathcote–Garawarra

	2022–23 financial year		20-year average	
	Area (ha)	% of reserve	Area (ha)	% of reserve
Total area burnt	3.1	0.02	336.7	1.76
Total area with canopy burnt	0.1	0	152	0.79
Total area unburnt	19,139	99.98	18,805	98.24
Prescribed burn area	3.1	0.02	189	0.99
Prescribed burn – canopy burnt	0.1	0	n/a	n/a
Prescribed burn by zone type:				
Area of SFAZ	2,218	11.59	n/a	n/a
Prescribed burn – actual area burnt – SFAZ	3.1	0.02	87.4	0.46
Area of LMZ	16,775	87.64	n/a	n/a
Prescribed burn – actual area burnt – LMZ	0	0	101	0.53
Bushfire area burnt	0	0	148	0.77
Number of bushfires	0	0	3.5	n/a
% of bushfires <10 ha	n/a	n/a	n/a	n/a
% of bushfires contained on-park	n/a	n/a	n/a	n/a

Area burnt metrics are calculated from NPWS Fire History data, and fire severity (canopy fires) is calculated from Fire Extent and Severity Map data.

Table 15 Fire patchiness in Royal–Heathcote–Garawarra

Fire patchiness	10-year average	20-year average	30-year average
Average (range) distance (m) between burnt and long-unburnt patches	7,558 (282–13,262)	7,558 (282–13,262)	7,105 (1,178–12,306)
Heterogeneity index (burnt/unburnt)	Being developed		
Heterogeneity index (canopy burnt)	Being developed		

Note: SFAZ = strategic fire advantage zone; LMZ = land management zone.

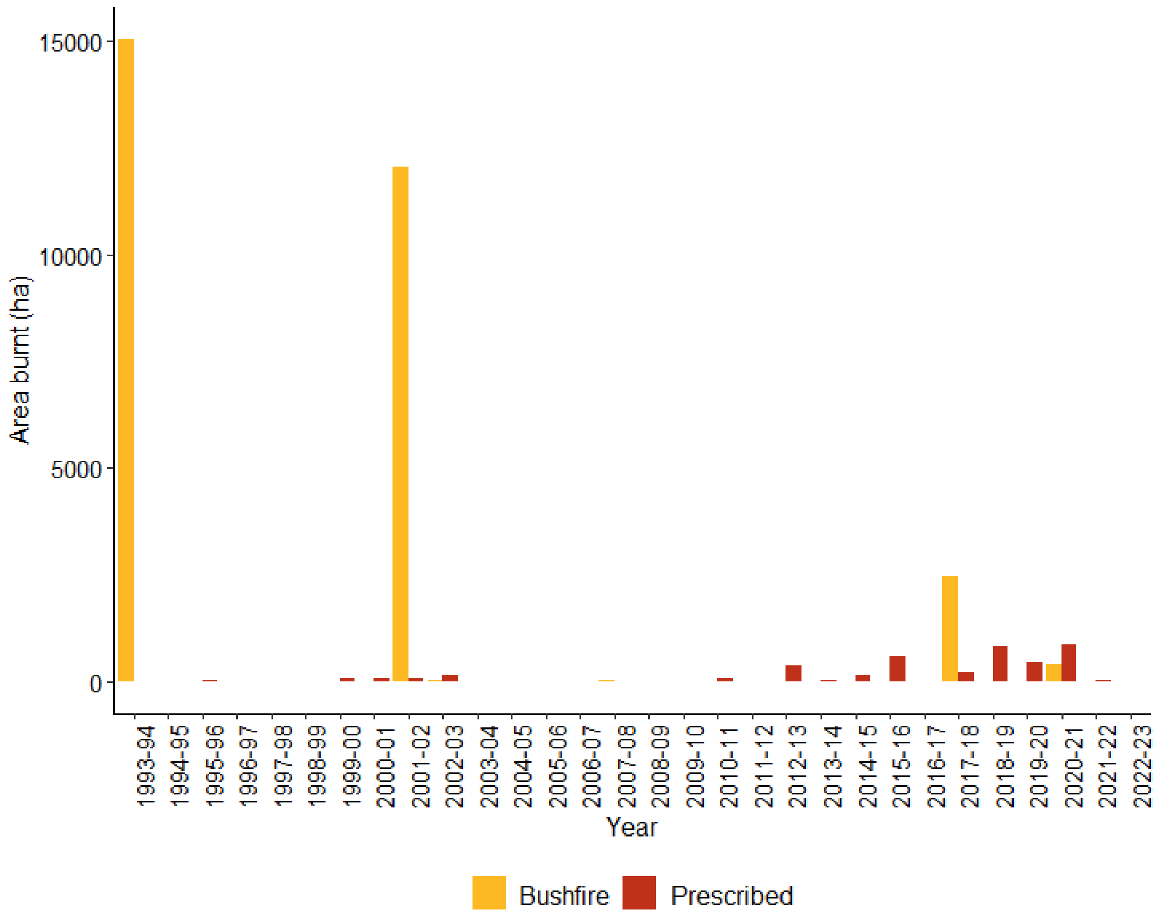


Figure 38 Area burnt by prescribed fires and bushfires in Royal–Heathcote–Garawarra between 1993–94 and 2022–23

The Scorecards program uses vegetation formation and vegetation class following the statewide vegetation classification hierarchy in Keith (2004) and mapped in the NSW State Vegetation Type Map. Fire metrics have been developed for the 5 major vegetation formations that cover 97% of RHG:

1. dry sclerophyll forests (shrubby sub-formation)
2. heathland
3. rainforest

4. wet sclerophyll forests (grassy sub-formation)
5. wet sclerophyll forests (shrubby sub-formation).

The remaining vegetation formations, comprising 3% of the park, include dry sclerophyll forests (shrubby/grass sub-formation), freshwater wetlands, forested wetlands, grasslands and saline wetlands. Descriptions of the 5 major vegetation formations can be found in Table 7 (see also Figure 2).

Fire metrics are reported below in 5-year intervals for the last 30 years and prior to that in 10-year intervals. This is a different approach to the usual reporting of fire metrics against desired fire thresholds, which limits the ability to assess overall park-wide ecological health because the fire thresholds are based on flora responses to fire, not fauna responses.

Dry sclerophyll forests

Dry sclerophyll forests (shrubby) cover 53.5% (10,238 ha) of RHG. The desired fire interval for this vegetation formation is 11 to 30 years (DCCEWW unpublished) although the plant community types representative of this formation vary in their time intervals for post-fire recovery.

Dry sclerophyll forests are adapted to persist and reproduce in an environment of recurrent fire through regeneration from seed banks (stored in the soil or canopy) determined by interactions between demographic processes and the fire regimes (frequency, intensity, season, severity) (Tozer et al. 2017). In Sydney, the peri-urban remnant bushland plant species diversity (driven by shrub species richness) has been found to increase with fire frequency (Pendall et al. 2022). In the long absence of fire, the understory of these communities becomes dominated by large woody shrubs and seed banks of out-competed species may become exhausted. Conversely, fires that are too frequent to allow plants to reach reproductive maturity and re-establish between fires may cause population decline and potential local extinction (Pendall et al. 2022). Climate change is creating more extreme conditions resulting in longer fire seasons associated with more extensive, intense and frequent fires in many fire-prone environments (Abatzoglou et al. 2019; Bowman et al. 2020; Jones et al. 2022).

Key findings:

- Around 30% of dry sclerophyll forests have burnt within 10 years, which is below the desired fire interval and indicates fire should be avoided in these areas (Table 16, Figures 39 and 40).
- Around 60% of dry sclerophyll forests have burnt within 11 to 30 years, with most within 20 to 30 years ago, and 40% by canopy fire (in the 1994 and 2001 fires) (Figures 41).
- There is very little dry sclerophyll forest that has been unburnt for more than 30 years, which may limit the availability of habitat for some tree hollow dependent species.

Table 16 Fire history for dry sclerophyll forests (shrubby) in Royal–Heathcote–Garawarra

Fire history		Area (ha) burnt	% of formation	Area (ha) burnt by canopy fire	% of formation
Time since last fire					
1 to 5 years	(2018–19 to 2022–23)	1,510	14.54	366	3.53
6 to 10 years	(2013–14 to 2017–18)	1,736	16.72	646	6.22
11 to 15 years	(2008–09 to 2012–13)	299	2.88	150	1.44

Fire history		Area (ha) burnt	% of formation	Area (ha) burnt by canopy fire	% of formation
16 to 20 years	(2003–04 to 2007–08)	18	0.17	1	0.01
21 to 25 years	(1998–99 to 2002–03)	5,523	53.20	1,969	18.97
26 to 30 years	(1993–94 to 1997–98)	1,263	12.17	1,999*	19.25
31 to 40 years	(1983–84 to 1992–93)	7	0.07	n/a^	n/a^
41 to 50 years	(1972–73 to 1982–83)	10	0.10	n/a	n/a
50+ years	(pre 1972–73)	n/a	n/a	n/a	n/a
30-year fire history					
Area unburnt		33	0.32	5,094	49.07
Area burnt once		2,906	27.99	4,130	39.78
Area burnt twice		5,601	53.95	920	8.86
Area burnt 3 times		1,798	17.32	81	0.78
Area burnt >3 times		44	0.42	0	0.00

Note: 10,238 ha in RHG. Desired fire interval 11 to 30 years based on plant species fire response.

Area burnt metrics are calculated from NPWS Fire History data, and fire severity (canopy fires) is calculated from Fire Extent and Severity Map data.

* Model output for canopy burnt in the 26-to-30-year period was greater than the total area burnt. This is due differences in data sources for mapping of FESM and Fire History data.

^ current fire severity data is only available to 1990–91, in subsequent years reporting of canopy fires will be extended to better represent the desired fire–interval range limits.

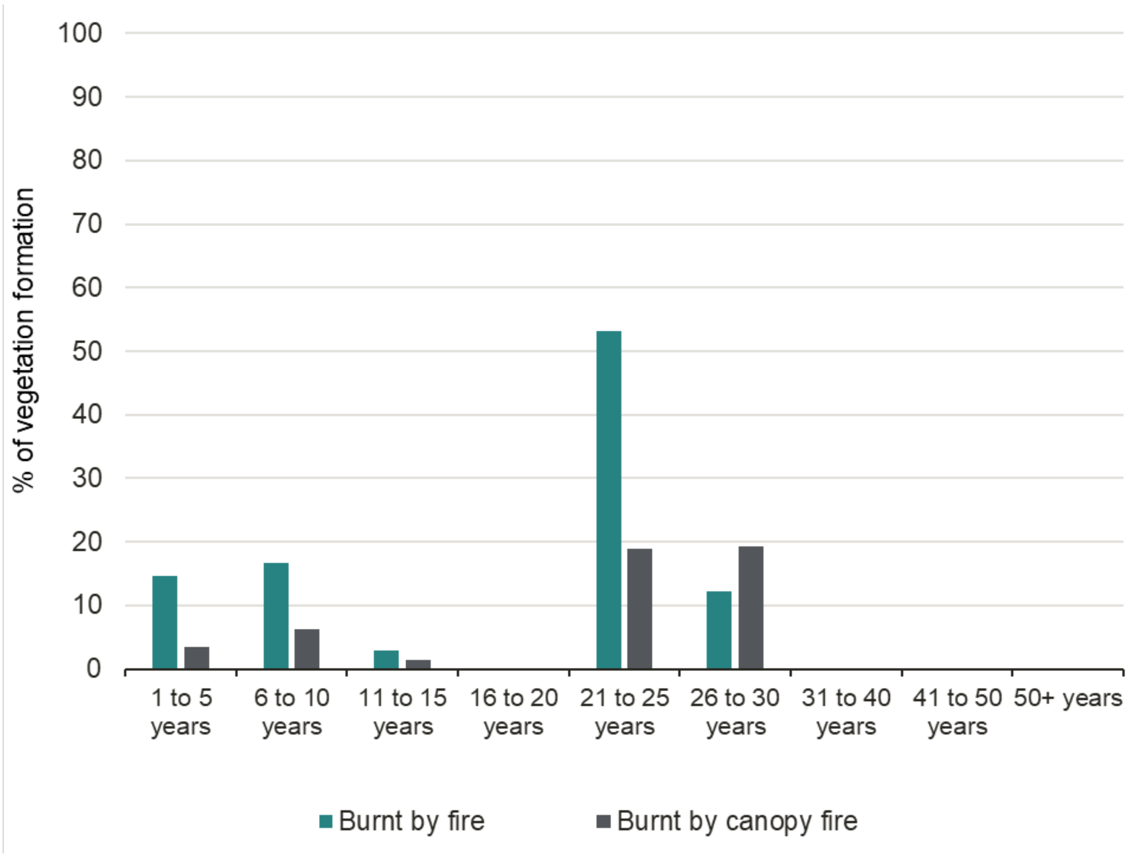


Figure 39 **Percent of dry sclerophyll forests burnt within each time interval for all fire and canopy fire (desired fire interval 11 to 30 years)**

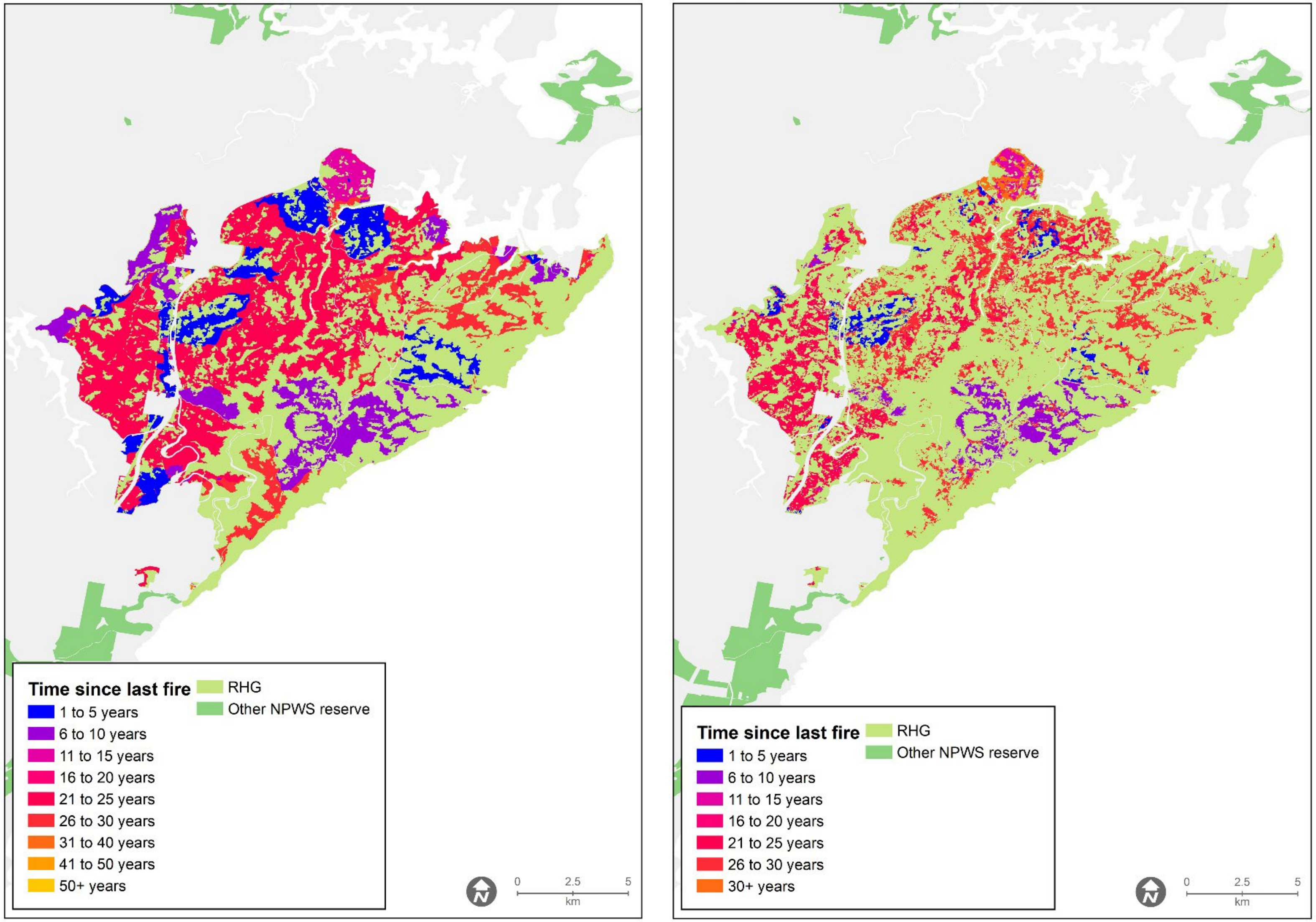


Figure 40 Fire history in dry sclerophyll forests: all fire (left) canopy fire (right)

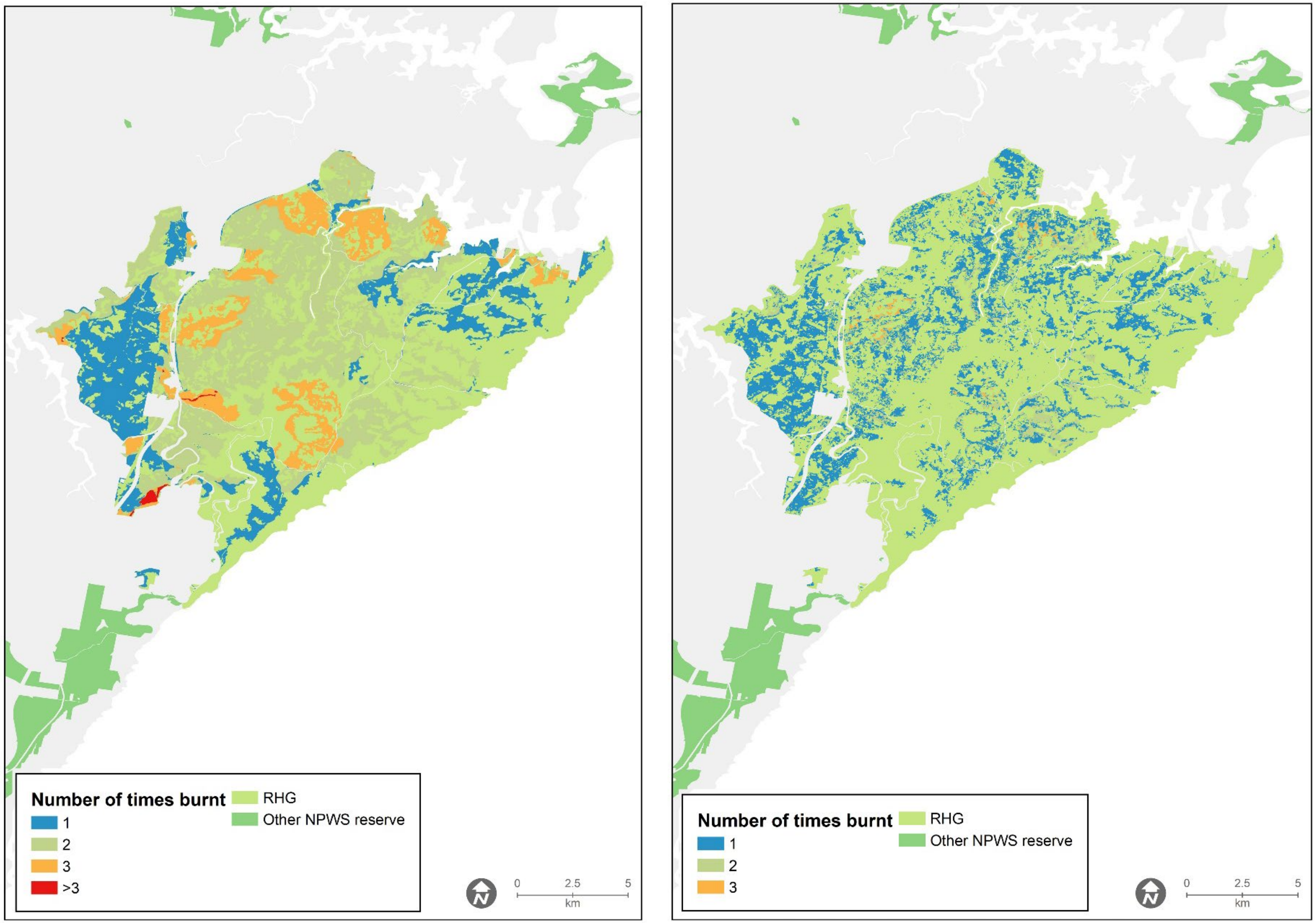


Figure 41 Fire frequency in dry sclerophyll forests over the last 30 years: all fire (left) canopy fire (right)

Heathlands

Heathlands are shrub-dominated fire-prone plant communities restricted to very infertile soils derived from sandstones covering 29% or 5,557 ha of RHG (Keith and Tozer 2012). Heathlands occur in the landscape as a mosaic ecosystem of different age stands of thicket and heath that changes over decadal timescales in response to fire regimes and climate variations, as well as endogenous processes such as competition between component species (Keith and Tozer 2012). Conventional fire management strategies that focus on fire history generally fail to account for the ecological state of heathlands and can lack the flexibility to influence variability in fire regimes and the persistence of diversity of plant functional types that support other species. For example, serotinous obligate seeder shrubs provide an important winter food source and nesting substrate for a range of avian and mammalian fauna.

Fire regimes for heathlands that promote both flora and fauna diversity need to:

1. have a frequency that promotes the life cycles of particular plant species and provides food sources or habitat suitability for particular animal species
2. not be too long apart so that plants disappear from natural senescence or are competitively elimination by dominant species
3. be of varying intensities as low-intensity fire may not provide sufficient cues or post-fire conditions for recruitment
4. be avoided preceding extended dry periods which may expose post-fire survivors and recruits to resource deprivation (Keith et al. 2014).

Key findings

- About 60% of heathlands in RHG have been burnt within the past 10 to 30 years, which is the desired fire interval for flora (Table 17, Figures 42 and 43).
- About 40% of heathlands have been burnt in the past 10 years, or less, which is below the time needed for the plant community to re-establish and restore seed banks after fire and indicates fire should be avoided in these areas.
- High-intensity fires have burnt about 81% of heathlands in the past 30 years (Table 17, Figures 43 to 44), which is essential for the regeneration of many heath plant species but not an ideal fire mosaic to promote the fauna community.

Table 17 Fire history for heathlands in Royal–Heathcote–Garawarra

Fire history		Area (ha) burnt	% of formation	Area (ha) burnt by canopy fire	% of formation
Time since last fire					
1 to 5 years	(2018–19 to 2022–23)	960	17.04	663	11.77
6 to 10 years	(2013–14 to 2017–18)	1,294	22.96	1,068	18.95
11 to 15 years	(2008–09 to 2012–13)	38	0.67	31	0.55
16 to 20 years	(2003–04 to 2007–08)	18	0.32	14	0.25
21 to 25 years	(1998–99 to 2002–03)	1,874	33.26	1,068	18.95
26 to 30 years	(1993–94 to 1997–98)	1,445	25.64	1,751	31.07
31 to 40 years	(1983–84 to 1992–93)	1	0.02	n/a^	n/a^
41 to 50 years	(1972–73 to 1982–83)	2	0.04	n/a	n/a
50+ years	(pre 1972–73)	n/a	n/a	n/a	n/a
30-year fire history					
Area unburnt		6	0.11	1,032	18.31
Area burnt once		1,819	32.28	2,764	49.05
Area burnt twice		2,983	52.94	1,639	29.09
Area burnt 3 times		827	14.68	197	3.50
Area burnt >3 times		0	0	3	0.05

Note: 5,557 ha in RHG. Desired fire interval 10 to 30 years based on plant species fire response.

Area burnt metrics are calculated from NPWS Fire History data, and fire severity (canopy fires) is calculated from Fire Extent and Severity Map data.

^ current fire severity data is only available to 1990–91, in subsequent years reporting of canopy fires will be extended to better represent the desired fire-interval range limits.

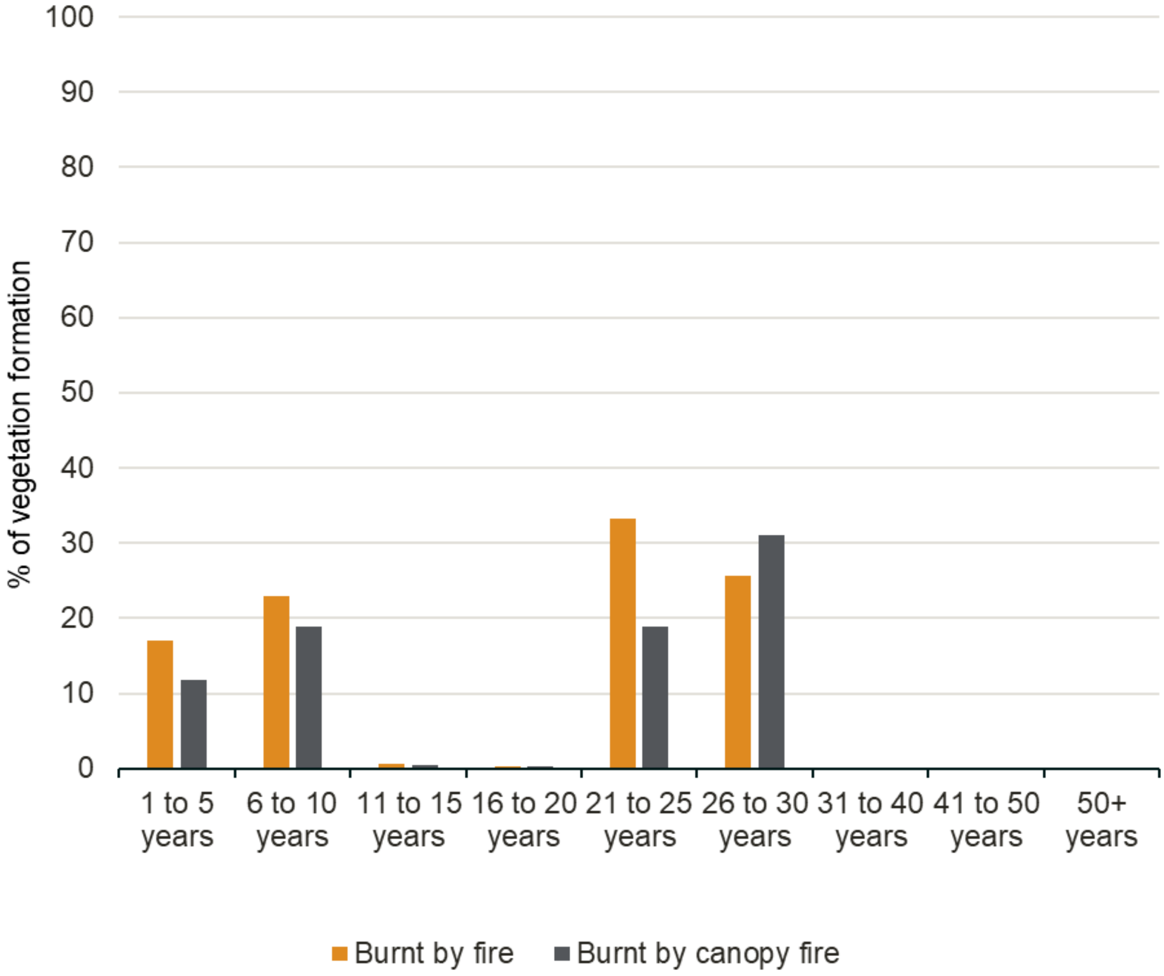


Figure 42 **Percent of heathlands burnt within each time interval for all fire and canopy fire (desired fire interval 10 to 30 years)**

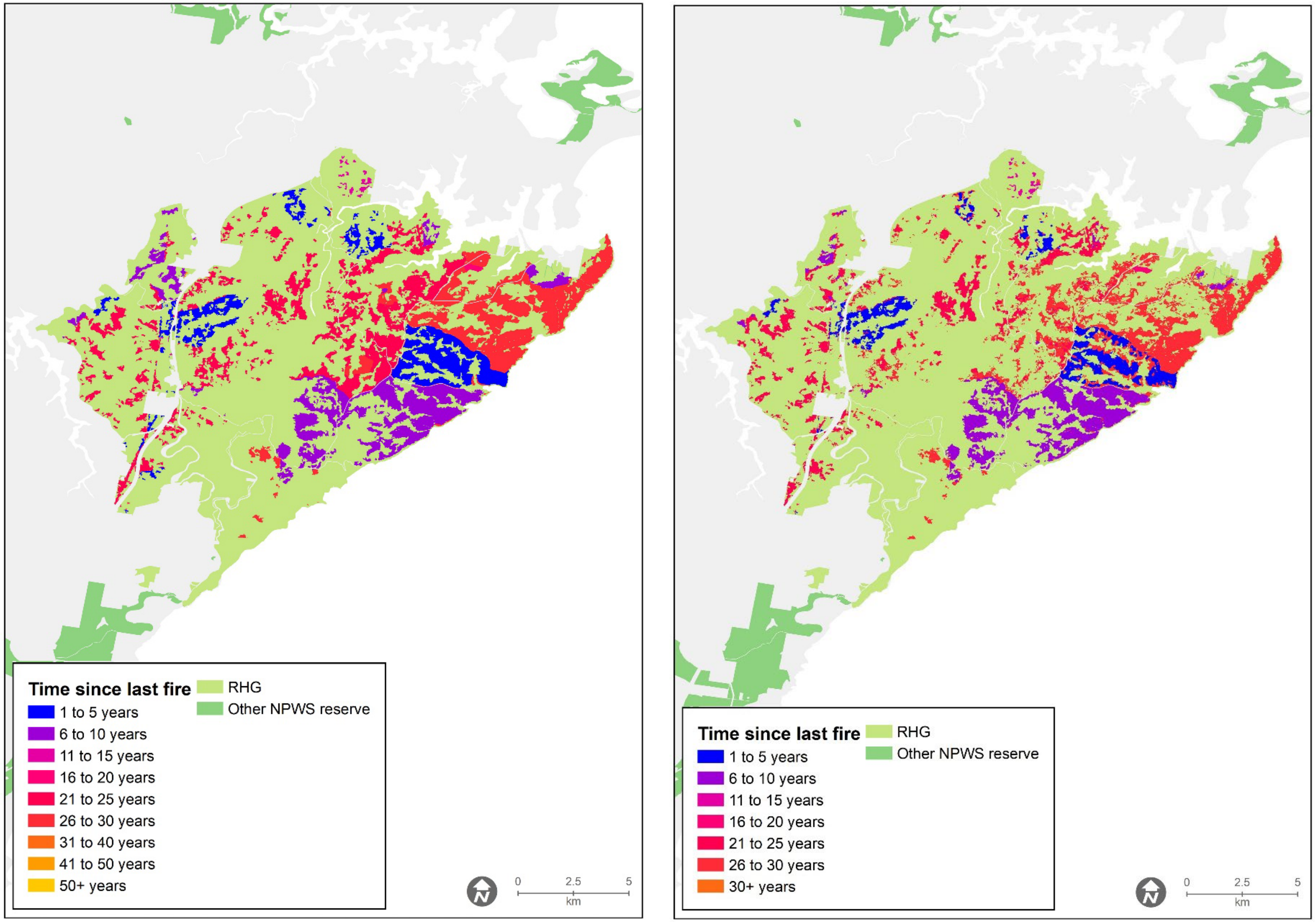


Figure 43 Fire history in heathlands: all fire (left) canopy fire (right)

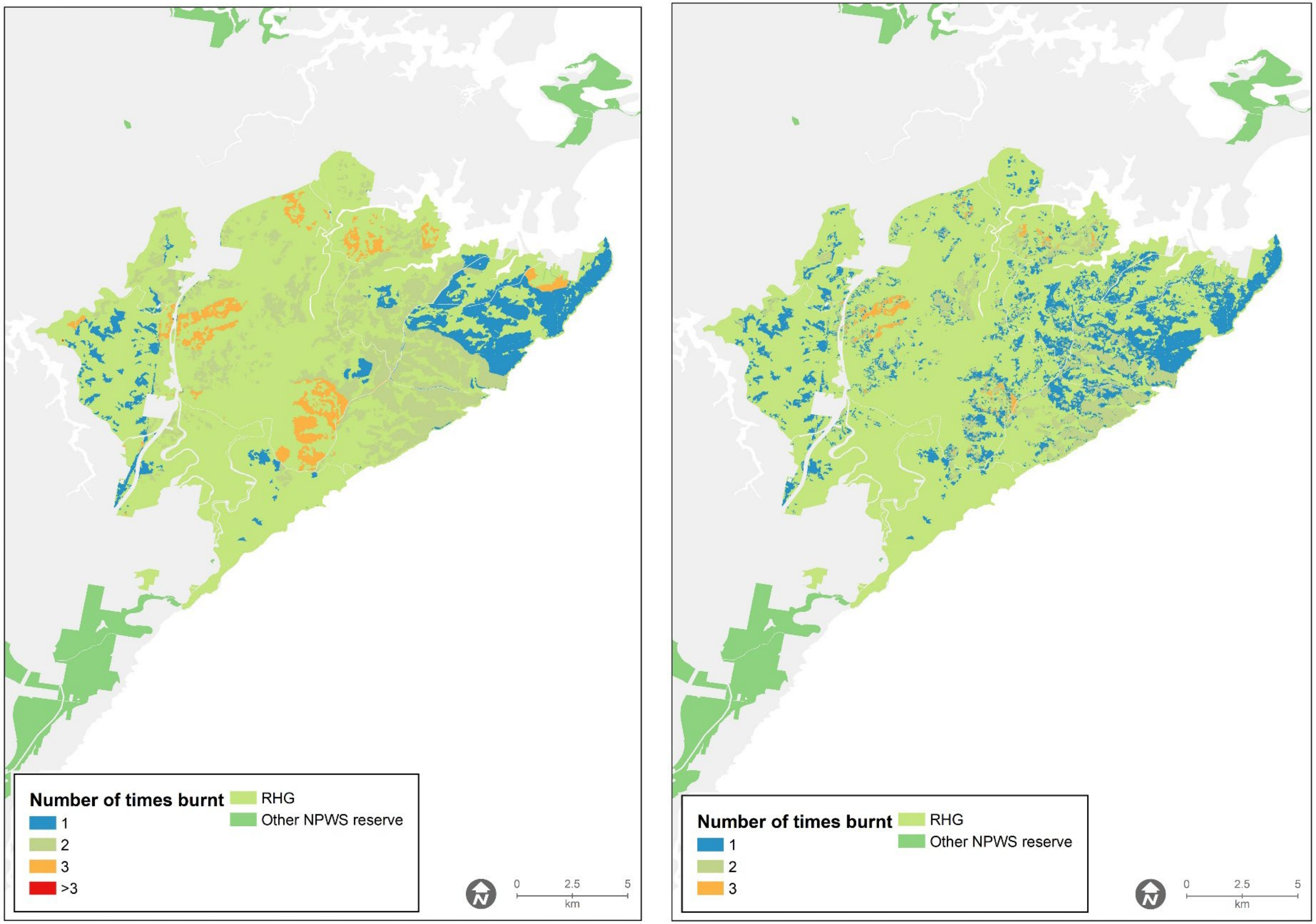


Figure 44 Fire frequency in heathlands over the last 30 years: all fire (left) canopy fire (right)

Rainforests

RHG rainforests can be found in the valley along the Hacking River and its tributaries, and in some coastal escarpment gullies and occupy 2.3% or 483 ha of RHG. The rainforests of RHG are remnants of a vegetation community that once covered the ancient super continent of Gondwana millions of years ago. Rainforests underwent large-scale contraction during the Quaternary and Miocene to small pockets on the east coast of Australia due to increasingly dry and seasonal climatic conditions (Hammill and Tasker 2010; Couper and Hoskin 2008). Rainforests persist in mesic areas that provide micro-climates that are cool, moist and largely sheltered from fire (Couper and Hoskin 2008).

Australian rainforests are classified as fire sensitive, or fire intolerant. Rainforests are an important and preferred habitat of many fauna species and provide important refuge from fire. Fire plays a major role in controlling rainforest boundaries, with rainforest communities usually limited to topographic positions that are sheltered from frequent fire. Under typical weather conditions, fires originating in fire-prone ecosystems typically extinguish along rainforest margins, where closed rainforest canopy reduces ecosystem flammability through a combination of reduced grassy fuels, lower temperatures, higher relative humidity, and higher moisture content and decomposition rates of litter fuels. However, the fuel and microclimate property differentials between open and closed ecosystems are changing under extreme fire weather and drought conditions, increasing the likelihood of fire encroachment into rainforest and a possible retraction of this vegetation type. In many regions of Australia, especially the south-east, climate change is projected to increase the number of extreme fire days, lightning ignitions, and the severity of drought, potentially leading to increased incidence of fires encroaching into rainforest. Rainforests do not need fire to regenerate, however many rainforest plants survive fire by resprouting and post-fire seedling recruitment. Rainforest species generally do not have soil-stored seed banks. Rainforests can tolerate single fires without long-term floristic or structural decline (Baker et al. 2022), however, they require long intervals between fire events to ensure species reach maturation. Rainforests are likely to be increasingly impacted by climate change–induced large-scale fire events such as the 2019–20 fires (EPA 2023).

Key findings:

- About 76% of the rainforest in RHG was burnt within the last 30 years, with very little canopy fire (Table 18, Figures 45 to 46).
- About 23% of the rainforest in RHG is long unburnt (no record of fire).
- Fire history data suggest that around 37% of rainforest has burnt once in the last 30 years, 31% has burnt twice and 8% has burnt three times in the last 30 years.

While these results suggest that multiple fires may have significantly impacted the health of the rainforests of RHG, they may in fact be an artefact of old fire mapping methodology which mapped the entire area within the perimeter of a burn as burnt. Most of the rainforest in RHG is likely to have only burnt once in the last 30 years, in the 1994 fire, which did impact these communities significantly. More recent advances in fire mapping enable the patchiness of burn to be identified, mapped and recorded, supporting a more nuanced approach to assessing fire extent and severity. Multiple fires in rainforests at relatively short time intervals may impact regeneration and fire should be avoided in these areas (Table 18, Figures 46 to 47).

Table 18 Fire history for rainforests in Royal–Heathcote–Garawarra

Fire history		Area (ha) burnt	% of formation	Area (ha) burnt by canopy fire	% of formation
Time since last fire					
1 to 5 years	(2018–19 to 2022–23)	10	2.23	2	0.45
6 to 10 years	(2013–14 to 2017–18)	74	16.48	4	0.89
11 to 15 years	(2008–09 to 2012–13)	6	1.34	1	0.22
16 to 20 years	(2003–04 to 2007–08)	0	0	0	0
21 to 25 years	(1998–99 to 2002–03)	189	42.09	3	0.67
26 to 30 years	(1993–94 to 1997–98)	63	14.03	15	3.34
31 to 40 years	(1983–84 to 1992–93)	6	1.34	n/a^	n/a^
41 to 50 years	(1972–73 to 1982–83)	6	1.34	n/a	n/a
50+ years	(pre 1972–73)	n/a	n/a	n/a	n/a
30-year fire history					
Area unburnt		107	23.83	423	94.34
Area burnt once		165	36.75	22	4.90
Area burnt twice		139	30.96	3	0.67
Area burnt 3 times		38	8.46	0.4	0.09
Area burnt >3 times		0	0	0	0

Note: 438 ha in RHG. Vegetation is sensitive to fire.

Area burnt metrics are calculated from NPWS Fire History data, and fire severity (canopy fires) is calculated from Fire Extent and Severity Map data.

^ current fire severity data is only available to 1990–91, in subsequent years reporting of canopy fires will be extended to better represent the desired fire–interval range limits.

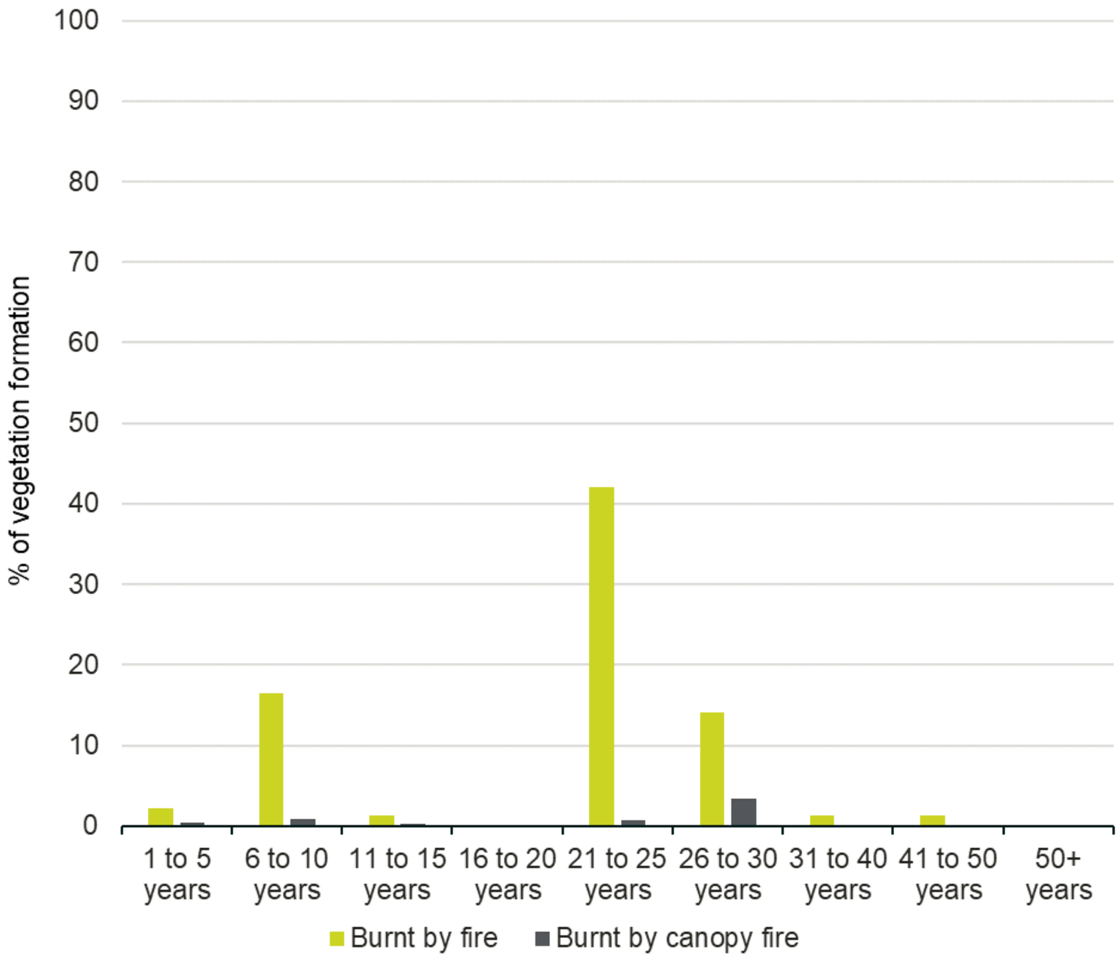
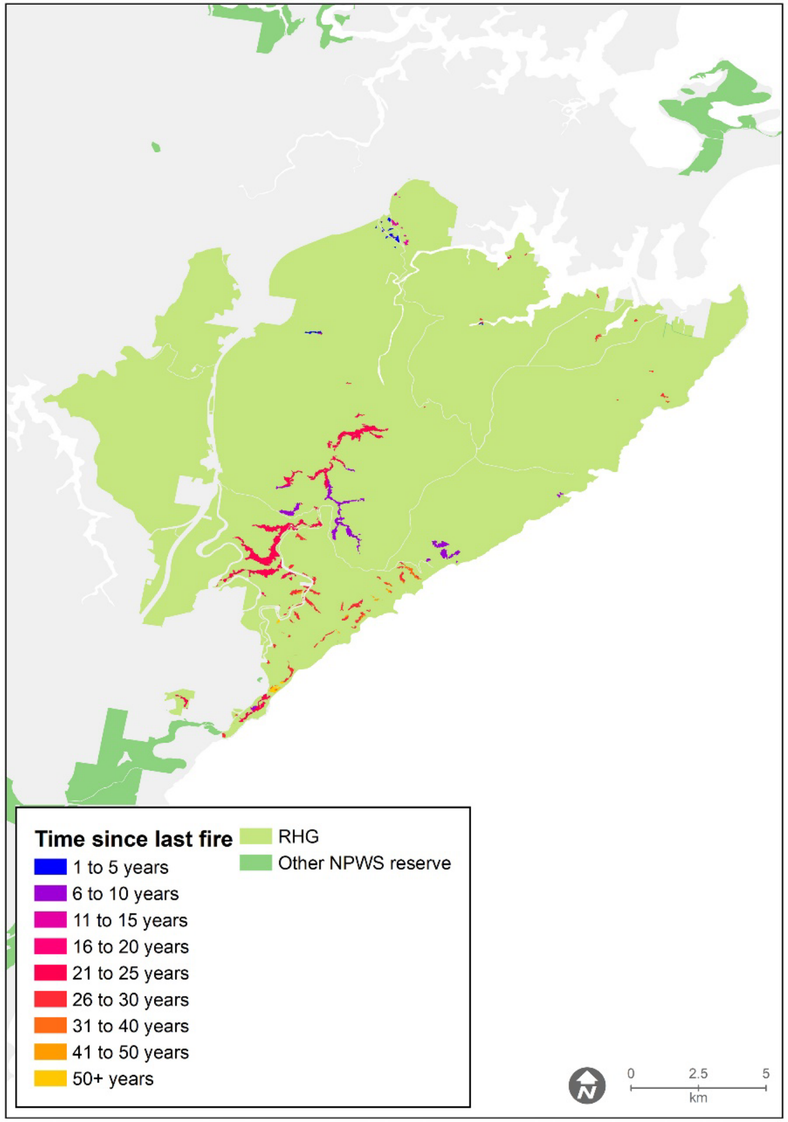


Figure 45 Percent of rainforests burnt within each time interval for all fire and canopy fire (fire sensitive)



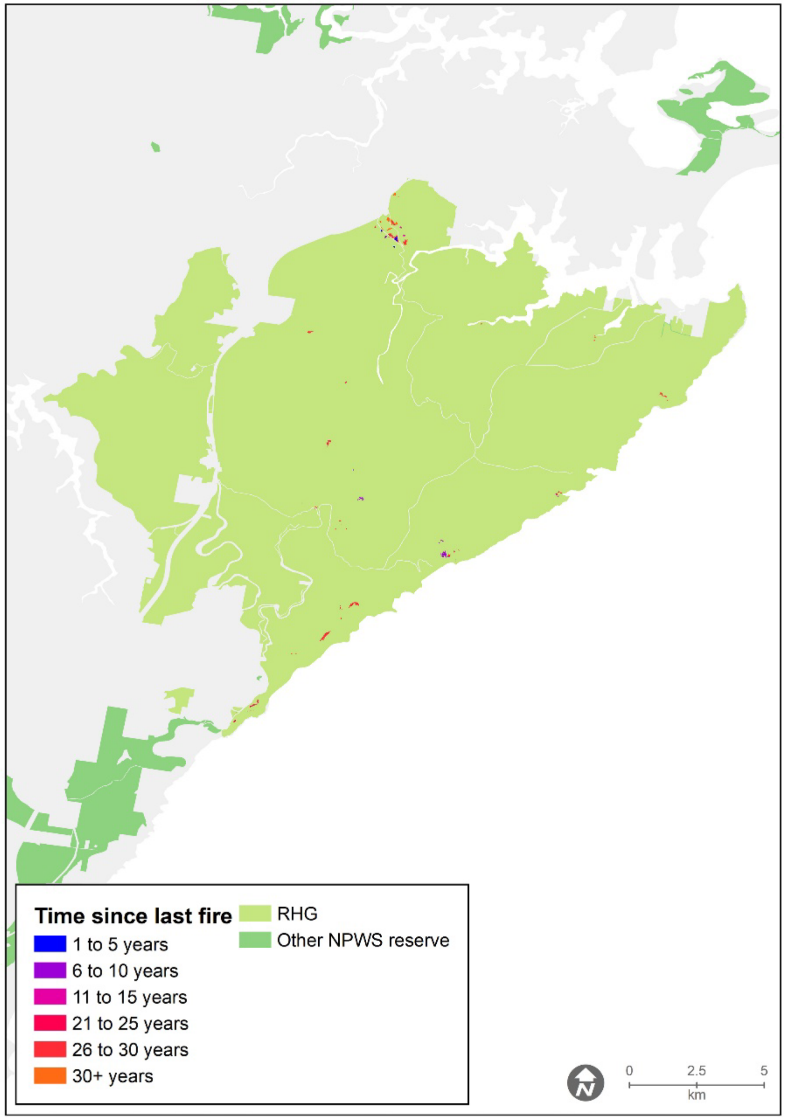


Figure 46 Fire history in rainforests: all fire (left) canopy fire (right)

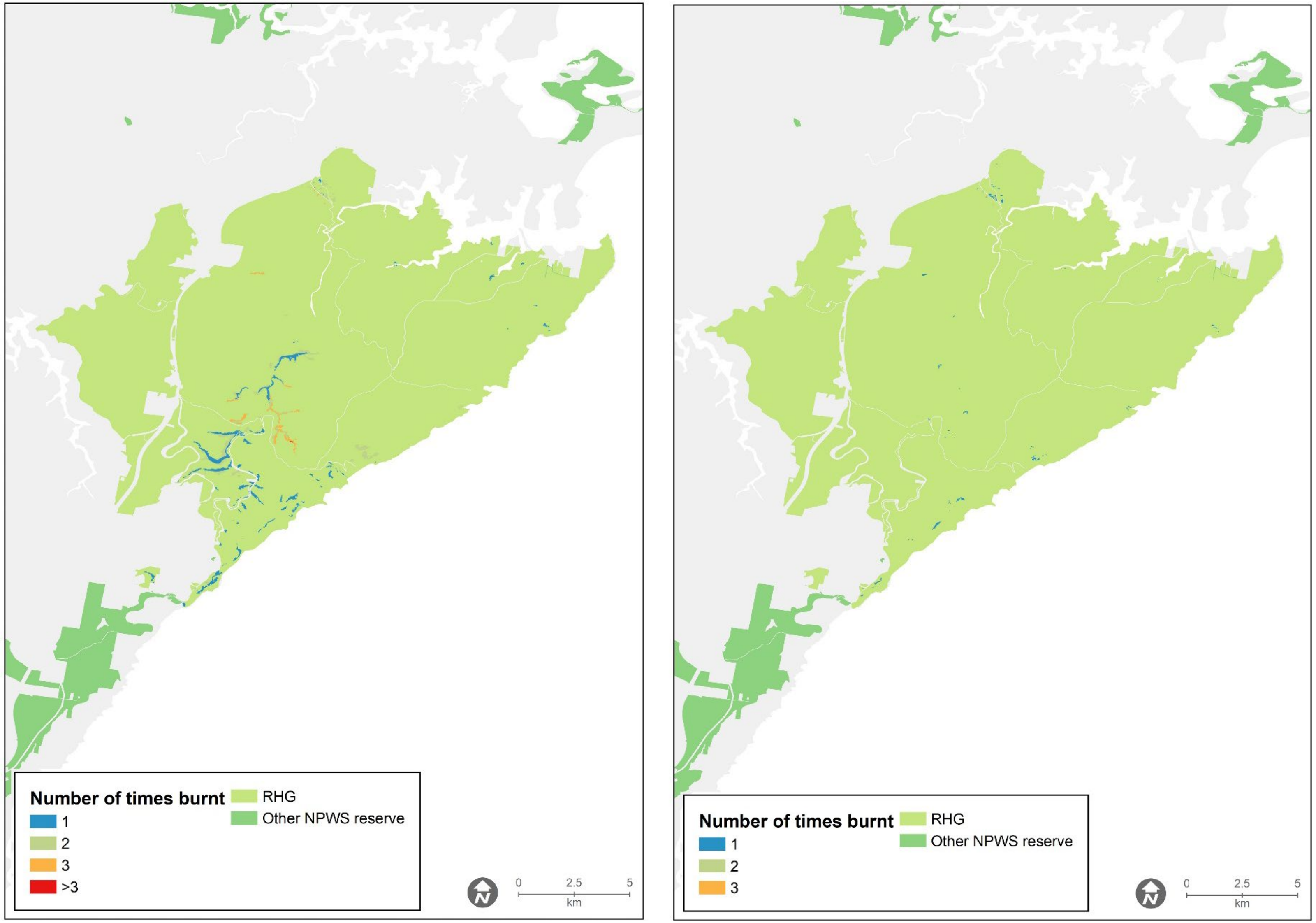


Figure 47 Fire frequency in rainforests over the last 30 years: all fire (left) canopy fire (right)

Wet sclerophyll forests

Wet sclerophyll forests are tall forests dominated by tall, straight-trunked eucalypt species and occupy 8.1% or 1,557 ha of RHG. The shrubby sub-formation is found as an ecotone between rainforests and dry sclerophyll forests either along the Hacking River corridor and/or, adjacent to coastal littoral rainforests at the southern end of Royal National Park. Wet sclerophyll forest grassy sub-formation is found on clay-influenced shale crests in the northwest area of RHG.

Fire regimes can shift the boundaries between dry sclerophyll forests, wet sclerophyll forests and rainforests; if fire infiltrates into rainforest, the rainforest can shift to wet sclerophyll forest. Conversely, if fire becomes extremely infrequent and beyond the life expectancy of the sclerophyll canopy species, then wet sclerophyll forest will convert to rainforest. Increased fire frequency may cause a transition towards dry sclerophyll forest (Wardell-Johnson et al. 2017). Like dry sclerophyll forests, wet sclerophyll forests regenerate from fire by resprouting and/or from seed banks (both canopy- and soil-stored) and resprouting, however, some wet sclerophyll forest eucalypts have a higher probability to be killed by intense fire resulting in areas of even-aged stands (Wardell-Johnson et al. 2017). Climate change is creating more extreme conditions resulting in longer fire seasons associated with more extensive, intense and frequent fires which are a threat to wet sclerophyll forests (Abatzoglou et al. 2019; Bowman et al. 2020; Jones et al. 2022). The hollows of the old trees of wet sclerophyll forests provide habitat for possums, gliders and hollow-nesting birds (Wardell-Johnson et al. 2017.

Key findings:

- Around 70% of the wet sclerophyll forests in RHG has burnt within desired fire interval of 13 to 60 years, with only 3% having experienced in canopy fire (Table 19, Figures 48 to 49).
- Around 20% of wet sclerophyll forest has burnt in in the past 13 years, or less, which is below the desired fire interval and indicates fire should be avoided in these areas.
- Only 8% of wet sclerophyll forest is long unburnt, 42% has burnt once, 34% has burnt twice, and 15% has burnt three time in the last 30 years (Table 19, Figures 49 to 50).
- There are no areas of long unburnt (>50 years) wet sclerophyll forest in RHG. However, most of the fire has not impacted the canopy of trees, suggesting a generally low impact on hollow-bearing species.

Table 19 Fire history for wet sclerophyll forests in Royal–Heathcote–Garawarra

Fire history		Area (ha) burnt	% of formation	Area (ha) burnt by canopy fire	% of formation
Time since last fire					
1 to 5 years	(2018–19 to 2022–23)	66	4.15	0	0
6 to 10 years	(2013–14 to 2017–18)	260	16.33	15	0.94
11 to 15 years	(2008–09 to 2012–13)	37	2.32	5	0.31
16 to 20 years	(2003–04 to 2007–08)	1	0.06	0	0
21 to 25 years	(1998–99 to 2002–03)	483	30.34	11	0.69
26 to 30 years	(1993–94 to 1997–98)	611	38.38	49	3.08
31 to 40 years	(1983–84 to 1992–93)	12	0.75	n/a^	n/a^
41 to 50 years	(1972–73 to 1982–83)	9	0.57	n/a	n/a
50+ years	(pre 1972–73)	n/a	n/a	n/a	n/a
30-year fire history					
Area unburnt		134	8.42	1512	94.97
Area burnt once		675	42.40	76	4.77
Area burnt twice		538	33.79	4	2.20
Area burnt 3 times		242	15.20	0	0.38
Area burnt >3 times		3	0.19	0	0

Note: 1,557 ha in RHG. Desired fire interval 13 to 60 years based on plant species fire response.

Area burnt metrics are calculated from NPWS Fire History data, and fire severity (canopy fires) is calculated from Fire Extent and Severity Map data.

^ current fire severity data is only available to 1990–91, in subsequent years reporting of canopy fires will be extended to better represent the desired fire–interval range limits.

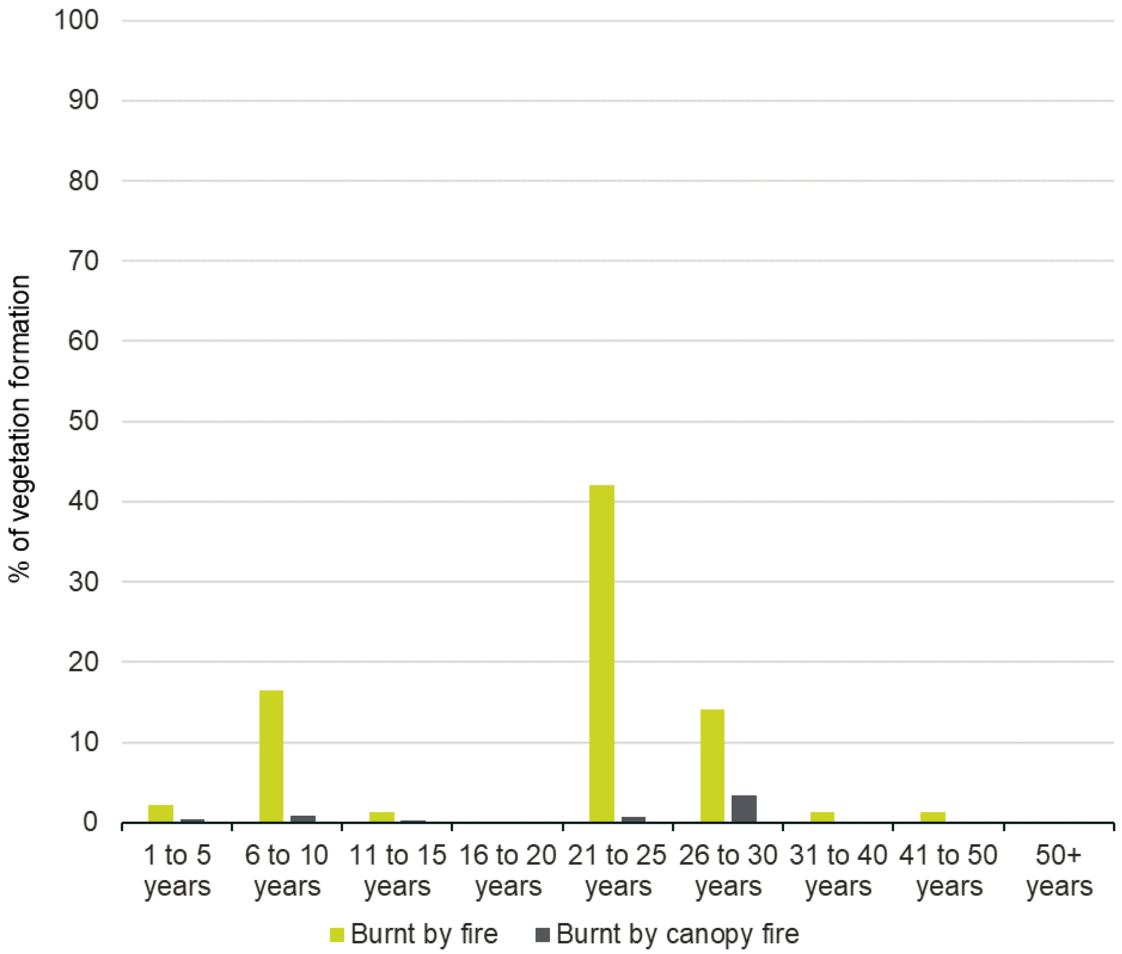


Figure 48 **Percent of wet sclerophyll forests burnt within each time interval for all fire and canopy fire (desired fire interval 13 to 60 years)**

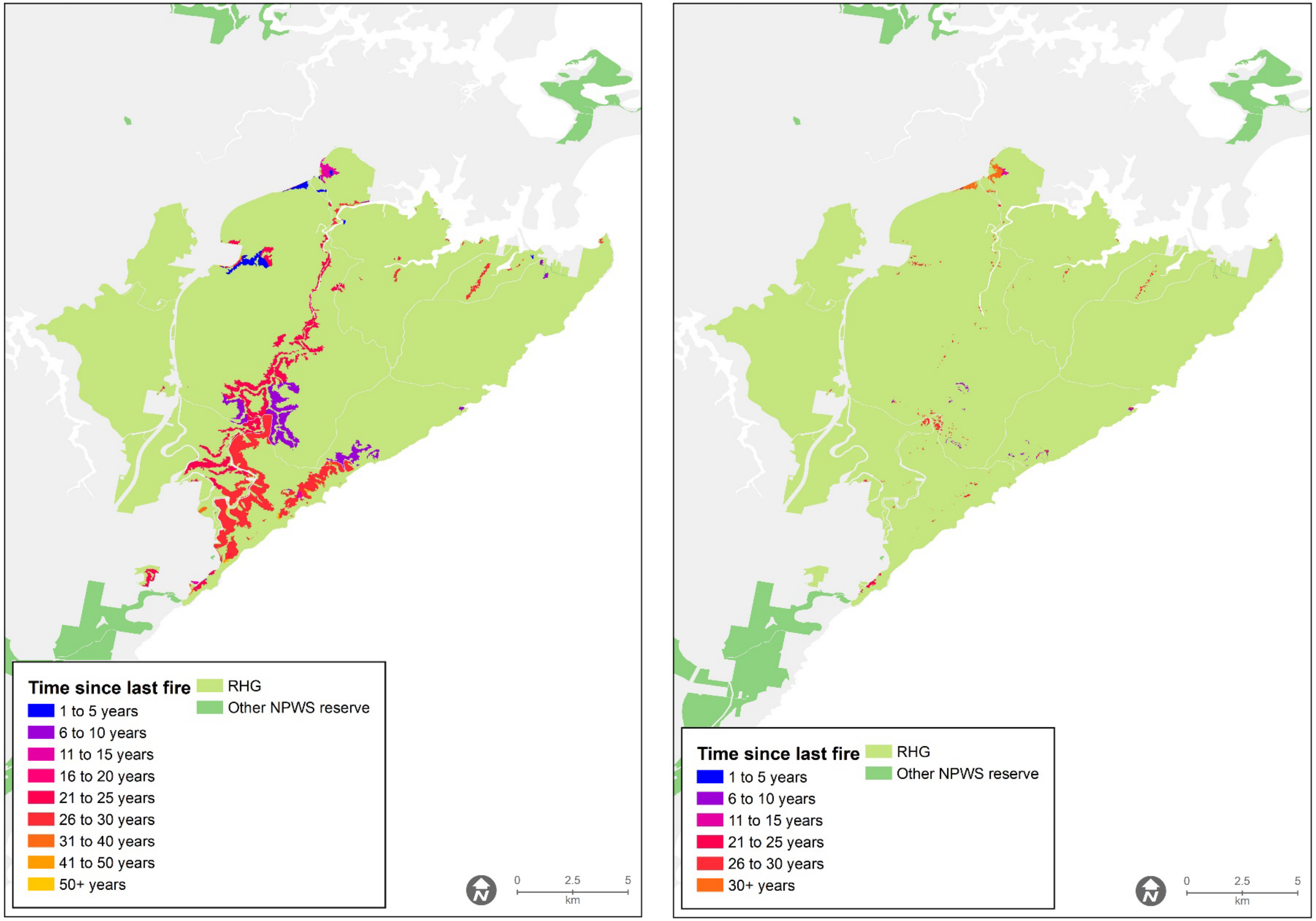


Figure 49 Fire history in wet sclerophyll forest: all fire (left) canopy fire (right)

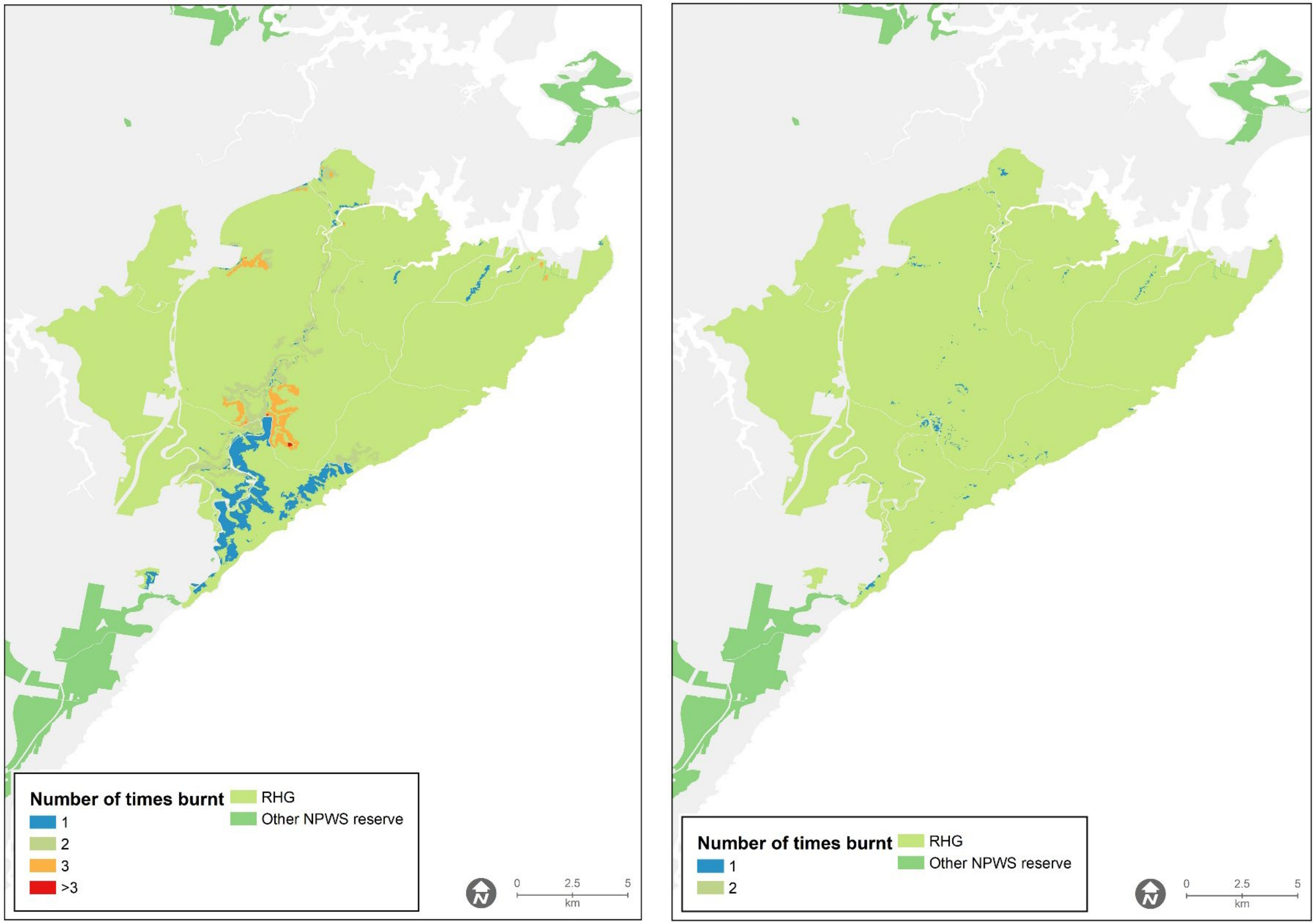


Figure 50 Fire frequency in wet sclerophyll forest over the last 30 years: all fire (left) canopy fire (right)

Discussion

Fire management across RHG needs to consider both the condition and diversity of flora and fauna species. RHG is a habitat island in an urban matrix for many terrestrial species, so that a bushfire that burns a majority of the park may have a severe impact on the populations of some species. The aim for fire management in RHG is to prevent bushfire burning the entire area, and to create a mosaic of different fire histories to provide habitats of different post-fire age classes for flora and fauna. Protecting unburnt refugial areas in each vegetation formation will be important to support the persistence of species and enable recolonisation of species following any fire event. The ongoing challenge is to achieve this using prescribed burning and fire suppression, while recognising the primacy of protecting life and property, especially given its location adjacent to Australia's largest city.

References

Abatzoglou JT, Williams AP and Barbero R (2019) 'Global emergence of anthropogenic climate change in fire weather indices', *Geophysical Research Letters*, 46:326–336.

AdaptNSW (2024) *Interactive climate change projections map*, AdaptNSW website, accessed on 9 May 2024.

Australian Government (2023) *Default guideline values*, Australian and New Zealand guidelines for fresh and marine water quality website, accessed on 23 January 2024.

Australian Government (2018) 'Australian and New Zealand guidelines for fresh and marine water quality', accessed on 2 February 2024.

Australian National Botanic Gardens (2009) *Australian flora statistics*, ANBG website, accessed on 19 February 2024.

Bain GC, MacDonald MA, Hamer R, Gardiner R, Johnson CN and Jones ME (2020) 'Changing bird communities of an agricultural landscape: declines in arboreal foragers, increases in large species', *Royal Society Open Science*, 7(3):200076.

Baker AG, Catterall C and Wiseman M (2022) 'Rainforest persistence and recruitment after Australia's 2019–2020 fires in subtropical, temperate, dry and littoral rainforests', *Australian Journal of Botany*, 28, 70(3):189–203.

Beilke EA and O'Keefe JM (2023) 'Bats reduce insect density and defoliation in temperate forests: an exclusion experiment', *Ecology*, 104(2):e3903.

Benson D and McDougall L (1998) 'Ecology of Sydney plants. Part 6: Dicotyledon family Myrtaceae', *Cunninghamia*, 5:809–986.

Birdlife Australia (2015) *Woodland birds of south-east Australia* [online brochure], Commonwealth of Australia, Canberra.

Black MP, Mooney SD and Haberle SG (2007) 'The fire, human and climate nexus in the Sydney Basin, eastern Australia', *The Holocene*, 17(4):469–480.

Bowman DM, Kolden CA, Abatzoglou JT, Johnston FH, van der Werf GR and Flannigan M (2020) 'Vegetation fires in the Anthropocene', *Nature Reviews Earth & Environment*, 1(10):500–515.

Burbidge AA (2023) 'Australian terrestrial mammals: how many modern extinctions?', *Australian Mammalogy*, 46, AM23037.

Bureau of Meteorology (2022) *State of the climate 2022*, BOM website, accessed 9 May 2024.

Bureau of Meteorology (2024) Australia's official weather forecasts & weather radar, BOM website, accessed on 12 January 2024.

Campbell S (2009) 'So long as it's near water: variable roosting behaviour of the large–footed myotis (*Myotis macropus*)', *Australian Journal of Zoology*, 57:89–98.

Cairns KM, Nesbitt BJ, Laffan SW, Letnic M and Crowther MS (2020) 'Geographic hot spots of dingo genetic ancestry in south–eastern Australia despite hybridisation with domestic dogs', *Conservation Genetics*, 21:77–90.

Carnegie AJ, Kathuria A, Pegg GS, Entwistle P, Nagel M and Giblin FR (2016) 'Impact of the invasive rust *Puccinia psidii* (myrtle rust) on native Myrtaceae in natural ecosystems in Australia', *Biological Invasions*, 18:127–144.

Chessman BC (2003) 'New sensitivity grades for Australian river macroinvertebrates', *Marine and Freshwater Research*, 54:95–103.

Chao A, Gotelli NJ, Hsieh TC, Sander EL, Ma KH, Colwell RK and Ellison AM (2014) ‘Rarefaction and extrapolation with Hill numbers: a framework for sampling and estimation in species diversity studies’, *Ecological Monographs*, 84(1):45–67.

Clarke D (2021) *Population assessment and monitoring of* Prostanthera densa *(villous mint bush) for the Saving our Species program (2020–2021)* [unpublished report to NPWS], DM Clarke Botanical Consulting Services.

Consulting Services Clarke D (2022) *Saving our Species program 2021–2022: monitoring of* Prostanthera densa *(villious mint bush)* [unpublished report to NPWS], DM Clarke Botanical Consulting Services.

Clarke D (2023) *Saving our Species program 2022–2023: monitoring of* Prostanthera densa *(villious mint bush)* [unpublished report to NPWS], Arcane Botanica.

Cogger H (2014) *Reptiles and amphibians of Australia,* seventh edition, CSIRO Publishing, Canberra.

Couper P and Hoskin C (2008) ‘Litho–refugia: the importance of rock landscapes for the long–term persistence of Australian rainforest fauna’, *Australian Zoologist*, *34*(4):554–560.

Cowley KL, Fryirs KA, Chisari R and Hose GC (2019) ‘Water sources of upland swamps in eastern Australia: implications for system integrity with aquifer interference and a changing climate’, *Water,* 11(1):102.

Cremona T, Baker AM, Cooper SJ, Montague-Drake R, Stobo-Wilson AM and Carthew SM (2021) ‘Integrative taxonomic investigation of *Petaurus breviceps* (Marsupialia: Petauridae) reveals three distinct species’, *Zoological Journal of the Linnean Society*, 191(2):503–27.

Cth DAWE (Cth Department of Agriculture, Water and the Environment) (2022), *Conservation advice for* Pycnoptilus floccosus *(pilotbird)*, DAWE, Canberra.

Cth Department of the Environment (2015) *Approved conservation advice for the Littoral Rainforest and Coastal Vine Thickets of Eastern Australia ecological community,* DoE website, accessed on 14 August 2023.

DCCEEW (NSW Department of Climate Change, Energy, the Environment and Water) (no date), NSW Tolerable fire intervals interim revision [unpublished internal report].

DECCW (NSW Department of Environment, Climate Change and Water) (2011) *The vertebrate fauna of Royal & Heathcote National Parks and Garawarra State Conservation Area*, [unpublished internal report].

Department of Planning and Environment (2022a) *Royal National Park, Heathcote National Park and Garrawarra State Conservation Area, Plan of Management,* NSW Government.

Department of Planning and Environment (2022b) *NSW State Vegetation Type Map* [data set], Sharing and Enabling Environmental Data, seed.nsw.gov.au, accessed 12 December 2023.

Department of Planning and Environment (2023) *NSW BioNet resources*, Environment and Heritage website, accessed 12 November 2023.

Dorrough J, Val J, Travers SK, Wilson B, Eldridge DJ, Carrillo Y, Nielsen UN, Powell JR, Wilks G, McPherson P and Oliver I (2023) ‘Integrated analysis of aboveground and belowground indicators support a comprehensive evaluation of ecosystem recovery’, *Restoration Ecology*, 31(8):e13987.

Enright NJ, Fontaine JB, Bowman DMJS, Bradstock RA and Williams RJ (2015) ‘Interval squeeze: altered fire regimes and demographic responses interact to threaten woody species persistence as climate changes’, *Frontiers in Ecology and the Environment,* 13(5):265–272.

EPA (NSW Environment Protection Authority) (2023) *State of the environment 2021*, EPA website, accessed on 21 December 2023.

Ford HA, Barrett GW, Saunders DA and Recher HF (2001) 'Why have birds in the woodlands of southern Australia declined?' *Biological Conservation*, 97(1):71–88.

Fryirs KA, Farebrother W and Hose GC (2019) 'Understanding the spatial distribution and physical attributes of upland swamps in the Sydney Basin as a template for their conservation and management', *Australian Geographer*, 50(1):91–110.

Gallagher RV, Allen S, Mackenzie BD, Yates CJ, Gosper CR, Keith DA and Auld TD (2021) 'High fire frequency and the impact of the 2019–2020 megafires on Australian plant diversity', *Diversity and Distributions,* 27(7):1166–1179.

Garnett ST (2021) *The action plan for Australian birds 2020*, CSIRO Publishing, Canberra.

Goldingay RL (2012) 'What role does ecological research play in managing biodiversity in protected areas? Australia's oldest national park as a case study', *Proceedings of the Linnean Society of New South Wales*, 134, B119–B1324.

Goldingay RL and Newell DA (2017) 'Small-scale field experiments provide important insights to restore the rock habitat of Australia's most endangered snake', *Restoration Ecology*, 25(2):243–52.

Hammill K and Tasker L (2010) *Vegetation, fire and climate change in the greater Blue Mountains World Heritage Area*, Department of Environment, Climate Change and Water.

Hopkins GL (2015) *Impacts of habitat fragmentation on microbats across an urban–rural landscape*, BEnvSci Hons, School of Earth & Environmental Science, University of Wollongong.

Hughes EJ, Austin VI, Backhouse F, Maisey AC, Lopez KA, Mikles CS, Odom KJ, Welbergen JA and Dalziell AH (2023) 'Preferred nesting habitat of the slow–breeding Superb Lyrebird is rare and was disproportionately impacted by Australia's "Black Summer" megafires (2019–2020) within a World Heritage Area', *Ornithological Applications*, 6;125(4): duad027.

Jones MW, Abatzoglou JT, Veraverbeke S, Andela N, Lasslop G, Forkel M, Smith A JP, Burton C, Betts RA, Werf GR, Sitch S, Canadell JG, Santín C, Kolden C, Doerr SH and Le Quéré C (2022) 'Global and regional trends and drivers of fire under climate change', *Reviews of Geophysics*, 60(3): e2020RG000726.

Kays R and Parsons AW (2014) 'Mammals in and around suburban yards, and the attraction of chicken coops', *Urban Ecosystems*, 17:691–705.

Keith DA (2004) '*Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT*,' Department of Environment and Conservation NSW, Hurstville, Australia.

Keith DA, Lindenmayer D, Lowe A, Russell–Smith J, Barrett S, Enright NJ, Fox BJ, Guerin G, Paton DC, Tozer MG, Yates CJ (2014) 'Heathlands', in Lindenmayer D, Burns E, Thurgate N and Lowe A (eds.), *Biodiversity and environmental change: monitoring, challenges and direction*, CSIRO Publishing, Canberra.

Keith D and Pellow B (2005) 'Effects of Javan rusa deer (*Cervus timorensis*) on native plant species in the Jibbon–Bundeena area, Royal National Park, New South Wales', *Proceedings of the Linnean Society of New South Wales*, 126:99–110.

Keith DA, Rodoreda S, Holman L and Lemmon J (2006) 'Monitoring change in upland swamps in Sydney's water catchments: the roles of fire and rain', Department of Environment and Conservation, Sydney

Keith DA, Rodoreda S, Bedward M (2010) 'Decadal change in wetland-woodland boundaries during the late 20th century reflects climatic trends', *Global Change Biology*, 16:2300–2306.

Keith DA and Tozer MG (2012, January) 'Vegetation dynamics in coastal heathlands of the Sydney basin', in *Proceedings of the Linnean Society of New South Wales*, 134, B181–B197.

King RJ (ed.) (2013) *Field guide to Royal National Park*, The Linnean Society of New South Wales, Kingsford NSW.

Legge S, Rumpff L, Woinarski JC, Whiterod NS, Ward M, Southwell DG, Scheele BC, Nimmo DG, Lintermans M, Geyle HM and Garnett ST (2022) 'The conservation impacts of ecological disturbance: Time-bound estimates of population loss and recovery for fauna affected by the 2019–2020 Australian megafires', *Global Ecology and Biogeography*, 31:2085–104.

Legge S, Rumpff L, Garnett ST and Woinarski JC (2023) 'Loss of terrestrial biodiversity in Australia: Magnitude, causation, and response', *Science*, 381(6658):622–31.

Local Land Services (2022) *Greater Sydney Regional Strategic Weed Management Plan 2023–2027* [PDF 3.4MB], accessed 12 January 2023.

Local Land Services (2023) *Regional strategic weed management plans*, Local Land Services webpage, accessed 12 January 2024.

Lydy MJ, Crawford CG and Frey JW (2000) 'A comparison of selected diversity, similarity, and biotic indices for detecting changes in benthic-invertebrate community structure and stream quality', *Archives of Environmental Contamination and Toxicology*, 39:469–79.

Maisey AC, Collins L, Newell G and Bennett AF (2023) 'Effects of a megafire vary with fire severity and forest type: The impact of Australia's 'Black Summer' fires on the superb lyrebird (*Menura novaehollandiae*), an iconic forest species', *Biological Conservation*, 288:110356.

Martin BG (2003) 'The role of small ground-foraging mammals in topsoil health and biodiversity: Implications to management and restoration', *Ecological Management & Restoration*, 4(2):114–119.

Menkhorst P and Knight F (2010) *Field guide to the mammals of Australia*, 3rd Edition, Oxford University Press.

Menkhorst P, Rogers D, Clarke R, Davies J, Marsack P and Franklin K (2017) *The Australian bird guide,* CSIRO Publishing, Canberra.

McKenzie D and Hines J (2023) PRESENCE software, USGS website, usgs.gov, accessed 27 November 2023.

Milledge D (2004) 'Large owl territories as a planning tool for vertebrate fauna conservation in the forests and woodlands of eastern Australia', in *Conservation of Australia's forest fauna forum of the Royal Zoological Society of New South Wales*, 493–507.

Mills D and Stokeld D (2023) 'The effect of different camera setup of species detectability: towards optimising camera–trap surveys', *Annual Conference of the Ecological Society of Australia Conference, Darwin, 3–7 July 2023*.

Mooney SD, Webb M, and Attenbrow V (2007) 'A comparison of charcoal and archaeological information to address the influences on Holocene fire activity in the Sydney Basin', *Australian Geographer*, 38(2):177–194.

NPWS (NSW National Parks and Wildlife Service) (2000) *Royal National Park, Heathcote National Park and Garawarra Recreation area plan of management*, New South Wales National Parks and Wildlife Service, Sydney, Australia.

Newell DA and Goldingay RL (2005) 'Distribution and habitat assessment of the broad–headed snake (*Hoplocephalus bungaroides*)', *Australian Zoologist*, 33:168–179.

NSW Government (2024) *About BioNet vegetation classification*, Environment and Heritage website, accessed 6 May 2024.

NSW RFS (NSW Rural Fire Service) (2013) *Threatened species hazard reduction list – part 1 – plants* [PDF 580KB], accessed 12 January 2024.

NSW Scientific Committee (2012) *Coastal Upland Swamp in the Sydney Basin Bioregion - endangered ecological community listing*, Environment and Heritage website, accessed 9 May 2024.

Nugent, DT, Leonard, SW and Clarke, MF (2014) 'Interactions between the superb lyrebird (*Menura novaehollandiae*) and fire in south–eastern Australia', *Wildlife Research*, 41(3):203–211.

Office of Environment and Heritage (OEH) (2019) 'Measuring biodiversity and ecological integrity in NSW: method for the Biodiversity Indicator Program', OEH, Sydney.

Pendall E, Hewitt A, Boer MM, Carrillo Y, Glenn NF, Griebel A, Middleton JH, Mumford PJ, Ridgeway P, Rymer, PD and Steenbeeke GL (2022) 'Remarkable resilience of forest structure and biodiversity following fire in the peri–urban bushland of Sydney, Australia', *Climate*, 10(6):86.

Penman TD, Pike DA, Webb JK and Shine R (2010) 'Predicting the impact of climate change on Australia's most endangered snake, *Hoplocephalus bungaroides'*, *Diversity and Distributions*, 16(1):109–18.

Pennay M, Law B and Reinhold L (2004) *Bat calls of New South Wales: region based guide to the echolocation of microchiropteran bats*, NSW Department of Environment and Conservation, Hurstville.

Pringle RM, Webb JK and Shine R (2003) 'Canopy structure, microclimate, and habitat selection by a nocturnal snake, *Hoplocephalus bungaroides*', *Ecology*, 84:2668–2679.

Raiter KG, Hobbs RJ, Possingham HP, Valentine LE and Prober SM (2018) Vehicle tracks are predator highways in intact landscapes, *Biological Conservation*, 228:281-90.

Reinhold L, Law B, Ford G. and Pennay M (2001) *Key to the bat calls of south–east Queensland and north–east New South Wales,* Queensland Department of Natural Resources and Mines, Indooroopilly.

Schulz M and Goldingay R (2022) *Broad-headed snake: Monitoring in Royal National Park*: Final Report.

Schulz M and Magarey E (2012) 'Vertebrate fauna: A survey of Australia's oldest national park and adjoining reserves', In *Proceedings of the Linnean Society of New South Wales*, 134, B215-B247.

Sollmann R, Mohamed A, Samejima, H and Wilting A (2013) 'Risky business or simple solution–Relative abundance indices from camera–trapping', *Biological conservation*, 159: 405–412.

State Government of NSW and Department of Planning and Environment (2015) *Temperate Highland Peat Swamps* VIS_ID 4087 [data set], Sharing and Enabling Environmental Data, seed.nsw.gov.au, accessed 9 May 2024.

Stokeld D, Frank AS, Hill B, Choy JL, Mahney T, Stevens A, Young S, Rangers D, Rangers W and Gillespie GR (2015) 'Multiple cameras required to reliably detect feral cats in northern Australian tropical savanna: an evaluation of sampling design when using camera traps', *Wildlife Research*, *42*(8): 642–649.

Tay, Y (2019) ‘Bird species richness and abundance: The effects of structural attributes, habitat complexity and tree diameter’, *ANU Undergraduate Research Journal*, 9: 123–137.

Tews J, Brose U, Grimm V, Tielbörger K, Wichmann MC, Schwager M and Jeltsch F (2004) ‘Animal species diversity driven by habitat heterogeneity/diversity: the importance of keystone structures’, *Journal of Biogeography*, 31(1):79–92.

Threatened Species Scientific Committee (2020) Conservation advice *Rhodamnia rubescens* Scrub Turpentine, Canberra: Department of Agriculture, Water and the Environment.

Tozer MG, Simpson CC, Jansens IB and Keith DA (2017) ‘Biogeography of Australia’s dry sclerophyll forests: drought, nutrients and fire’, in in Keith, D (ed.) *Australian vegetation*, Cambridge University Press, New York.

Turak E, Waddell N (2002) *Development of AUSRIVAS models for New South Wales*, Environment Australia.

University of New South Wales (UNSW) (2022) ‘Managing Thirlmere Lakes in a Changing Climate Final Report.’ WRL Research Report 273.

Van Dyck S and Strahan R (eds) (2008) *The Mammals of Australia,* New Holland Publishers, Sydney

Wagner B, Kreft H, Nitschke CR, Schrader J (2023) ‘Remotely sensed tree height and density explain global gliding vertebrate richness’, *Ecography*, e06435.

Wardell–Johnson G, Neldner J and Balmer J (2017) ‘Wet sclerophyll forests’, in Keith, D (ed.) *Australian vegetation*, Cambridge University Press, New York.

Webb JK and Shine R (1997) ‘Out on a limb: Conservation implications of tree–hollow use by a threatened snake species’, *Biological Conservation*, 81: 21–33.

Williams ER and Thomson B (2018) ‘Aspects of the foraging and roosting ecology of the large-eared pied bat (*Chalinolobus dwyeri*) in the western Blue Mountains, with implications for conservation’, *Australian Mammalogy*, 41(2): 212-219.

Woinarski JCZ and Recher HF (1997) ‘Impact and response: a review of the effects of fire on the Australian avifauna’, *Pacific Conservation Biology*,3(3), 183–205.

Woinarski JC, Burbidge AA and Harrison PL (2014) *The Action Plan for Australian Mammals 2012*, CSIRO Publishing, Australia.

Woinarski JC, Burbidge AA and Harrison PL (2015) ‘Ongoing unravelling of a continental fauna: decline and extinction of Australian mammals since European settlement’, *Proceedings of the National Academy of Sciences*, 112(15): 4531–4540.

Wysong ML, Iacona GD, Valentine LE, Morris K and Ritchie EG (2020) ‘On the right track: placement of camera traps on roads improves detection of predators and shows non-target impacts of feral cat baiting’, *Wildlife Research*, 47(8):557-69.

Appendix 1: Mammals

List of mammals for Royal–Heathcote–Garawarra

The 3 tables below list:

- all species of mammals recorded in RHG in the last 5 years from the Scorecards program and database records from BioNet and ALA (Table 20)
- additional mammal species recorded from RHG which haven't been recorded in the last 5 years (Table 21)
- mammals species suspected to have occurred in RHG at the time of European settlement (c. 1750) based on bioregion records and suspected historic distributions (from Woinarski et al. 2014) (Table 22).

Table 20 Mammals recorded in Royal–Heathcote–Garawarra in the last 5 years (BioNet, ALA and Scorecards)

Mammal guild	Common name	Scientific name
Small ground-dwelling (<250g)	Brown antechinus	*Antechinus stuartii*
	Bush rat	*Rattus fuscipes*
	Common dunnart	*Sminthopsis murina*
	Mainland dusky antechinus	*Antechinus mimetes*
	New Holland mouse	*Pseudomys novaehollandiae*
	Swamp rat	*Rattus lutreolus*
	Yellow-footed antechinus	*Antechinus flavipes*
Medium sized (250 g to 15 kg)	Long-nosed bandicoot	*Perameles nasuta*
	Platypus	*Ornithorhynchus anatinus*
	Short-beaked echidna	*Tachyglossus aculeatus*
Large sized (>15 kg)	Bare-nosed wombat	*Vombatus ursinus*
	Common wallaroo	*Osphrantar robustus*
	Eastern grey kangaroo	*Macropus giganteus*
	Swamp wallaby	*Wallabia bicolor*
Arboreal	Common brushtail possum	*Trichosurus cunninghami*
	Common ringtail possum	*Pseudocheirus peregrinus*
	Eastern pygmy-possum	*Cercartetus nanus*
	Feathertail glider	*Acrobates pygmaeus*
	Koala	*Phascolarctos cinereus*
	Mountain brushtail possum	*Trichosurus cunninghami*
	Southern greater glider	*Petauroides volans*
	Krefft's glider/sugar glider	*Petaurus* sp.
Bats – mega	Grey-headed flying fox	*Pteropus poliocephalus*

Mammal guild	Common name	Scientific name
Bats – micro	Chocolate wattled bat	*Chalinolobus morio*
	Eastern false pipistrelle	*Falsistrellus tasmaniensis**
	Eastern broad-nosed bat	*Scotorepens orion*
	Eastern coastal free-tailed bat	*Micronomus norfolkensis*
	Eastern free-tailed bat	*Ozimops ridei*
	Eastern horseshoe-bat	*Rhinolophus megaphyllus*
	Gould's long-eared bat	*Nyctophilus gouldi*
	Gould's wattled bat	*Chalinolobus gouldii*
	Greater broad-nosed bat	*Scoteanax rueppellii**
	Large bent-winged bat	*Miniopterus orianae oceanensis**
	Large forest bat	*Vespadelus darlingtoni*
	Large-eared pied bat	*Chalinolobus dwyeri**
	Lesser long-eared bat	*Nyctophilus geoffroyi*
	Little bent-winged bat	*Miniopterus australis**
	Little forest bat	*Vespadelus vulturnus*
	South-eastern free-tailed Bat	*Mormopterus planiceps*
	Southern myotis	*Myotis macropus*
	White-striped freetail-bat	*Austronomus australis*
	Yellow-bellied sheath-tailed bat	*Saccolaimus flaviventris*

*species as listed as threatened under the *Biodiversity Conservation Act 2016*.

Table 21 Additional mammals recorded in Royal–Heathcote–Garawarra from all records available in BioNet and ALA

Mammal guild	Common name	Scientific name	Last record
Small ground-dwelling (<250 g)	Rakali (water rat)	*Hydromys chrysogaster*	1964
Medium sized (250 g to 15 kg)	Spotted-tailed quoll	*Dasyurus maculatus*	2007
Large sized (>15 kg)	Dingo	*Canis lupus dingo*	Uncertain due to hybridisation with domestic dogs

Table 22 Mammal species that may have been extant at time of European arrival (c. 1750)*

Mammal guild	Common name	Scientific name
Medium sized (250 g to 15 kg)	Brush-tailed rock-wallaby	*Petrogale penicillata*
	Eastern quoll	*Dasyurus viverrinus*
	Long-nosed potoroo	*Potorous tridactylus*
	Parma wallaby	*Macropus parma*
	Southern brown bandicoot	*Isoodon obesulus*
Arboreal	Brush-tailed phascogale	*Phascogale tapoatafa*

*Bioregional records, Woinarski et al. (2014).

Appendix 2: Birds

List of bird species for Royal–Heathcote–Garawarra

The tables below list:

- all species of birds recorded in RHG in the last 5 years from the Scorecards program and database records from BioNet and ALA (Table 23)
- additional bird species recorded from RHG which haven't been recorded in the last 5 years (Table 24).

Table 23 Birds recorded in Royal–Heathcote–Garawarra in the last 5 years (BioNet, ALA and Scorecards)

Common name	Scientific name
Arctic jaegar	*Stercorarius parasiticus*
Australasian darter	*Anhinga novaehollandiae*
Australasian figbird	*Sphecotheres vieilloti*
Australasian gannet	*Morus serrator*
Australasian grebe	*Tachybaptus novaehollandiae*
Australasian shoveler	*Spatula rhynchotis*
Australian brushturkey	*Alectura lathami*
Australian hobby	*Falco longipennis*
Australian king-parrot	*Alisterus scapularis*
Australian magpie	*Gymnorhina tibicen*
Australian owlet-nightjar	*Aegotheles cristatus*
Australian pelican	*Pelecanus conspicillatus*
Australian pipit	*Anthus novaeseelandiae*
Australian raven	*Corvus coronoides*
Australian reed-warbler	*Acrocephalus australis*
Australian white Ibis	*Threskiornis moluccus*
Australian wood Duck	*Chenonetta jubata*
Azure kingfisher	*Ceyx azureus*
Barn owl	*Tyto alba*
Bar-shouldered dove	*Geopelia humeralis*
Bar-tailed godwit	*Limosa lapponica*
Bassian thrush	*Zoothera lunulata*
Beach stone-curlew	*Esacus magnirostris*
Beautiful firetail	*Stagonopleura bella*
Bell miner	*Manorina melanophrys*
Black swan	*Cygnus atratus*

Common name	Scientific name
Black-browed albatross	*Thalassarche melanophris*
Black-faced cuckoo-shrike	*Coracina novaehollandiae*
Black-faced monarch	*Monarcha melanopsis*
Black-fronted dotterel	*Elseyornis melanops*
Black-shouldered kite	*Elanus axillaris*
Brown cuckoo-dove	*Macropygia phasianella*
Brown falcon	*Falco berigora*
Brown gerygone	*Gerygone mouki*
Brown goshawk	*Accipiter fasciatus*
Brown honeyeater	*Lichmera indistincta*
Brown quail	*Synoicus ypsilophora*
Brown skua	*Stercorarius antarcticus*
Brown thornbill	*Acanthiza pusilla*
Brown treecreeper	*Climacteris picumnus*
Brown-headed honeyeater	*Melithreptus brevirostris*
Brush bronzewing	*Phaps elegans*
Brush cuckoo	*Cacomantis variolosus*
Buff-banded rail	*Gallirallus philippensis*
Buff-rumped thornbill	*Acanthiza reguloides*
Caspian tern	*Hydroprogne caspia*
Cattle egret	*Bubulcus ibis*
Channel-billed cuckoo	*Scythrops novaehollandiae*
Chestnut teal	*Anas castanea*
Chestnut-rumped heathwren	*Hylacola pyrrhopygia*
Cicadabird	*Edolisoma tenuirostris*
Collared sparrowhawk	*Accipiter cirrocephalus*
Common bronzewing	*Phaps chalcoptera*
Common tern	*Sterna hirundo*
Crescent honeyeater	*Phylidonyris pyrrhopterus*
Crested pigeon	*Ocyphaps lophotes*
Crested tern	*Thalasseus bergii*
Crimson rosella	*Platycercus elegans*
Dollarbird	*Eurystomus orientalis*
Double-banded plover	*Charadrius bicinctus*
Dusky moorhen	*Gallinula tenebrosa*
Dusky woodswallow	*Artamus cyanopterus cyanopterus*
Eastern curlew	*Numenius madagascariensis*

Common name	Scientific name
Eastern koel	*Eudynamys orientalis*
Eastern osprey	*Pandion cristatus*
Eastern reef egret	*Egretta sacra*
Eastern rosella	*Platycercus eximius*
Eastern shrike-tit	*Falcunculus frontatus frontatus*
Eastern spinebill	*Acanthorhynchus tenuirostris*
Eastern whipbird	*Psophodes olivaceus*
Eastern yellow robin	*Eopsaltria australis*
Eurasian coot	*Fulica atra*
Fairy martin	*Petrochelidon ariel*
Fan-tailed cuckoo	*Cacomantis flabelliformis*
Flesh-footed shearwater	*Ardenna carneipes*
Fluttering shearwater	*Puffinus gavia*
Fork-tailed swift	*Apus pacificus*
Fuscous honeyeater	*Ptilotula fusca*
Galah	*Eolophus roseicapilla*
Gang-gang cockatoo	*Callocephalon fimbriatum*
Glossy black-cockatoo	*Calyptorhynchus lathami*
Glossy ibis	*Plegadis falcinellus*
Golden whistler	*Pachycephala pectoralis*
Great cormorant	*Phalacrocorax carbo*
Great egret	*Ardea alba*
Great-winged petrel	*Pterodroma macroptera*
Green catbird	*Ailuroedus crassirostris*
Grey butcherbird	*Cracticus torquatus*
Grey currawong	*Strepera versicolor*
Grey fantail	*Rhipidura albiscapa*
Grey goshawk	*Accipiter novaehollandiae*
Grey shrike-thrush	*Colluricincla harmonica*
Grey teal	*Anas gracilis*
Grey-faced petrel	*Pterodroma gouldi*
Grey-tailed tattler	*Tringa brevipes*
Hardhead	*Aythya australis*
Hoary-headed grebe	*Poliocephalus poliocephalus*
Horsfield’s bronze-cuckoo	*Chalcites basalis*
Hutton’s shearwater	*Puffinus huttoni*
Jacky winter	*Microeca fascinans*

Common name	Scientific name
Kelp gull	*Larus dominicanus*
King quail	*Synoicus chinensis*
Large-billed scrubwren	*Sericornis magnirostra*
Latham’s snipe	*Gallinago hardwickii*
Laughing kookaburra	*Dacelo novaeguineae*
Leaden flycatcher	*Myiagra rubecula*
Lewin’s honeyeater	*Meliphaga lewinii*
Lewin’s rail	*Lewinia pectoralis*
Little Black cormorant	*Phalacrocorax sulcirostris*
Little corella	*Cacatua sanguinea*
Little eagle	*Hieraaetus morphnoides*
Little egret	*Egretta garzetta*
Little friarbird	*Philemon citreogularis*
Little lorikeet	*Glossopsitta pusilla*
Little penguin	*Eudyptula minor*
Little pied cormorant	*Microcarbo melanoleucos*
Little tern	*Sternula albifrons*
Little wattlebird	*Anthochaera chrysoptera*
Logrunner	*Orthonyx temminckii*
Long-billed corella	*Cacatua tenuirostris*
Magpie-lark	*Grallina cyanoleuca*
Mangrove gerygone	*Gerygone levigaster*
Masked lapwing	*Vanellus miles*
Mistletoebird	*Dicaeum hirundinaceum*
Musk lorikeet	*Glossopsitta concinna*
Nankeen kestrel	*Falco cenchroides cenchroides*
Nankeen night heron	*Nycticorax caledonicus*
New holland honeyeater	*Phylidonyris novaehollandiae*
Noisy friarbird	*Philemon corniculatus*
Noisy miner	*Manorina melanocephala*
Noisy pitta	*Pitta versicolor*
Northern giant-petrel	*Macronectes halli*
Olive-backed oriole	*Oriolus sagittatus*
Pacific baza	*Aviceda subcristata*
Pacific black duck	*Anas superciliosa*
Pacific gull	*Larus pacificus*
Painted button-quail	*Turnix varius*

Common name	Scientific name
Peaceful dove	*Geopelia striata*
Peregrine falcon	*Falco peregrinus*
Pheasant coucal	*Centropus phasianinus*
Pied butcherbird	*Cracticus nigrogularis*
Pied cormorant	*Phalacrocorax varius*
Pied currawong	*Strepera graculina*
Pied oystercatcher	*Haematopus longirostris*
White-headed stilt	*Himantopus leucocephalus*
Pilotbird	*Pycnoptilus floccosus*
Plumed egret	*Ardea plumifera*
Pomarine jaeger	*Stercorarius pomarinus*
Powerful owl	*Ninox strenua*
Purple swamphen	*Porphyrio porphyrio*
Rainbow lorikeet	*Trichoglossus haematodus*
Red wattlebird	*Anthochaera carunculata*
Red-backed button-quail	*Turnix maculosus*
Red-browed finch	*Neochmia temporalis*
Red-browed treecreeper	*Climacteris erythrops*
Red-rumped parrot	*Psephotus haematonotus*
Restless flycatcher	*Myiagra inquieta*
Rockwarbler	*Origma solitaria*
Rose robin	*Petroica rosea*
Royal spoonbill	*Platalea regia*
Rufous fantail	*Rhipidura rufifrons*
Rufous songlark	*Cincloramphus mathewsi*
Rufous whistler	*Pachycephala rufiventris*
Sacred kingfisher	*Todiramphus sanctus*
Satin bowerbird	*Ptilonorhynchus violaceus*
Satin flycatcher	*Myiagra cyanoleuca*
Scaly-breasted lorikeet	*Trichoglossus chlorolepidotus*
Scarlet honeyeater	*Myzomela sanguinolenta*
Shining bronze-cuckoo	*Chalcites lucidus*
Short-tailed shearwater	*Ardenna tenuirostris*
Shy albatross	*Thalassarche cauta*
Silver gull	*Chroicocephalus novaehollandiae*
Silvereye	*Zosterops lateralis*
Sooty owl	*Tyto tenebricosa*

Common name	Scientific name
Sooty oystercatcher	*Haematopus fuliginosus*
Sooty shearwater	*Ardenna grisea*
Sooty tern	*Onychoprion fuscata*
Southern boobook	*Ninox novaeseelandiae*
Southern emu-wren	*Stipiturus malachurus*
Southern giant-petrel	*Macronectes giganteus*
Spangled drongo	*Dicrurus bracteatus*
Spectacled monarch	*Symposiachrus trivirgatus*
Spotted harrier	*Circus assimilis*
Spotted pardalote	*Pardalotus punctatus*
Spotted quail-thrush	*Cinclosoma punctatum*
Square-tailed kite	*Lophoictinia isura*
Straw-necked ibis	*Threskiornis spinicollis*
Striated heron	*Butorides striata*
Striated pardalote	*Pardalotus striatus*
Striated thornbill	*Acanthiza lineata*
Sulphur-crested cockatoo	*Cacatua galerita*
Superb fairy-wren	*Malurus cyaneus*
Superb fruit-dove	*Ptilinopus superbus*
Superb lyrebird	*Menura novaehollandiae*
Swamp harrier	*Circus approximans*
Swift parrot	*Lathamus discolor*
Tawny frogmouth	*Podargus strigoides*
Tawny-crowned honeyeater	*Gliciphila melanops*
Topknot pigeon	*Lopholaimus antarcticus*
Tree martin	*Petrochelidon nigricans*
Varied sittella	*Daphoenositta chrysoptera*
Variegated fairy-wren	*Malurus lamberti*
Wedge-tailed eagle	*Aquila audax*
Wedge-tailed shearwater	*Ardenna pacifica*
Welcome swallow	*Hirundo neoxena*
Whimbrel	*Numenius phaeopus*
Whistling kite	*Haliastur sphenurus*
White-bellied cuckoo-shrike	*Coracina papuensis*
White-bellied sea-eagle	*Haliaeetus leucogaster*
White-browed scrubwren	*Sericornis frontalis*
White-cheeked honeyeater	*Phylidonyris niger*

Common name	Scientific name
White-eared honeyeater	*Nesoptilotis leucotis*
White-faced heron	*Egretta novaehollandiae*
White-fronted tern	*Sterna striata*
White-headed pigeon	*Columba leucomela*
White-naped honeyeater	*Melithreptus lunatus*
White-necked heron	*Ardea pacifica*
White-necked petrel	*Pterodroma cervicalis*
White-plumed honeyeater	*Ptilotula penicillata*
White-throated gerygone	*Gerygone olivacea*
White-throated needletail	*Hirundapus caudacutus*
White-throated nightjar	*Eurostopodus mystacalis*
White-throated treecreeper	*Cormobates leucophaea*
White-winged triller	*Lalage sueurii*
Willie wagtail	*Rhipidura leucophrys*
Wonga pigeon	*Leucosarcia melanoleuca*
Yellow thornbill	*Acanthiza nana*
Yellow-billed spoonbill	*Platalea flavipes*
Yellow-faced honeyeater	*Caligavis chrysops*
Yellow-nosed albatross	*Thalassarche chlororhynchos*
Yellow-rumped thornbill	*Acanthiza chrysorrhoa*
Yellow-tailed black-cockatoo	*Zanda funereus*
Yellow-throated scrubwren	*Neosericornis citreogularis*
Yellow-tufted honeyeater	*Lichenostomus melanops*

Table 24 Additional birds recorded in RHG from all records available in Bionet, ALA and eBird

Common name	Scientific name
Antarctic prion	*Pachyptila desolata*
Australasian bittern	*Botaurus poiciloptilus*
Australian gull-billed tern	*Gelochelidon macrotarsa*
Australian little bittern	*Ixobrychus dubius*
Australian painted-snipe	*Rostratula australis*
Australian spotted crake	*Porzana fluminea*
Baillon’s crake	*Porzana pusilla*
Barking owl	*Ninox connivens*
Black bittern	*Ixobrychus flavicollis*
Black kite	*Milvus migrans*
Black-chinned honeyeater	*Melithreptus gularis*

Common name	Scientific name
Black-necked stork	*Ephippiorhynchus asiaticus*
Black-tailed godwit	*Limosa limosa*
Black-winged petrel	*Pterodroma nigripennis*
Blue petrel	*Halobaena caerulea*
Blue-faced honeyeater	*Entomyzon cyanotis*
Broad-billed prion	*Pachyptila vittata*
Broad-billed sandpiper	*Limicola falcinellus*
Brown booby	*Sula leucogaster*
Brown songlark	*Cincloramphus cruralis*
Budgerigar	*Melopsittacus undulatus*
Buller's albatross	*Thalassarche bulleri*
Buller's shearwater	*Ardenna bulleri*
Bush stone-curlew	*Burhinus grallarius*
Cape petrel	*Daption capense*
Citrine wagtail	*Motacilla citreola*
Common greenshank	*Tringa nebularia*
Common noddy	*Anous stolidus*
Common sandpiper	*Actitis hypoleucos*
Cook's petrel	*Pterodroma cookii*
Crimson chat	*Epthianura tricolor*
Curlew sandpiper	*Calidris ferruginea*
Double-barred finch	*Stizoptera bichenovii*
Eastern bristlebird	*Dasyornis brachypterus*
Eastern grass owl	*Tyto longimembris*
Eastern ground parrot	*Pezoporus wallicus wallicus*
Emerald dove	*Chalcophaps indica*
Fairy prion	*Pachyptila turtur*
Fairy tern	*Sternula nereis*
Flame robin	*Petroica phoenicea*
Forest kingfisher	*Todiramphus macleayii*
Golden-headed cisticola	*Cisticola exilis*
Gould's petrel	*Pterodroma leucoptera leucoptera*
Great knot	*Calidris tenuirostris*
Great skua	*Catharacta skua*
Greater sand plover	*Charadrius leschenaultii*
Grey plover	*Pluvialis squatarola*
Grey-crowned babbler	*Pomatostomus temporalis*

Common name	Scientific name
Hooded plover	*Thinornis rubricollis*
Lesser frigatebird	*Fregata ariel*
Lesser sand plover	*Charadrius mongolus*
Little grassbird	*Poodytes gramineus*
Little raven	*Corvus mellori*
Little shearwater	*Puffinus assimilis*
Long-tailed jaeger	*Stercorarius longicaudus*
Marsh sandpiper	*Tringa stagnatilis*
Masked owl	*Tyto novaehollandiae*
Musk duck	*Biziura lobata*
Olive whistler	*Pachycephala olivacea*
Pacific golden plover	*Pluvialis fulva*
Painted honeyeater	*Grantiella picta*
Pallid cuckoo	*Heteroscenes pallidus*
Pectoral sandpiper	*Calidris melanotos*
Pink-eared duck	*Malacorhynchus membranaceus*
Plumed whistling-duck	*Dendrocygna eytoni*
Providence petrel	*Pterodroma solandri*
Red knot	*Calidris canutus*
Red-backed kingfisher	*Todiramphus pyrrhopygius*
Red-capped plover	*Charadrius ruficapillus*
Red-kneed dotterel	*Erythrogonys cinctus*
Red-necked avocet	*Recurvirostra novaehollandiae*
Red-necked stint	*Calidris ruficollis*
Regent bowerbird	*Sericulus chrysocephalus*
Regent honeyeater	*Anthochaera phrygia*
Rose-crowned fruit-dove	*Ptilinopus regina*
Ruddy turnstone	*Arenaria interpres*
Salvin's prion	*Pachyptila salvini*
Sanderling	*Calidris alba*
Scarlet robin	*Petroica boodang*
Sharp-tailed sandpiper	*Calidris acuminata*
Slender-billed prion	*Pachyptila belcheri*
Soft-plumaged petrel	*Pterodroma mollis*
Sooty albatross	*Phoebetria fusca*
Southern fulmar	*Fulmarus glacialoides*
Speckled warbler	*Chthonicola sagittata*

Common name	Scientific name
Spotless crake	*Porzana tabuensis*
Striated fieldwren	*Calamanthus fuliginosus*
Stubble quail	*Coturnix pectoralis*
Tawny grassbird	*Cincloramphus timoriensis*
Terek sandpiper	*Xenus cinereus*
Wandering albatross	*Diomedea exulans*
Wandering tattler	*Tringa incana*
Weebill	*Smicrornis brevirostris*
Westland petrel	*Procellaria westlandica*
White-breasted woodswallow	*Artamus leucorynchus*
White-browed woodswallow	*Artamus superciliosus*
White-faced storm petrel	*Pelagodroma marina*
White-fronted chat	*Epthianura albifrons*
White-headed petrel	*Pterodroma lessonii*
White-tailed tropicbird	*Phaethon lepturus*
Zebra finch	*Taeniopygia guttata*