NSW National Parks and Wildlife Service

Ecological Health Performance Scorecard report

Kosciuszko National Park 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This resource may contain images or names of deceased persons in photographs or historical content.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: Mt Blue Cow, Kosciuszko National Park. Mel Schroder/DCCEEW

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The Ngunnawal, Monaro Ngarigo, Wiradjuri, Wolgalu, GunaiKurnai, Bidawal, Dudhuroa, Jaithmathang, Mitambuta, Ngarigu-Currawong, Taungurung, Waywurru and Wurundjeri are the traditional owners of Australia's alpine country. We acknowledge that many other Aboriginal clans and people also have associations with the mountains. We acknowledge those Indigenous nations that are the traditional custodians of Kosciuszko National Park, and acknowledge Elders past, present and future, the living spiritual connections with the land, traditional laws, and customs and beliefs passed on through the generations. Indigenous people are recognised and respected as the original caretakers for the ecological health of Kosciuszko National Park, its waters, soils, animals and plants. The continued role of Indigenous people and organisations as custodians is integral to protecting, managing, and interpreting the needs of Kosciuszko National Park.

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Cultural and historical connections

The area now known as Kosciuszko National Park has been home to numerous Indigenous groups and clans for thousands of years. The Ngunnawal, Monaro Ngarigo, Wiradjuri, Wolgalu, GunaiKurnai, Bidawal, Dudhuroa, Jaithmathang, Mitambuta, Ngarigu-Currawong, Taungurung, Waywurru and Wurundjeri are the traditional owners of Australia's alpine country. Aboriginal people have a deep spiritual and cultural connection to this Country. The continued role of Indigenous people as custodians is integral to protecting, managing, and interpreting the needs of Kosciuszko National Park (DPE 2022a).

Kosciuszko National Park is one of Australia's largest and most iconic conservation reserves and covers an area of approximately 689,672 ha. The park extends from an elevation of approximately 220 m above sea level, along the lower Snowy River, to Australia's highest peak, Mount Kosciuszko at 2,228 m above sea level. Occurring across this gradient is a vast diversity of climatic conditions, landforms, vegetation types, flora and fauna, and cultural heritage values. It incorporates 4 major biogeographic regions: Australian Alps, NSW South Western Slopes, South East Corner, and South Eastern Highlands. The headwaters of the Snowy, Murray and Murrumbidgee rivers are all located in the park.

The park has historic European heritage, including cattle grazing from the 1800s and the construction of the Snowy Mountains hydro-electricity scheme from 1949, which has had a legacy of environmental change. The seasonal presence of snow provides a unique opportunity for alpine recreation, in addition to bushwalking, camping, cycling, and attracts millions of recreational visitors annually.

Snowy River from Jacks Lookout. Madeleine de Montfort/DCEEW

Scorecard location

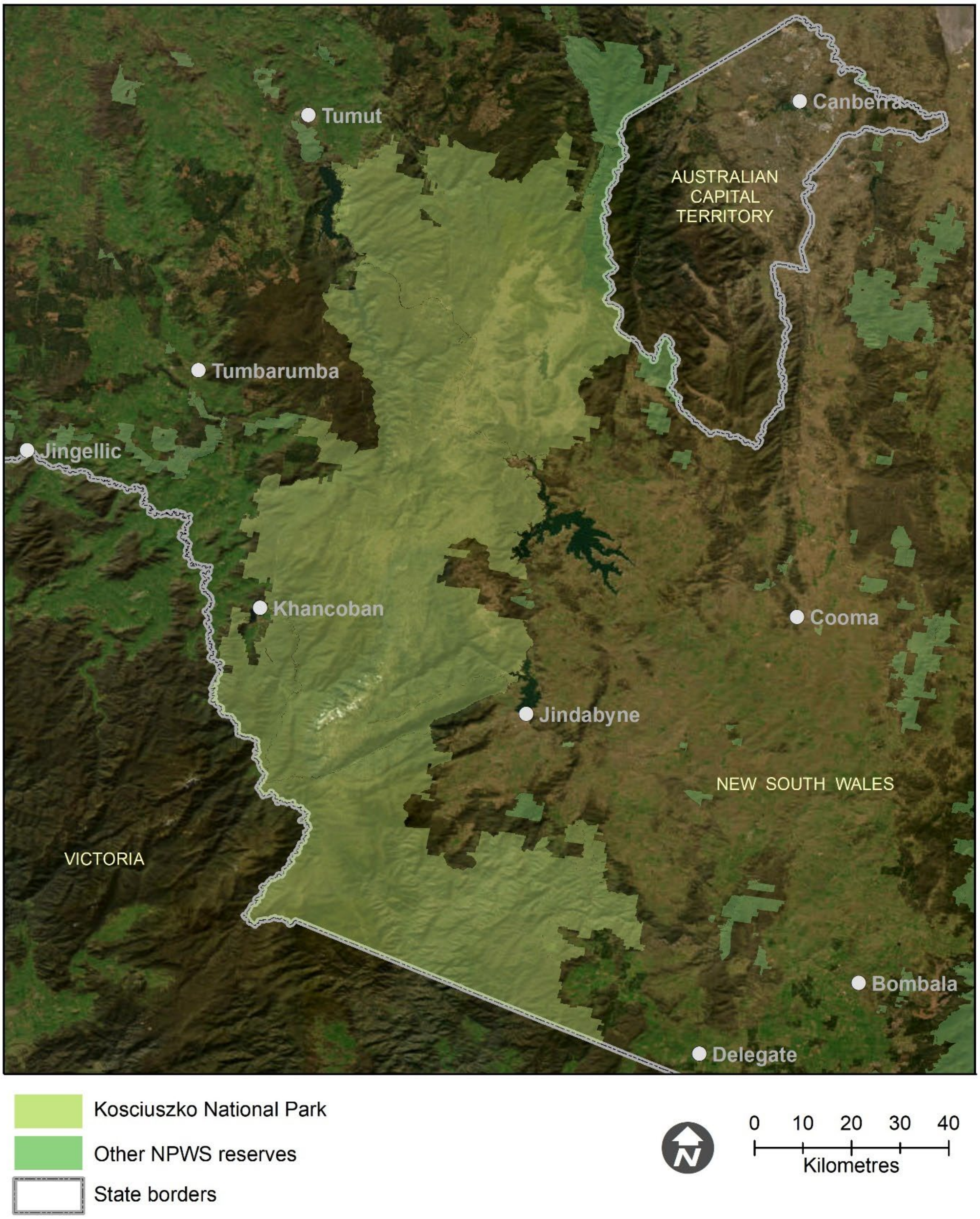


Figure 1 The Kosciuszko Ecological Health Performance Scorecard site

Located in the south-east of New South Wales and marked by the towns of Tumut to the north, Tumbarumba to the west, Jindabyne to the east, and Delegate to the south.

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 in the national park estate.

Kosciuszko National Park (KNP) was gazetted in 1967 (Figure 1). It has the greatest elevational range of any park in Australia (~ 2010 m) and is the largest contiguous area of the Australian Alps bioregion in the country. For these reasons KNP is an important choice for inclusion in the first tranche of the NSW National Parks and Wildlife Service (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 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 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 KNP and will be amended and expanded over time as the program is further developed and as our knowledge about the ecological health of KNP improves. As new ecological risks emerge, and as technology improves, our capacity for measuring and monitoring ecological health will also adapt.

Threatened species are a significant focus of monitoring due to their higher extinction risk, the fact they are a significant focus of management, and attract a high level of public interest in how their populations are faring. However, a range of common species and vegetation communities 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 impact on native biota, including feral animals such as horse (*Equus caballus*), feral cat

(*Felis catus)*, sambar deer (*Rusa unicolor*) and red fox (*Vulpes vulpes*), priority weeds such as mouse-ear hawkweed (*Pilosella officinarum*), and inappropriate fire regimes, 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, by measuring and reporting changes in the population (or similar metric) of key threatened species, the density or activity of feral animals, the extent and threat of weed species, and changes in park-wide fire metrics. This first report provides a baseline against which to measure changes in ecological health over time including changes driven by management initiatives (such as a reduction in the population of horses and other feral animals) and changes that are driven by factors that are beyond the control of park management (for example, as a result of climate change).

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 to explain ecological trends. For example, it is well documented that an increase in the fox population may cause reductions in populations of small to medium-sized native mammals and that horse populations damage bogs and fens. 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 a review of expenditure, management activity and outputs, and positive ecological outcomes. As the 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 such as feral cats or foxes. 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 taxa 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 the 2022–23 financial year and generated a significant amount of data highlighting the large scale of this program (Table 1).

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 KNP. Apart from one or 2 exceptions, 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 opportunities for improved analysis of the trajectories and status of native species and ecosystem processes.

Targeted indicators and monitoring effort may change over time as data are collected and analysed. This will be informed by quantifying monitoring efficacy (e.g. 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 in the future.

Table 1 Park-wide survey effort in the Kosciuszko National Park Scorecards site in 2022–23 financial year

Survey type	Survey effort	Survey timing	Data output
Camera	2022–23: 400 cameras at 100 sites for a mean of 41 nights (16,913 total trap nights)	Nov–Feb	511,804 animal images (5,048,527 total images)
Audible sound recorder	2022–23: 92 recorders at 92 sites for a mean of 27 nights (2,592 total trap nights)	Nov–Feb	48,307 sound files (16,000 hours)
Ultrasonic sound recorder	2022–23: 74 recorders at 74 sites for a mean of 26 nights (1,924 total trap nights)	Nov–Feb	630,381 sound files
Bird	2023: 88 surveys at 44 sites	Feb–April	1,225 individual records
Vegetation	2023: 95 sites each with: 20 × 20 m floristic plots, 50 m point intersect transects, 50 × 20 m tree density plots	Feb–April	Floristic plots: 3,966 records Tree density plots: 10,066 records (stems) Point intercept transect: 23,586 records
Soil	2023: 95 soil cores for bulk density and 380 soil cores for composite analysis	Feb–April	475 soil cores
Water quality	2023: 20 sites, + additional 34 as part of other programs	Mar–April	54 samples for water quality and invertebrates

Wildlife

In the last 5 years, 45 native mammal species have been recorded in KNP (Appendix 1). This represents 79% (or 12 species less) of the likely pre-European (circa 1750 CE) mammal assemblage of 57 species, based on records from BioNet and Atlas of Living Australia (ALA). Of the 12 mammal species not recorded from KNP in the last 5 years, 4 species are probably still extant in KNP: yellow-footed antechinus (*Antechinus flavipes*), brush-tailed phascogale (*brush-tailed phascogale*), eastern broad-nosed bat (*Scotorepens orion*) and south-eastern freetail bat (*Ozimops planiceps*). Eight mammal species (14% of the pre-European assemblage) are suspected to be lost since European settlement; 3 are small ground-dwelling mammals: Hastings River mouse (*Pseudomys oralis*), long-tailed mouse (*Pseudomys higginsi*), and New Holland mouse (*Pseudomys novaehollandiae*); 3 are medium-sized: eastern quoll (*Dasyurus viverrinus*), long-footed potoroo (*Potorous longipes*), and southern brown bandicoot (*Isoodon obesulus*); one is large: brush-tailed rock-wallaby (*Petrogale penicillata*); and one is an arboreal mammal: white-footed rabbit-rat (*Conilurus albipes*). While the loss of 14% of the pre-European mammal species assemblage is considered a high rate of local extinction by global standards (Woinarski et al. 2015), KNP still retains a reasonable proportion of the original mammal diversity, especially when compared to western New South Wales. However, several species are particularly vulnerable, notably cool-climate/high-elevation specialists such as the mountain pygmy-possum (*Burramys parvus*), broad-toothed rat (*Mastacomys fuscus*), Guthega skink (*Liopholis guthega*) and alpine she-oak skink (*Cyclodomorphus praealtus*). Of the 8 mammal species suspected to be locally extinct within KNP, all but one (white-footed rabbit rat), survive elsewhere in Australia and could potentially be reintroduced.

Park-wide surveillance in 2022–23 financial year (FY) recorded 155 species of native fauna in KNP. This comprised 109 bird species, 34 mammal species (12 microbats, 6 large mammals, 7 small ground-dwelling mammals, 5 arboreal mammals, 3 medium-sized mammals and 1 semi-aquatic) and 12 reptile species. Key results from the 2022–23 park-wide surveillance for native mammal species include:

- The spotted-tailed quoll appears to be restricted to the south-east of KNP in the Lower Snowy and Byadbo Wilderness areas.
- The eastern pygmy-possum (*Cercartetus nanus*) was recorded throughout most of the park with the exception of the alpine complex vegetation and at a few sites in grassy woodlands.
- Native mammals with the highest occupancy and activity levels were common brushtail possum (*Trichosurus vulpecula*), bare-nosed wombat (*Vombatus ursinus*), bush rat (*Rattus fuscipes*), swamp wallaby (*Wallabia bicolor*), and mountain brushtail possum (*Trichosurus cunninghami*).
- KNP is a stronghold for the eastern false pipistrelle (*Falsistrellus tasmaniensis*) with a high level of occupancy across monitoring sites.
- One species of bat, yellow-bellied sheathtail, had not been detected in the last 5 years until the Scorecard survey.

A total of 187 bird species have been recorded in KNP over the last 5 years (ALA, BioNet and eBird records, June 2018 – June 2023). There are 17 species that have not been recorded in the last 5 years but are expected to still occur in KNP (Appendix 2 Table 21). Thirty-nine bird species are suspected to have been lost since European settlement, representing 16% of the original bird assemblage (243 species).

Targeted monitoring captures information on KNP species that are not well represented in the park-wide surveillance monitoring. Alpine she-oak skink monitoring sites have been established across the known distribution of the species. Mountain pygmy-possum monitoring suggests the population is stable. Smoky mouse surveys are underway to determine the distribution of the species across the park. Abundance estimates for the spotted-tailed quoll have shown an increase in the past 7 years. The broad-toothed rat appears to be in decline in part of its range, but recent park-wide surveys have shown the species to be widespread throughout KNP and further assessment is required. Guthega skink monitoring showed a recent decline in the number of active burrows, and monitoring suggests the populations of alpine tree frog (*Litoria verreauxii alpina*), booroolong frog (*Litoria booroolongensis*), and southern corroboree frog (*Pseudophryne corroboree*) are stable. Northern corroboree frog (*Pseudophryne pengilleyi*) monitoring suggests a decline, and spotted tree frog (*Litoria spenceri*) monitoring suggests an increase in its population. Targeted monitoring is to be implemented in the future for koalas, yellow-bellied gliders (*Petaurus australis*), eastern false pipistrelle (*Falsistrellus tasmaniensis*) and southern myotis (*Myotis adversus*).

Flora and vegetation communities

There are 5 major vegetation formations in KNP: alpine complex, grassy woodlands, dry sclerophyll forests (shrub/grass sub-formation), dry sclerophyll forests (shrubby sub-formation), and wet sclerophyll forests (grassy sub-formation). KNP supports over 1,100 plant species, approximately 5.2% of Australia's total plant species (DPIE 2021b; Australian National Botanic Gardens 2009) and 24% of New South Wales vascular flora (Doherty et al. 2015). There are 4 recognised threatened ecological communities (TECs) including: Montane peatlands and swamps of the Australian Alps bioregion; Snowpatch feldmark in the Australian Alps bioregion; Windswept feldmark in the Australian Alps bioregion; and the Snowpatch herbfield in the Australian Alps bioregion.

A total of 501 native plant species and 55 weed species were recorded from floristic surveys at park-wide surveillance monitoring sites across the 5 major vegetation formations. Vegetation communities were found to have good diversity in terms of species richness and abundance.

Key results from the 2022–23 park-wide surveillance for the 5 major vegetation formations include:

- The most speciose formation was wet sclerophyll forest with 303 native species.
- The least speciose formation was dry sclerophyll forest (shrub/grass sub-formation) with 126 native species.
- A high number of wet sclerophyll forests, dry sclerophyll forests (shrubby sub-formation) and grassy woodlands sites had the highest density of large trees, however there were very few trees alive which measured >50 cm diameter at breast height (DBH).
- More weed species were recorded in wet sclerophyll forest compared to other formations, with 34 weed species recorded in 78% of the sites.
- The least number of weeds (11 species) were recorded in alpine complex vegetation but at 100% of monitoring sites.
- Three significant environmental weed species were detected during the park-wide surveillance monitoring, with 9 sites recording blackberry (*Rubus* sp.), one site recording ox-eye daisy (*Leucanthemum vulgare*), and sweet vernal grass (*Anthoxanthum odoratum*) detected at 23 sites.

KNP is the key site for the conservation of flora species which are restricted to the alpine areas of Australia. In the 2022–23 scorecard, targeted surveys of 4 of the 24 threatened plant species recorded in KNP have been reported on: anemone buttercup (*Ranunculus anemoneus*), leafy anchor plant (*Discaria nitida*), Max Mueller's burr-daisy (*Calotis pubescens*), and Suggan Buggan mallee (*Eucalyptus saxatilis*). Monitoring recruitment and persistence in the landscape over the long-term will inform management about the impacts that threats such as fire, weed invasion, trampling and herbivory by feral species will have on these species. Generally, data indicates the populations of all 4 threatened species are stable at monitoring locations, but further assessment is required.

Ecological processes

The soils in KNP were generally found to be quite variable across the park. Total nitrogen, phosphorus and organic carbon were highest in the alpine complex sites, which tend to have humus soils developed from the breakdown of organic material (i.e. decomposing plant material). These soils are an important store of carbon. Alpine soils are susceptible to erosion associated with deer and horses. Total nitrogen, phosphorus and organic carbon were also high in grassy woodland sites.

The waterways of KNP have been impacted by historical land use, feral herbivore (including horse) impacts and wastewater inputs from tourist resort areas. Across 54 water monitoring sites, 80% recorded one or more environmental stressor attributes outside recommended guideline levels, and 35% exceed one or more biological condition attribute guidelines. Many alpine stream sites are impacted by tourist activities, stormwater and snow melt runoff from hard surfaces. Upland river sites being monitored for horse impacts observed increased turbidity in areas under high horse activity resulting in increased stress on sensitive macroinvertebrate taxa.

Feral animals and weeds

Ten species of introduced mammals were detected during the park-wide surveillance monitoring: sambar deer (*Rusa unicolor*), fallow deer (*Dama dama*), red deer (*Cervus elaphus*), feral horse (*Equus caballus*), feral pig (*Sus scrofa*), cat (*Felis catus*), red fox (*Vulpes vulpes*), rabbit (*Oryctolagus cuniculus*), brown hare (*Lepus capensis*) and black rat (*Rattus rattus*). An eleventh species, feral goat, while not detected is known to be present at low densities.

Sambar deer occur throughout KNP and were detected at 42% of monitoring sites, with very high levels of activity. Fallow deer were detected at 20% of sites and confined to the south-east section of the park and associated with dry sclerophyll forests (shrub/grassy sub-formation). Control programs aimed at feral herbivores (deer and pigs) along the western edge of KNP and adjoining parks have reduced the number of fallow deer, with 1,206 fallow deer being shot in 2022–23 and 493 sambar deer shot in the same period. One other species of deer, red deer, was also detected but at only one site. For the 2022–23 period, 15 red deer were shot.

The red fox is widespread in KNP, detected at 38% of sites, with high activity levels. Foxes are likely to be impacting populations of native species, particularly small to medium-sized ground-dwelling mammals.

Feral cats were detected at 40% of sites in KNP and are widespread throughout the park. Due to the low detectability of cats from camera-based surveys (Stokeld et al. 2015) this figure is lower than the estimated modelled occupancy of 46%, indicating cats are more widespread. Dedicated surveys to better understand occurrence and density will be established in the 2024–25.

Feral pigs were detected at 19% of sites. In the 2022–23 period, control programs shot 238 feral pigs: 122 individuals from aerial shooting, 86 from trapping and 30 from ground-based shooting. Pig occupancy was strongly associated with dry sclerophyll (shrubby sub-formation) at approximately 5 times the level of other vegetation formations.

In October 2023, the number of horses in KNP was estimated to be 17,393 (95% confidence interval: 12,797 to 21,760). Between February 2022 and June 2023, 1,606 horses were removed.

Feral goats (*Capra hircus*) were not detected in KNP from camera-based surveys but are still known to be present at low numbers (M. Schroder pers. comm. 2023). Aerial shooting programs have significantly reduced the numbers of goats in KNP with no records of goats being shot since 2018.

There are several significant weeds present in KNP, including blackberry, mouse-ear hawkweed, orange hawkweed (*Pilosella aurantiaca*), ox-eye daisy and scotch broom (*Cytisus scoparius*). All have targeted control programs, and control of other weed species is focussed on threatened ecological communities. In 2022–23, 15,850 ha of weeds were treated by NPWS staff and volunteers; and targeted control of mouse-ear hawkweed has resulted in a decline in infestation since 2015.

Climate change

The effects of a changing climate have been widely acknowledged as impacting species and ecosystems, either directly (e.g. prolonged droughts) or indirectly (e.g. more severe and frequent fires as a result of prolonged droughts). Likely interactions between climate change and other factors such as the loss of snow cover, impacts from weeds and feral predation, introductions of disease or plant pathogens, and habitat loss, compound and complicate monitoring. Relating short (5-year) to medium (10-year) changes in KNP species and ecosystems to broad-scale climate-related effects only becomes achievable with long-term data (>10 years) collected across multiple sites in the landscape. 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 KNP is to protect life and property, notwithstanding the geographic extent of the park, a wide range of access conditions, and remoteness of much of the park. This is integrated within a broad ecological objective to prevent widespread, severe and frequent fire.

In the last 20 years there have been 2 widespread and severe bushfires (i.e. unplanned fires) in KNP: one in the 2002–03 fire season and the other during the 2019–20 fire season which burnt 69% and 34% of the park, respectively. On average, nearly 5,300 ha has been burnt annually in prescribed burns, usually as low-severity burns.

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

- In the last 30 years, only 25% of the fire-sensitive alpine complex formation remains unburnt, with the remaining area covered by this formation in KNP experiencing one or more fire events.
- Canopy loss in fire-sensitive tree species, such as alpine ash (*Eucalyptus delegatensis*) and snow gum (*E. pauciflora*), are of concern due to their slow growth rate.
- The delivery of planned fire in the landscape will assist with the ecological management of KNP 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 has 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 Kosciuszko National Park (KNP) and the aggregate of Royal National Park, Heathcote National Park and Garawarra State Conservation Area – collectively called Royal–Heathcote–Garawarra (RHG). The KNP and RHG scorecards are the first scorecards to be developed for the program.

The ecological health monitoring approach for KNP 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 metrics of each indicator and to track changes over time. For example, ecological health monitoring is intended to report on the population (or similar metric) of both common species, such as antechinus, and threatened species, such as mountain pygmy-possum and spotted-tailed quoll, 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 monitoring

To effectively monitor the overall ecological health of assets, threats, and processes across KNP, survey sites have been stratified by vegetation formation (Keith 2004), fire history and elevation: 3 critical factors that can underpin variations in ecological health metrics. Wet sclerophyll forests and grassy woodlands dominate the landscape of KNP and, for this reason, more sites were allocated to these vegetation formations than the other formations to ensure adequate replication and representation across the vegetation formations

(Figure 2, Table 2). Five vegetation formations comprise 97.2%% of the total park area (Table 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 KNP. Four fire-history categories were used for stratification of sites within each vegetation formation to achieve broad representation of the park's fire history, especially over the previous 20 years. These categories were: no fire 20+ years (<2003); one fire (impacted 2003); one fire (impacted 2020); and 2 or more fires (since 2003).

Ground-truthing of the NSW state vegetation type map (DPE 2022b) resulted in some modifications to the original number of sites for each plant community type (PCT) surveyed. Park-wide surveys were completed in 2022–23 at 100 of the proposed 125 sites due to access and weather constraints.

Table 2 The number of proposed sites in each vegetation formation selected in Kosciuszko National Park for the establishment of long-term park-wide surveillance monitoring

Vegetation formation	% area of KNP	No. of sites
Alpine complex	11.9	16
Dry sclerophyll forests (shrubby)	15.2	15
Dry sclerophyll forests (shrub/grass)	2.1	11
Grassy woodlands	24.7	30
Wet sclerophyll forests (grassy)	43.3	53
Total	**97.2**	**125**

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. At each surveillance monitoring site, camera-based surveys 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-ha 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: 2 with a mixture of peanut butter, oats and honey and one deployed with a meat (raw chicken) lure. The 4th camera, with no lure, was placed on game pathways where possible.

Two passive acoustic devices were installed per site. One device recorded sound in the audible range (<24 kHz) to detect fauna species such as powerful owls (*Ninox strenua*), koalas and yellow-bellied gliders, and the other device detected echolocating microbats into the audible to ultrasonic range (8–128 kHz).

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 effects such as poor weather, and increase species-richness estimates. 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 midpoints 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 points within each vegetation plot using a soil corer (0–10 cm core with a 4 cm diameter). Information on tree diameter was recorded from a 20 × 50 m plot that overlap 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.

The park-wide survey effort completed in 2022–23 is summarised in Table 2, which includes information on the number of sites completed and the raw data collected for each survey component.

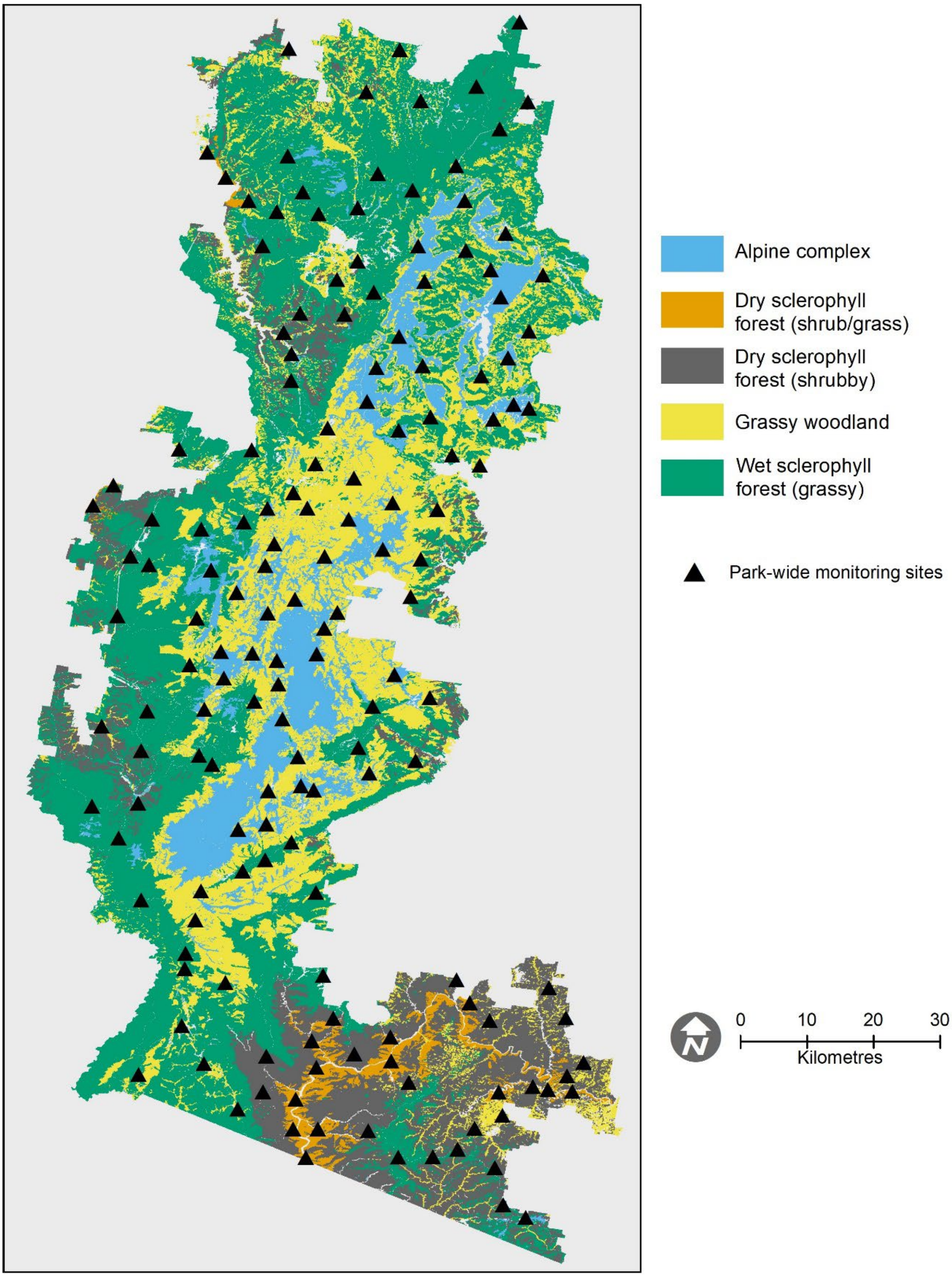


Figure 2 Location of park-wide surveillance monitoring sites across the 5 major vegetation formations for Kosciuszko National Park

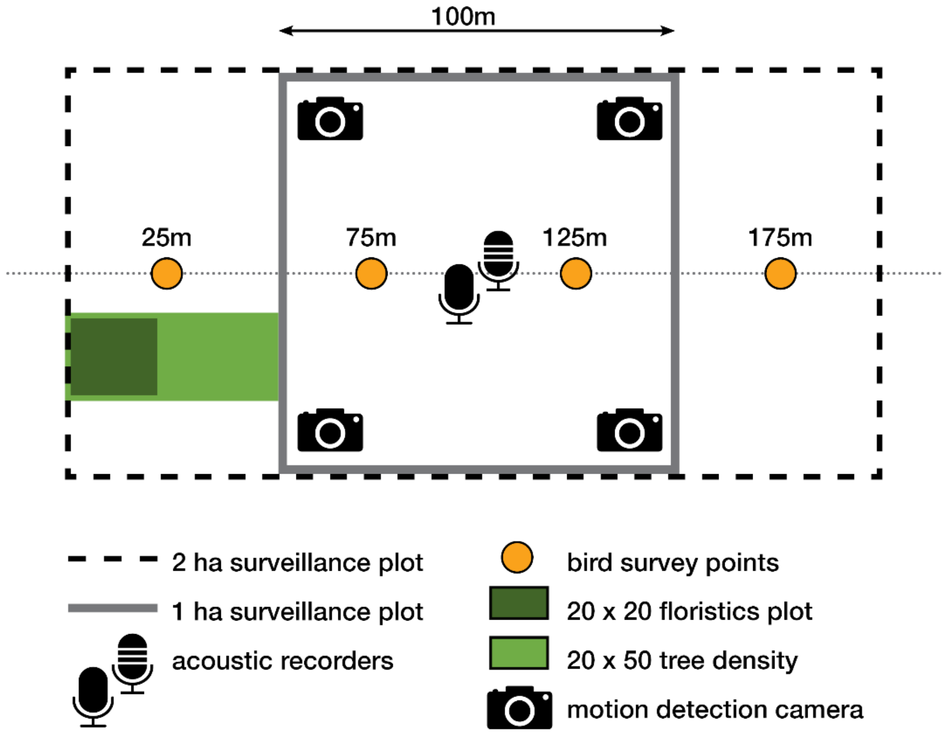


Figure 3 Survey site layout showing placement of each camera and audio device, bird point survey transects, and vegetation plots at each park-wide surveillance monitoring site

Targeted monitoring

While the most representative vegetation communities and fauna species which occur throughout KNP 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, such as Saving our Species. However, the monitoring objectives may differ to those of the Scorecards program – for example, some pre-existing monitoring programs measure the population of a species at a defined site, or small set of sites, which is not representative of the overall population across KNP. Opportunities to leverage, align and supplement existing park monitoring programs will be undertaken following a process of review. Future targeted monitoring for the scorecard program will provide a metric relevant to the KNP population as a whole.

Park-wide surveillance: fauna

Terrestrial and arboreal mammals

Conservation context

In the 200 years since European colonisation, Australia has lost at least 40 mammalian species (Burbidge 2024), which is probably the highest rate of extinction globally. Of the 138 mammal species known in New South Wales, 84 (61%) are listed as threatened under the NSW Biodiversity Conservation Act. Of these, 37 are vulnerable, 19 endangered, 3 critically endangered and 25 are presumed extinct.

Based on subfossil records, the estimated number of mammal species considered to be extant in KNP before European colonisation, was 57 (Aplin et al. 2010; Ford 2015; ALA and BioNet; Appendix 1). Eight of these are now considered to no longer occur in KNP: Hastings River mouse, long-tailed mouse, New Holland mouse, brush-tailed rock-wallaby, eastern quoll, long-footed potoroo, southern brown bandicoot and white-footed rabbit rat. An additional 4 species – yellow-footed antechinus, brush-tailed phascogale, eastern broad-nosed bat and south-eastern freetail bat – have not been recorded in the last 5 years but are expected to still be present in KNP (Appendix 1). A comparison of the present-day fauna assemblage to expected pre-European colonisation (circa 1750) assemblage provides an indicator that measures, directly and indirectly, the overall amount of biodiversity that currently exists (OEH and CSIRO 2019).

KNP is a critical conservation refuge for fauna species not just in Australia, but globally. A number of species have strongholds in the park, notably the mountain pygmy-possum, broad-toothed rat, and spotted-tailed quoll. In the case of the mountain pygmy-possum, it is endemic to the Australian Alps bioregion with the majority of individuals occurring within KNP. The broad-toothed rat is known from only a few other locations in New South Wales (NSW) and Victoria. The spotted-tailed quoll occurs along the eastern seaboard of NSW.

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. In implementing camera-based surveillance monitoring, the presence and absence (occupancy) of a range of species are recorded and reported on. Other important metrics are provided, such as the detection probability of species based on the 4 different camera set-ups employed at each surveillance site. Understanding the relationships between species ecology, survey techniques, and analytical methods is important in implementing a cost-effective and meaningful monitoring program. In the case of camera-based surveys it means understanding how best to deploy cameras to maximise detection probability and reduce variability in occupancy estimates. This extends to how analyses are conducted and the inclusion of survey and habitat covariates in explaining detection probability and occupancy.

Methods and results

Naïve occupancy figures for all native mammals are reported. Where possible, modelled occupancy estimates are provided as a comparison but only where there is sufficient data. As a rule, modelled occupancy analyses have been done only where naïve occupancy is greater than 15%. Detection probabilities are provided to get a better understanding of how the different camera set-ups affect detection probability as this will aid in developing better estimates of occupancy.

Between November 2022 and February 2023, 21 species of native mammals were recorded using camera-based surveys (Figure 4). Cameras were deployed for an average of 42 days at 100 of a proposed 125 park-wide surveillance sites. Of the 400 cameras deployed, there were 4 cameras that failed to record a single image and a further 31 that did not record beyond 10 days, predominantly due to battery failure resulting from excessive false triggering. Despite this, the majority of camera failures and shortened deployments occurred at only one of 4 cameras per site which meant that overall estimates of naïve occupancy were not compromised. The exception to this is for species for which high probabilities of detection (>90%) are not obtained until camera deployments reach 30 days, such as spotted-tailed quoll and feral cat.

Seven small ground-dwelling mammals were detected: agile antechinus (*Antechinus agilis*), dusky antechinus (*A. swainsonii*), common dunnart (*Sminthopsis murina*), bush rat (*Rattus fuscipes*), swamp rat (*Rattus lutreolus*), broad-toothed rat and smoky mouse. Nine species of medium and large mammals were detected: long-nosed bandicoot (*Perameles nasuta*), swamp wallaby, red-necked wallaby (*Notamacropus rufogriseus*), short-beaked echidna (*Tachyglossus aculeatus*), eastern grey kangaroo (*Macropus giganteus*), common wallaroo (*Osphranter robustus*), dingo (*Canis familiaris)*, bare-nosed wombat, and spotted-tailed quoll. Four species of arboreal mammals were also detected on cameras: common ringtail possum (*Pseudocheirus peregrinus*), mountain brushtail possum, common brushtail possum and eastern pygmy-possum. The rakali (the Aboriginal name for water-rat), a semi-aquatic mammal, was also detected using camera-based surveys.

Twenty-nine species of arboreal and terrestrial native mammal species have been recorded in KNP in the last 5 years (30 June 2018 – 30 June 2023), based on records from the current survey, incidental sightings and database records (BioNet and ALA). The only species of ground-dwelling mammal species not captured by the 2022–23 monitoring and absent from recent records was the yellow-footed antechinus. A number of arboreal mammals were not captured by the park-wide surveillance monitoring: southern greater glider, feathertail glider (*Acrobates pygmaeus*), yellow-bellied glider, sugar glider (*Petaurus breviceps*), and squirrel glider (*Petaurus norfolcensis*); primarily because cameras were targeting terrestrial species. More targeted use of cameras aimed at tree trunks is currently being trialled at other ecological health locations to monitor these species more effectively.

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), modelled occupancy (proportion of sites where a species was detected accounting for imperfect detection, and inconsistent survey effort) and activity. Activity has been defined as the number of unique camera detections separated by a 30-minute interval for all camera days recorded and standardised to a 100-day deployment period. 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 2024; Kays and Parsons 2014).

Species richness

The average number of native mammal species observed from camera-based surveillance monitoring sites was 6, with a range of 0 to 12 species per site. More mammal species were detected in wet sclerophyll (grassy sub-formation) and dry sclerophyll (shrub/grass sub-formation) forests than any other vegetation formations (Figure 5). These 2 formations recorded, on average, 7 native mammal species per site. Alpine complex recorded the lowest native mammal diversity with just under 3 species per site.

An analysis was undertaken to assess difference in mammal species richness between vegetation formations. Rarefaction and extrapolation curves were calculated using the iNEXT R package (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 across 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 projected mammal species richness was highest in wet sclerophyll forest (grassy sub-formation), most likely due to the relatively high number of sites sampled (n=44). Similar species richness was observed in the other 4 vegetation formations (Figure 5) but the uncertainty in projected species richness was much greater in alpine complex and dry sclerophyll forest (shrubby sub-formation). The sample and projected native mammal species richness was similar in dry sclerophyll forest (shrub/grass sub-formation) to the other 4 formations. However, the sampled and projected species richness with this formation was the same (n=10) with extremely low error estimates (estimated species richness range = 10-11).

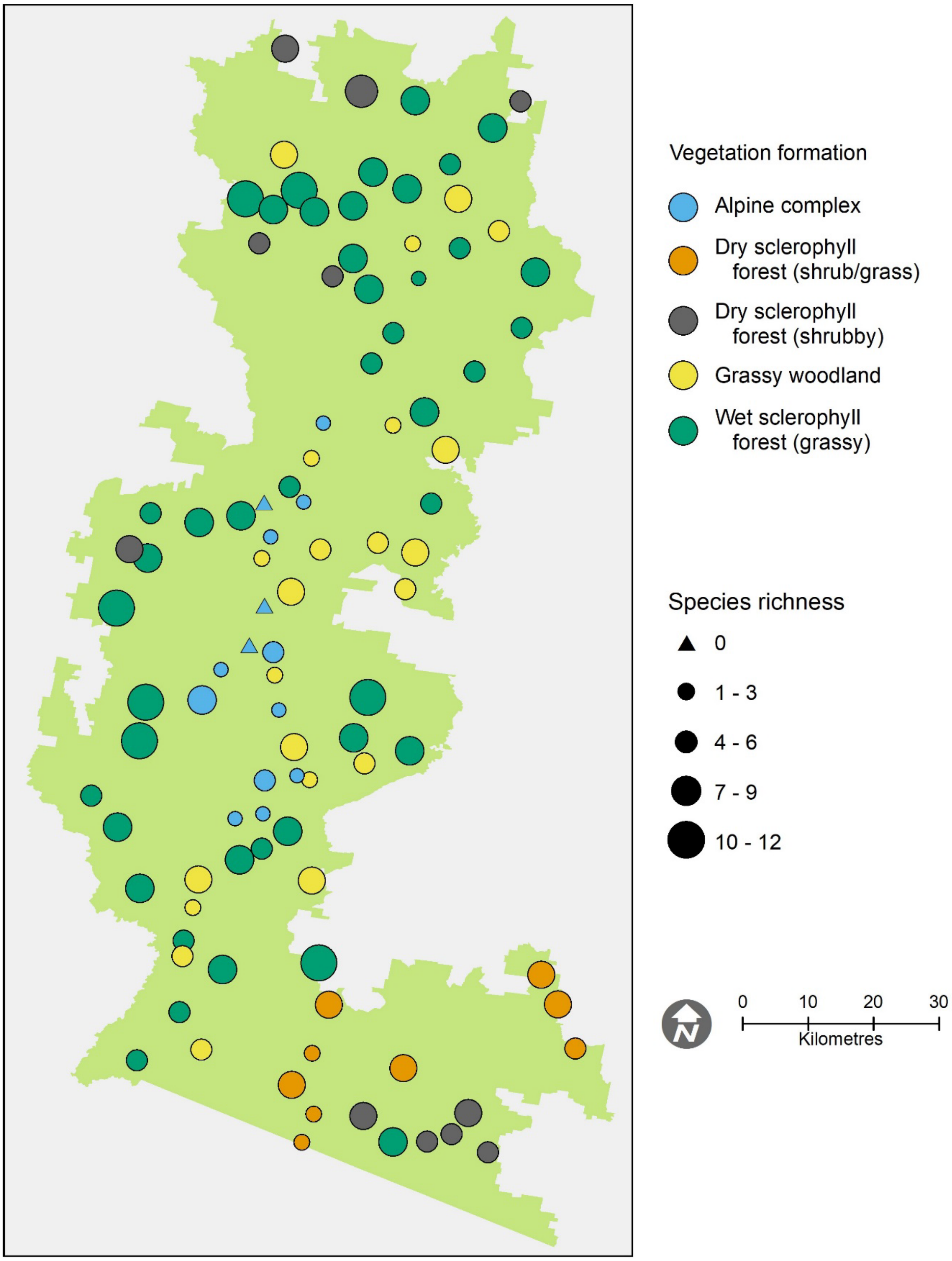


Figure 4 Native mammal species richness from camera-based surveys at 100 park-wide surveillance monitoring sites in Kosciuszko National Park

Symbol sizes are graduated by the number of species per site, with the larger symbols representing more diverse sites. Triangles denote no mammal species detected.

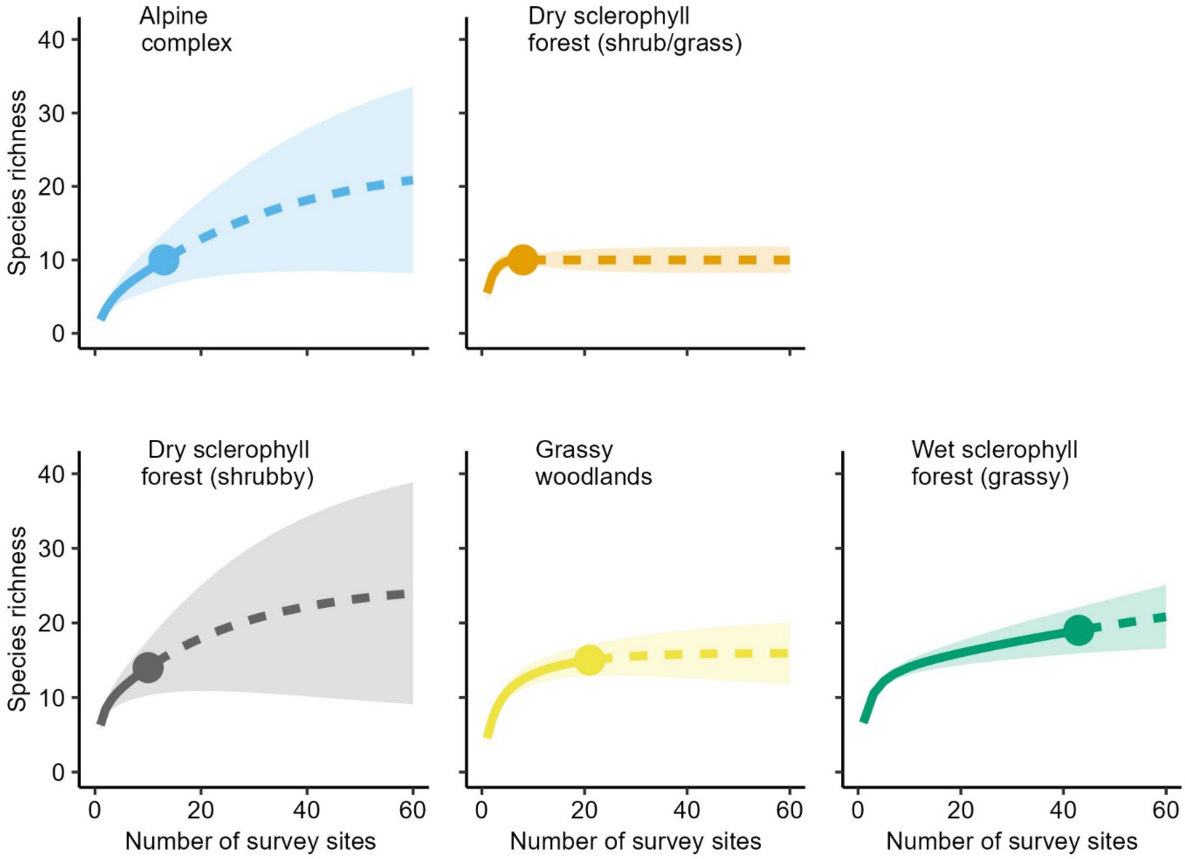


Figure 5 **Sample (solid lines) and projected (dashed lines) species richness of native mammals from 100 park-wide surveillance monitoring sites in Kosciuszko National Park for each of the 5 main vegetation formations**

Species occupancy and activity

Five ground-dwelling mammal species were detected at more than 60% of all sites in KNP: common brushtail possum, bare-nosed wombat, bush rat, swamp wallaby, and mountain brushtail possum (Table 3). Three species (short-beaked echidna, red-necked wallaby, and eastern pygmy-possum) were recorded at between 35% and 55% of all sites. Four species were recorded at between 20 and 25% of all sites: agile antechinus, dingo, eastern grey kangaroo, and long-nosed bandicoot. Noting there is no attempt to distinguish between dingo and other wild dogs in KNP (NPWS notes there is an obligation under the *NSW Biosecurity Act* in relation to wild dogs).

The least commonly occurring ground-dwelling species (less than 10% of sites) were broad-toothed rat, smoky mouse, spotted-tailed quoll, swamp rat, common dunnart, water-rat, and common wallaroo. Except for the common dunnart and common wallaroo, this group of species are habitat specialists and would most likely require more targeted monitoring to enumerate changes in occupancy or population numbers.

Native mammal species were recorded at varying rates across the 5 major vegetation formations surveyed. Detections of the 3 species of large macropods with respect to vegetation formations were similar. Eastern grey kangaroos were detected evenly across all vegetation formations except the alpine complex. Red-necked wallabies were detected most frequently in dry sclerophyll forests (both sub-formations) and wet sclerophyll (grassy sub-formation). There were no detections of red-necked wallabies in the alpine complex formation. A similar pattern was observed for swamp wallabies with detections most common in the 3 sclerophyll forest formations, and very few in alpine complex formation as this species is rarely recorded above the tree line (Green and Osborne 2012). For small ground-dwelling mammals, the associations with vegetation formation varied. Agile antechinus was predominantly associated with wet sclerophyll forest formations. Bush rats were observed in all vegetation formations in relatively high proportions (60–80%), with the exception of dry sclerophyll forest (shrub/grass sub-formation) where they were recorded at only 11% of sites within this formation. The dusky antechinus was recorded in predominantly the alpine complex and wet sclerophyll forest sites and was not recorded at all in the 2 dry sclerophyll formations. Long-nosed bandicoots were recorded mostly in dry sclerophyll (shrubby sub-formation) and wet sclerophyll (grassy sub-formation) forest formations and not at all in the alpine complex formation. The short-beaked echidna was detected across all 5 major vegetation formations with the highest detections in the 2 dry sclerophyll forest sub-formations and, although it was recorded in the alpine complex formation, it was detected in only 21% of these sites (3 of 14 sites). The eastern pygmy-possum was recorded at 35 sites (naïve occupancy) and was predicted to occur at 38% of sites (modelled occupancy) (Table 3, Figure 6). The species was not recorded in alpine complex or grassy woodland vegetation formations but was widely distributed throughout the rest of KNP (Figure 6).

Multi-method occupancy modelling using the R package RPresence (MacKenzie and Hines 2023) was used to assess species detection probability for 4 commonly detected mammal species (Figure 7). Detection probabilities for each of the 4 different camera set-ups deployed at each site were estimated:

1. infra-red camera 2 m from lure (IR200)
2. infra-red camera (no lure) with focus at 4 m (IR400)
3. white-flash camera 1.5 m from lure (WL150)
4. white-flash camera 2.5 m from lure (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). It is also able to account for individual camera failures within a site and adjust occupancy estimates due to the reduced sampling effort that arises from camera failures.

The figures reported for detection probability are estimates of the daily detection probability which is the probability of detecting an animal given it is present at a site for a single 24-hour period. Over the deployment duration of a camera, or cameras, this estimate increases incrementally. An overall detection probability of 90% is desirable, and the point at which this is realised can be calculated. The higher the daily detection probability, the shorter the deployment period needs to be to reach an overall detection probability of 90%. For example, a daily detection probability of 0.15 equates to an overall detection probability of 90% after 14 days, and for a daily detection probability of 0.10 this figure is 22 days.

The detection probabilities of eastern pygmy-possum and agile antechinus strongly suggest these species were better detected by white-flash cameras with a lure (Figure 7). The WL150 camera was particularly effective in detecting the presence of agile antechinus. Brushtail possums were also more detectable using white-flash cameras but both infra-red set-ups were also effective, albeit not as much as the white-flash cameras. Detection probabilities for the long-nosed bandicoot did not show much difference with respect to camera set-up. Detection probabilities of all 4 camera set-ups for red-necked and swamp wallabies were generally high (>0.15) with the IR400 camera the most effective. The IR200 camera was the only camera set-up that did not have the best detection for any species (Figure 7).

The total number of images acquired from the 399 cameras that were retrieved (one was lost) was just over 5 million. The number of animal images from this was just over 500,000. The remaining 4,500,000 images, or 90%, did not record any animals and were largely the result of false triggers. This resulted in a relatively high proportion of camera failures due to SD cards filling up, or batteries being depleted, particularly after 30 days of deployment. For most species this would not have affected the overall detection probability as 20–30 days is usually sufficient to reach a 90% probability of detection if the species is present at a site. However, for species that are at low densities or have large home ranges (e.g. feral cat, dingo, spotted-tailed quoll) a 30-day deployment may not be sufficient to confidently detect a species given that it is actually present in an area.

Table 3 Occupancy (naive and modelled) and activity of terrestrial mammals across the park-wide surveillance monitoring sites in Kosciuszko National Park

Species	Occupancy (naïve)	Occupancy (modelled)	Activity[#]
Agile antechinus*	21%	24.3%	
Broad-toothed rat	7%	-	-
Bush rat*	64%	67.5%	
Common brushtail possum*	75%	78.1%	
Common dunnart	2%	-	-
Common ringtail possum	11%	-	-
Common wallaroo	1%	-	-
Dingo or wild dog	22%	28.5%	
Eastern grey kangaroo	23%	24.7%	
Eastern pygmy-possum*	35%	37.9%	2.4 ± 0.7
Echidna	52%	60.4%	0.5 ± 0.2
Long-nosed bandicoot*	22%	29.5%	1.7 ± 0.4
Mainland dusky antechinus*	17%	18.6%	
Mountain brushtail possum*	60%	65.2%	
Red-necked wallaby*	48%	49.3%	
Smoky mouse	2%	-	-
Spotted-tailed quoll	5%	-	1.2 ± 0.4
Swamp rat	4%	-	-
Swamp wallaby*	62%	62.1%	13.6 ± 1.9
Wombat*	69%	69.8%	
Water-rat	1%	-	-

* Species that can be monitored with an appropriate level of precision.

[#] Activity figure is mean ± standard error unique detections, separated by 30 minutes, per 100 camera-based survey days.

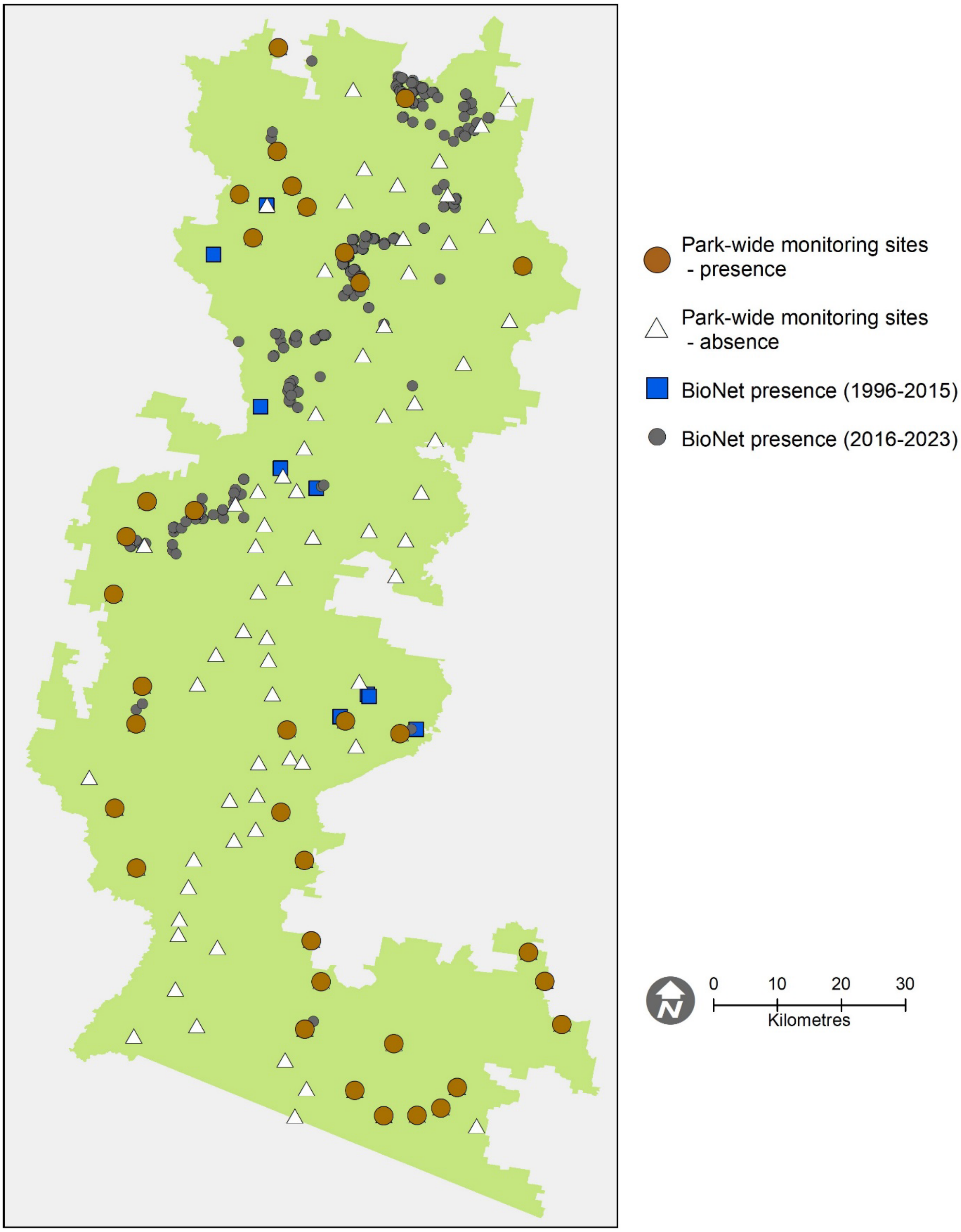


Figure 6 **Eastern pygmy-possum records from park-wide surveillance monitoring sites and BioNet records in Kosciuszko National Park**

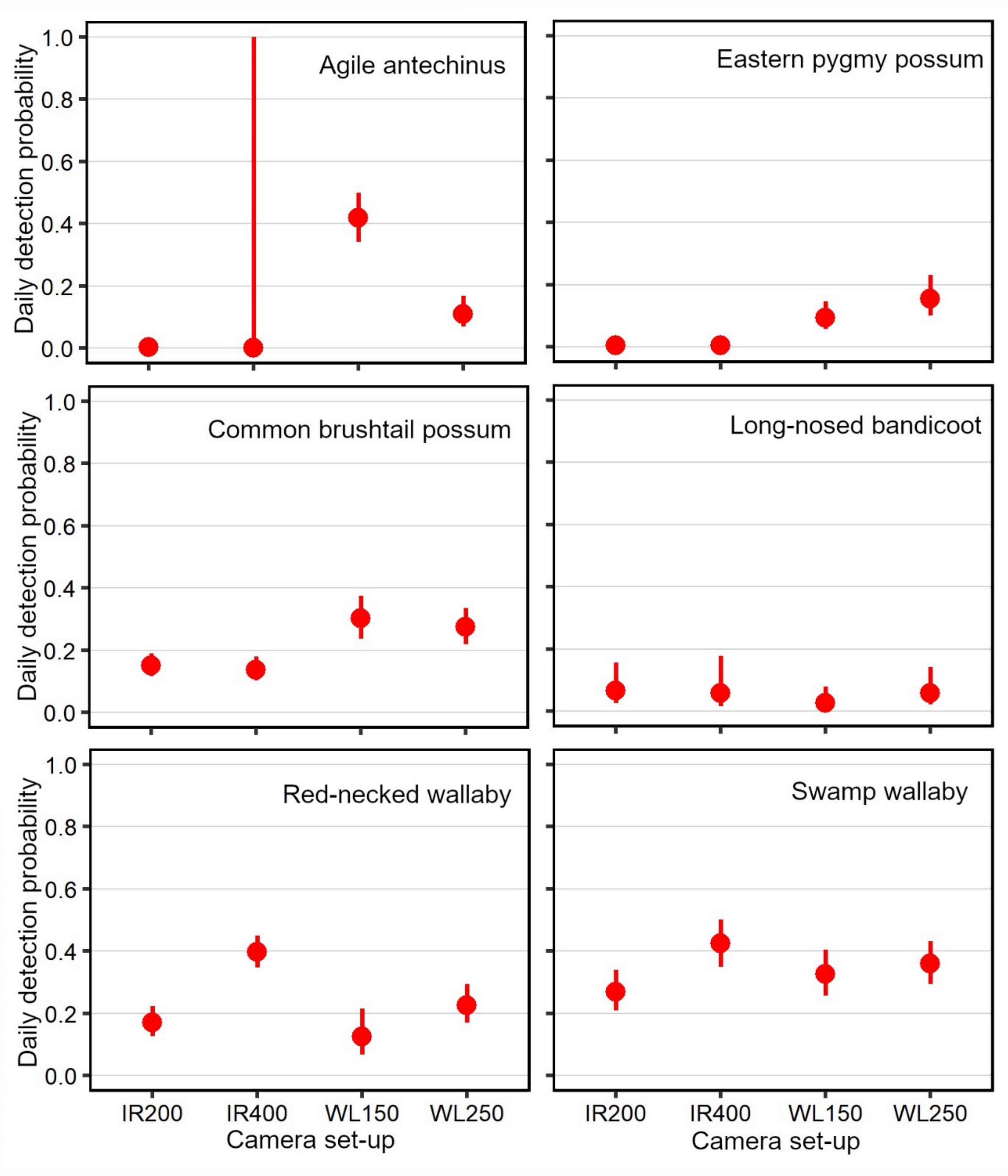


Figure 7 A comparison of daily detection probabilities for 4 different camera set-ups for 6 mammal species: agile antechinus, eastern pygmy-possum, common brushtail possum, long-nosed bandicoot, red-necked wallaby, and swamp wallaby across the park-wide surveillance monitoring sites in Kosciuszko National Park

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

Discussion

Twenty-one species of terrestrial native mammal were recorded in the camera-based park-wide surveillance monitoring. Rarefaction estimates predict this figure should be close to the maximum number of native mammals expected from camera-based surveillance sites, although it is clear some vegetation formations were under-sampled. Confidence intervals for alpine complex and dry sclerophyll forest (shrubby sub-formation) are very large (Figure 5). This is understandable given the low number of sites that were sampled in these formations and the fact that a low proportion of sites within each formation recorded a relatively large number of native mammal species.

There are several factors that are likely to influence the efficacy of the camera-based surveillance program in quantifying native mammal species richness. Firstly, at least 2 species (common wallaroo and yellow-footed antechinus) are at the edge of their geographic range within KNP, with both being more common in the western edge of the park. Similar issues arise where species are habitat specialists such as the broad-toothed rat, mountain pygmy-possum, water-rat and platypus (*Ornithorhynchus anatinus)*. The available habitat may not have been sampled at a sufficient density to obtain enough detections using camera-based surveys. The second factor is identification uncertainty from camera images. This particularly relates to rodents and dasyurids which can be extremely difficult to distinguish from camera, especially in black and white images. In the current survey, the greatest uncertainty is with the following species: smoky mouse, house mouse (*Mus musculus*), common dunnart, agile antechinus, swamp rat, bush rat, brown rat, and black rat. The use of more white-flash cameras will improve species identification in future surveys. Further, while some arboreal mammal species were recorded on cameras, targeted surveys are needed to adequately record the presence and activity of this mammal guild.

The detection of eastern pygmy-possum at 35% of all surveillance sites was not expected. Previous records of the species within KNP gave no indication of its distribution throughout the park. In the period from 1994 to 2015, there were only 10 records of this species across the whole of KNP. Since that time, there have been 326 records reported in BioNet, with all but 7 of these records from the northern section of KNP (Figure 6). This species was recorded frequently in 3 of the main vegetation formations: dry sclerophyll (shrubby sub-formation), dry sclerophyll (shrub/grass sub-formation) and wet sclerophyll (grassy sub-formation) forests. Despite the ubiquity of records, the detection probability of this species is relatively low, and more work is required to improve camera-survey methodology for this and other species.

The long-nosed bandicoot was detected at 22% of sites located across most of KNP and predominantly in wet sclerophyll (grassy sub-formation) vegetation formation. Modelled occupancy estimates were slightly higher than naïve with the species predicted to occur at 29% of all sites. This difference is predominantly a result of the low detection probability which means some uncertainty around the true absence of long-nosed bandicoots. Three of the four camera set-ups (IR200, WL150, and WL250) were adequate in detecting the presence of this species, therefore longer deployment periods may improve monitoring outcomes.

Based on the current camera-based surveillance monitoring design and number of sites, approximately 10 (out of 21) species detected can be effectively monitored for occupancy trends over the entire park, and over multiple years, with a sufficient level of precision. These species:

- are easy to identify from camera images (e.g. wombat)
- have an estimated occupancy of 20% to 80% (e.g. eastern pygmy-possum, eastern grey kangaroo)

- if present, have a probability of detection greater than 0.10.

These species will provide the best data for more statistical modelling to quantify habitat associations and characterise environmental and methodological factors that may influence species detectability and occupancy. However, the addition of more sites and refined camera set-ups may improve monitoring effectiveness for other species.

The diversity of small and medium-sized mammals detected in KNP suggests the ecosystem services mammal guilds perform are widespread and contributing to the health of KNP. 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 (Tulloch and Dickman 2006). The ubiquity of echidnas and wombats across KNP (>50% occupancy) is also a positive sign the park is able to provide habitat to support different mammal species. The mammal diversity detected across KNP reinforces the need for fire management to conduct hazard reduction burns of varying intensities and frequencies to provide a diversity of habitats and variation in successional stages.

Bat fauna

Conservation context

After rodents, bats (order Chiroptera) are the most diverse mammalian order on the planet with over 1,000 species identified. Australia is home to more than 70 species of microbat, and 11 species of megabat or flying-foxes (family Pteropodidae). Almost 80% of Australia's bat fauna is endemic.

Most Australian microbat species are insectivorous; one species, southern myotis (*Myotis macropus*), feeds on aquatic vertebrates and invertebrates. Most Australian species roost in tree hollows, with only a few species regularly roosting in caves and other subterranean structures. The absence of microbats from forests has been linked to measurable increases in defoliation, suggesting microbats influence the health, structure and composition of forests (Beilke and O'Keefe 2023).

At least 17 species of microbat are known from KNP (Churchill 2008; BioNet). Five of these – eastern false pipistrelle, greater broad-nosed bat (*Scoteanax rueppellii*), large bentwing bat (*Miniopterus orianae oceanensis*), southern myotis, and yellow-bellied sheathtail bat (*Saccolaimus flaviventris*) – are listed as vulnerable under the Biodiversity Conservation Act.

Two species of microbat were chosen as target species for monitoring: eastern false pipistrelle and southern myotis. Detailed information regarding park-wide monitoring for these species can be found in the targeted monitoring section of this report.

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 seasonal visitor to the KNP survey area. It is not currently monitored as part of the Scorecards program, as there are no known camps in KNP.

Methods and results

Microbats were surveyed in KNP using Song Meter Mini Bat ultrasonic sound recorders deployed from November 2022 to February 2023 at 74 of a proposed 125 park-wide surveillance monitoring sites. The average number of deployment nights was 27 (range 1–55). Of the 74 sites sampled, only 2 were operable for less than 10 nights. The average number of passes acquired for each site was 8,500 and the total number of passes from all 74 sites was just over 630,000. Extraction of call parameters of sound files was undertaken using SonoBat (v4.0.6p). The classification of species was based on the extracted call parameters in R statistical software (v4.1.0; R Core Team 2021) using the clustering and classification packages 'ellipse', 'kmeans', and 'randomForest'.

At least 12 species of microbat were identified with high confidence (Table 4), all previously known in KNP. Calls from *Nyctophilus* species could not be resolved at the species level. Species richness per site ranged from 1–9 (Figure 8) and no relationship was apparent between species richness and vegetation formation.

Naïve occupancy was calculated for all species which were identified with a high degree of confidence (Table 4), all but 3 were found to be widespread across KNP, occurring at greater than 50% of all sites. The large bentwing bat was recorded at just 8% of sites, southern myotis at 3% of sites, and the yellow-bellied sheathtail bat at 4% of sites.

Table 4 Naive occupancy of microbat species detected on ultrasonic devices deployed at park-wide surveillance monitoring sites in Kosciuszko National Park

Scientific name	Common name	Naive occupancy (% of sites)
Austronomus australis	White-striped freetail bat	89%
Chalinolobus gouldii	Gould's wattled bat	89%
Chalinolobus morio	Chocolate wattled bat	72%
*Falsistrellus tasmaniensis**	Eastern false pipistrelle	81%
*Miniopterus orianae oceanensis**	Large bentwing bat	8%
*Myotis macropus**	Southern myotis	3%
Nyctophilus spp.	Long-eared bat species	81%
Ozimops ridei	Eastern freetail bat	72%
*Saccolaimus flaviventris**	Yellow-bellied sheathtail bat	4%
Vespadelus darlingtoni	Large forest bat	84%
Vespadelus regulus	Southern forest bat	50%
Vespadelus vulturnus	Little forest bat	84%

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

Figure 6 Microbat species richness at park-wide surveillance monitoring sites in Kosciuszko National Park

Symbol sizes are graduated by the number of species per site, with the larger symbols representing more diverse sites.

Discussion

Park-wide surveillance monitoring detected at least 12 species of microbat in 2022–23. Although only one unnamed species of *Nyctophilus* (long-eared bat) is listed, it is almost certain that both *N. geoffroyi* and *N. gouldi* occur in KNP. Therefore, it is most likely that 13 species occur as both *N. geoffroyi* and *N. gouldi* are widespread and common in NSW. Recent advances in call analysis techniques using neural networks have enabled more confident identification of these 2 species and it is likely this uncertainty will be resolved in the near future. One species, the yellow-bellied sheathtail bat was detected at 2 sites, and had not been recorded in KNP in the previous 5 years. This species generally flies high and above the canopy, and its calls can be difficult to detect.

Four microbat species that have previously been recorded in KNP in the past 30 years were not detected from ultrasonic surveillance monitoring. The eastern horseshoe bat (*Rhinolophus megaphyllus*) is known from only 4 records in BioNet, 3 of these are in the last 5 years. This species is, therefore, at extremely low densities in KNP based on past records and park-wide ultrasonic surveillance monitoring results. Misidentification with other microbat species is extremely unlikely as it is the only species of Rhinolophid in New South Wales and is very easy to identify from ultrasonic calls. The greater broad-nosed bat (*Scoteanax rueppellii*) is known only from 3 recent (since 2019) records in KNP and is therefore considered to be extremely rare in the park. Similarly, the presence of the eastern broad-nosed bat (*Scotorepens orion*) in KNP is known from only 4 records, all in 1999 (confirmed from trapping surveys). The paucity of records may be related to survey effort but most likely is a result of extremely low densities of this species. The south-eastern freetail bat is known from only 6 records in the past 30 years, and none in the past 8.

Most species recorded from park-wide surveillance monitoring occur at a very high proportion (>50%) of sites. 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.

Although the eastern false pipistrelle was recorded at 81% of the ultrasonic surveillance sites, just under 14% of the sites recorded this species at moderate or high activity levels. This species is regarded as a habitat specialist and was recorded in the wet sclerophyll forest (grassy sub-formation) at approximately 3 times the level of all other vegetation formations, consistent with what is known about its habitat associations.

Data will also be analysed to ensure the survey method has adequate power to detect the species with high confidence, and to evaluate the sampling power of the current spatial array of sites. Further analyses will also be undertaken to estimate the deployment duration that is required to monitor temporal trends in occupancy for the species. This will determine if future monitoring of species occupancy in the park needs supplementing with additional sites and/or increased duration of deployment of recording devices.

Bird fauna

Conservation context

Nine Australian bird species (1.2% of the total Australian bird species known) and 22 subspecies (of 16 species) have become extinct since European colonisation (Woinarski et al. 2024). Many more species have experienced local extinctions of some of their populations or across parts of their range (Garnett and Baker 2021; Woinarski et al. 2024). A total of 243 bird species have been recorded in KNP from all available records (ALA, BioNet and eBird databases, Appendix 2). This number provides an indication of the assemblage present at the time of European arrival. Based on records from BioNet, eBird and ALA, 187 bird species have been recorded in KNP in the past 5 years (Appendix 2). At least 17 species have not been recorded in KNP for 5 years but are expected to still occur in the park (Appendix 2). The inclusion of these 17 species brings the total bird species expected to be in KNP to 204 (84% of the pre-European assemblage). In addition, 39 bird species have not been recorded in the last 5 years and are considered to no longer occur in the park (16% of the pre-European assemblage) (Appendix 2).

Birds are an integral component of ecosystem functioning providing many direct and indirect services such as pollination, seed dispersal and as ecosystem engineers (Whelan et al. 2008). KNP habitats are important sites for supporting many bird species, for example, the alpine wetlands provide refuge to migratory birds, such as Latham's snipe (*Gallinago hardwickii*) which is a frequent visitor and listed under the Japan–Australia Migratory Bird Agreement and China–Australia Migratory Bird Agreement. Many bird species are seasonal, international or elevational migrants in KNP, such as the flame robin, olive whistler, Australian pipit (*Anthus australis*), nankeen kestrel, Australian magpie (*Gymnorhina tibicen*), and pied (*Strepera graculina*) and grey currawongs (*Strepera versicolor*) which occupy the treeless alpine areas during summer and move to lower elevations in autumn (NSW NPWS 2023b). Their mobility and use of seasonally available resources means bird species may play a role in linking ecological processes across separated geographic areas (Bennett et al. 2024). Over 60 species of bird use the alpine and sub-alpine areas of the park during the summer months (NSW NPWS 2023a).

Birds are sensitive to environmental change and are negatively impacted by inappropriate fire regimes, habitat degradation from feral herbivores, and predation by feral predators (Lindenmayer et al. 2014; Rayner et al. 2014; Doherty et al. 2017). Around 40% of threatened bird species in KNP are hollow-dependent species, such as owls, and parrots. For example, the gang-gang cockatoo relies on tree hollows to nest. They also remain in higher elevation areas of the park throughout winter if food resources are available. The gang-gang cockatoo became listed as endangered under the Environment Protection and Biodiversity Conservation Act in 2022 after the species declined by 69% across its range (Cameron et al. 2021) resulting from substantial mortality and varying loss of habitat due to the 2019–20 fires. Their recent decline may also be a compounding consequence of warmer weather observed over the past few decades and 2 severe fire seasons in 2003 and 2019–20 (NSW NPWS 1988, 2003b). Monitoring bird populations in KNP can provide an insight into how birds are using the landscape in a changing climate.

Birds are relatively easy to monitor as most species are diurnal, easy to identify, and there are standardised methods for surveying them. Bird functional groups such as raptors are a top-order predator, and their presence or abundance can be used as a surrogate for prey availability and ecosystem health (Burgas et al. 2014). Other species such as the superb lyrebird (*Menura novaehollandiae*) are important for a range of activities including the raking of soil and litter while foraging, which in turn decreases soil compaction and increases litter depth leading to greater aeration and filtration of soils, thus supporting other soil-functioning processes (Maisey et al. 2021). Woodland birds are considered threatened at a national scale due, in part, to historical and ongoing change to their habitat through clearing, fragmentation and degradation of woodlands due to human activity (Ford 2011; NSW NPWS 2003a). KNP has had a history of land use that puts pressure on ecosystems in the park including grazing, mining and the Snowy Mountains Hydro-Electric Scheme (NSW NPWS 2003a). The continuing effects of historical land use, feral predators, fire and fire management, and the potential for encroachment of woodland into the alpine areas with a warming climate may be reflected in changes in the bird assemblages observed in the park over time. Park-wide surveillance monitoring of bird species is designed to detect changes in species richness and occurrence in the park across identified bird groups and indicator species.

Methods and results

Native birds were surveyed using multiple methods. Diurnal surveys using a 20-minute timed search within a 2-ha plot is a standard approach to monitoring diurnal bird species (Watson 2003), and these were undertaken in KNP at 44 park-wide surveillance monitoring sites from mid-February to late April 2023. The 44 sites were selected from the possible 100 park-wide surveillance monitoring sites for the diurnal bird surveys based on site access and financial considerations. Of the 44 sites, 5 were in the alpine complex, 9 in dry sclerophyll forests (4 shrub/grass and 5 shrubby sub-formations), 9 in grassy woodlands, and 21 in wet sclerophyll forest. Acoustic devices were also used to target nocturnal and diurnal birds and were deployed at 92 park-wide surveillance monitoring sites between early November 2022 and mid-January 2023. Analyses of acoustic recordings have been undertaken for three species, the gang-gang cockatoo, powerful owl and boobook owl. Further analyses of acoustic data are ongoing. Camera-based surveys were used to target the superb lyrebird but also recorded a significant number of incidental bird records, including nocturnal and cryptic species. Detections of all bird species from park-wide surveillance monitoring and incidental observations were collated and contribute to the total number of species recorded for KNP.

In 2023, a total of 109 native bird species were recorded at park-wide surveillance monitoring sites from both systematic (within 20-min/2-ha search) and non-systematic (outside of the 20-min/2-ha search) observations. This included 13 threatened species: 9 listed as threatened under the Biodiversity Conservation Act – powerful owl (*Ninox strenua*), dusky woodswallow (*Artamus cyanopterus cyanopterus),* brown treecreeper, eastern subspecies (*Climacteris picumnus victoriae),* olive whistler (*Pachycephala olivacea),* diamond firetail (*Stagonopleura guttata)*, varied sittella (*Daphoenositta chrysoptera)*, scarlet robin (*Petroica boodang)*, flame robin (*Petroica phoenicea)*, and turquoise parrot (*Neophema pulchella),* and 2 species are listed as threatened under the Environment Protection and Biodiversity Conservation Act: white-throated needletail (*Hirundapus caudacutus*) and pilotbird *(Pycnoptilus floccosus*). Two species are listed under both the State and Commonwealth Acts – gang-gang cockatoo (*Callocephalon fimbriatum),* and glossy black-cockatoo (*Calyptorhynchus lathami)*.

Species richness

The mean number of bird species observed per site from the 2-ha diurnal searches was 10, ranging from 1 to 37 (Figure 9). Rarefaction and extrapolation curves were calculated for bird species richness within each vegetation formation using the R package iNEXT (Chao et al. 2014). These curves indicate that observed and projected diurnal bird species richness was highest in the wet sclerophyll forest (grassy sub-formation) vegetation formation (Figure 10). Both dry sclerophyll forest formations (shrubby and shrub/grass sub-formations) and the grassy woodlands vegetation formation had similar observed (sampled) richness, with the alpine complex formation recording the least number of species, likely in part due to the treeless nature of this vegetation type (Figure 10). All 5 major vegetation formations in KNP had greater predicted richness than what was observed during the park-wide monitoring. All vegetation formations, with the possible exception of alpine complex, require many more survey sites to adequately characterise bird species richness. In future, bird surveys will be carried out at all 125 surveillance monitoring sites.

A total of 8 species of raptors were recorded across the park: 2 species were recorded during the park-wide surveys – brown goshawk (*Accipiter fasciatus*) and collared sparrowhawk (*Accipiter cirrocephalus*). The remaining 6 – swamp harrier (*Circus approximans*), wedge-tailed eagle (*Aquila audax*), brown falcon (*Falco berigora*), nankeen kestrel, Australian hobby (*Falco longipennis*) and peregrine falcon (*Falco peregrinus*) – were recorded as incidental observations within the park.

A total of 7 species of robins (family Petroicidae) were recorded across the park. Five species were recorded in park-wide surveys: jacky winter (*Microeca fascinans*), scarlet robin, red-capped robin (*Petroica goodenovii*), flame robin, and eastern yellow robin. Two species, pink robin (*Petroica rodinogaster*) and rose robin (*Petroica rosea*) were recorded as incidental observations only.

Eastern yellow robins were recorded from 3 vegetation formation sites: both dry sclerophyll forest formations (shrubby and shrub/grass sub-formation), and wet sclerophyll forest (grassy sub-formation). Scarlet robins were also recorded from both dry sclerophyll forest vegetation formations. Flame robins were recorded from 3 vegetation formations: alpine complex, grassy woodlands and wet sclerophyll forests (grassy sub-formation). Red-capped robins were recorded only in dry sclerophyll forest (shrub/grass sub-formation), and jacky winter robins were recorded only from the grassy woodland vegetation formation.

Figure 7 Native bird species richness at 44 park-wide surveillance monitoring sites (20-min/2-ha search) in Kosciuszko National Park

Symbol sizes are graduated by the number of species per site, with the larger symbols representing more diverse sites.

Table 5 Naive occupancy and abundance of diurnal birds at Kosciuszko National Park based on 20-min/2-ha diurnal surveys

Species	Naive occupancy (%)	Abundance (individuals per survey)
Brown thornbill	84	2.057
White-throated treecreeper	75	0.977
Grey fantail	64	1.420
Crimson rosella	50	0.830
Silvereye	50	1.943
Pied currawong	45	0.614
Grey shrike-thrush	43	0.318
Rufous whistler	41	0.341
Spotted pardalote	41	0.659
Red wattlebird	34	0.773
White-browed scrubwren	34	0.875
Yellow-faced honeyeater	32	0.420
Australian magpie	25	0.375
Eastern yellow robin	25	0.216
Striated pardalote	23	0.261
Striated thornbill	23	0.966
White-naped honeyeater	23	0.409
Flame robin	18	0.159
Golden whistler	18	0.136
Laughing kookaburra	14	0.170
Little raven	14	0.625
Superb fairy-wren	14	0.216
White-eared honeyeater	14	0.068
Australian king-parrot	11	0.091
Eastern rosella	11	0.136
Gang-gang cockatoo	11	0.148
Grey currawong	11	0.080
Eastern spinebill	9	0.068
Red-browed finch	9	0.125
Australian pipit	7	0.068
Australian raven	7	0.182
Brown treecreeper	7	0.045
Dusky woodswallow	7	0.102
Eastern whipbird	7	0.091
Yellow-rumped thornbill	7	0.182

Species	Naive occupancy (%)	Abundance (individuals per survey)
Sulphur-crested cockatoo	7	0.045
Black-faced cuckoo-shrike	5	0.023
Buff-rumped thornbill	5	0.068
Lewin's honeyeater	5	0.034
Noisy friarbird	5	0.091
Rainbow bee-eater	5	0.023
Red-capped robin	5	0.023
Satin bowerbird	5	0.023
Scarlet robin	5	0.023
Weebill	5	0.057
Brown goshawk	2	0.011
Collared sparrowhawk	2	0.011
Crescent honeyeater	2	0.011
Crested pigeon	2	0.011
Diamond firetail	2	0.034
Fan-tailed cuckoo	2	0.011
Galah	2	0.034
Grey butcherbird	2	0.011
Jacky winter	2	0.011
Leaden flycatcher	2	0.034
Little friarbird	2	0.011
Little wattlebird	2	0.023
Noisy miner	2	0.011
Pilotbird	2	0.011
Red-browed treecreeper	2	0.011
Rufous fantail	2	0.011
Shining bronze-cuckoo	2	0.011
Superb lyrebird	2	0.023
Varied sittella	2	0.011
White-plumed honeyeater	2	0.034
White-winged chough	2	0.114
Wonga pigeon	2	0.011
Yellow-tailed black-cockatoo	2	0.023
Yellow-tufted honeyeater	2	0.034

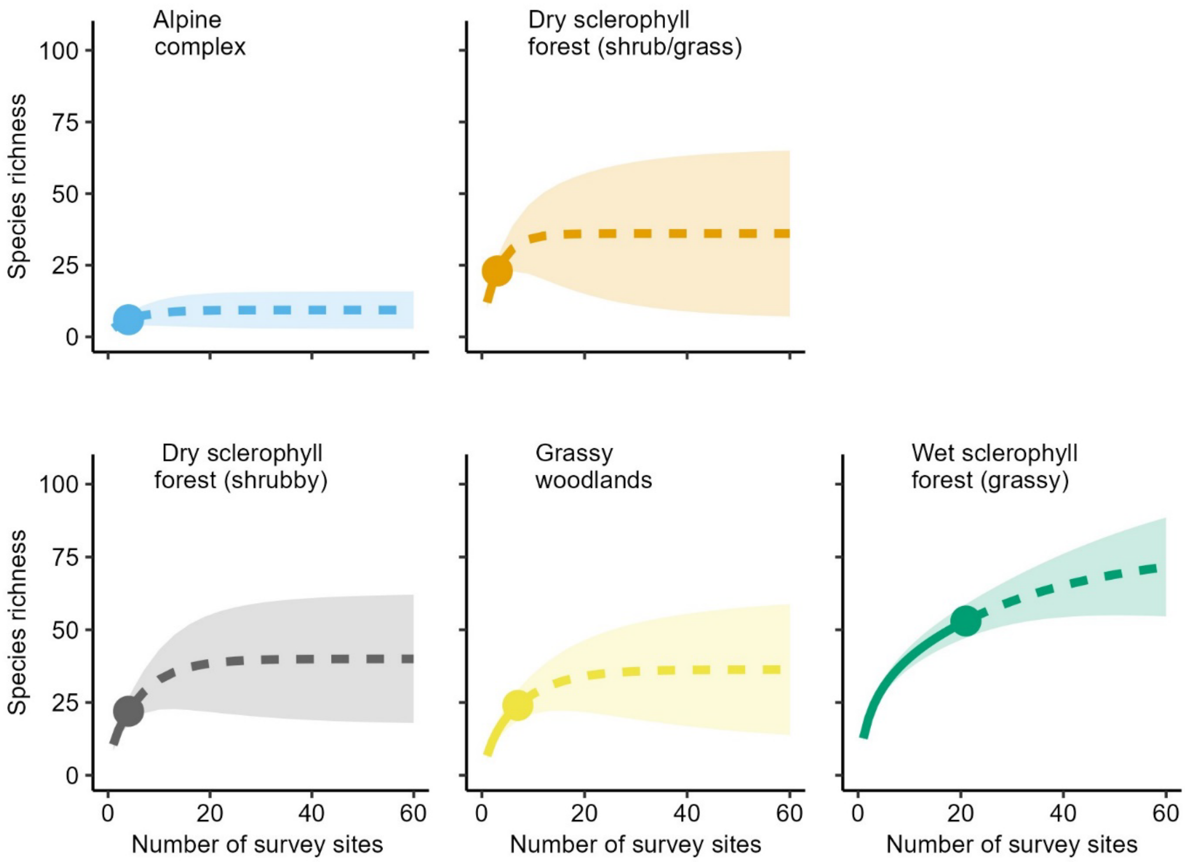


Figure 8 Diurnal bird species richness (observed and predicted) for each vegetation formation at park-wide surveillance monitoring sites (20-min/2-ha search) in Kosciusko National Park

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.

Occupancy and activity

Seventy-seven diurnal bird species were identified and recorded within the park-wide monitoring sites during the 20-min/2-ha diurnal bird surveys (Table 5). The 3 species that recorded the highest naive occupancy were brown thornbill (84% of sites), white-throated treecreeper (75%) and grey fantail (64%).

Approximately 15 of the 77 species recorded from the 20-min/2-ha diurnal searches are considered suitable for monitoring for changes in occupancy. This group of species occurred at between 20–65% of sites where diurnal searches were conducted.

Superb lyrebirds were observed at 53% of park-wide camera-based surveillance sites surveyed in 2022–23 (Figure 11; Table 5). They were most frequently recorded in dry sclerophyll (shrubby sub-formation) and wet sclerophyll (grassy sub-formation) forests, at 82% and 73% of those sites, respectively. No superb lyrebirds were recorded in the alpine complex vegetation formation.

Figure 9 **Presence and absence of superb lyrebird from park-wide surveillance monitoring in Kosciuszko National Park**

Lyrebird presence–absence was modelled as a function of foliage projected cover (FPC) derived from Landsat imagery taken in January 2023. This coincided with the period of vegetation surveys and camera deployments. The model predicted the probability of superb lyrebird occupancy would increase as FPC increased (Figure 12). A predictive map was generated based on these FPC values and the logistic equation derived from lyrebird presence–absence from camera surveillance monitoring (Figure 13).

Gang-gang cockatoos were recorded at 77% of the 92 sites where acoustic recorders were deployed (Figure 14). This species was recorded at only 15% (7/44) of all diurnal bird survey plots. All but 2 of the 7 sites where gang-gang cockatoos were recorded during the 20-min/2-ha searches also recorded calls from acoustic devices. The majority of observations of gang-gang cockatoos were recorded in dry sclerophyll forests (shrubby sub-formation) and wet sclerophyll forests (grassy sub-formation).

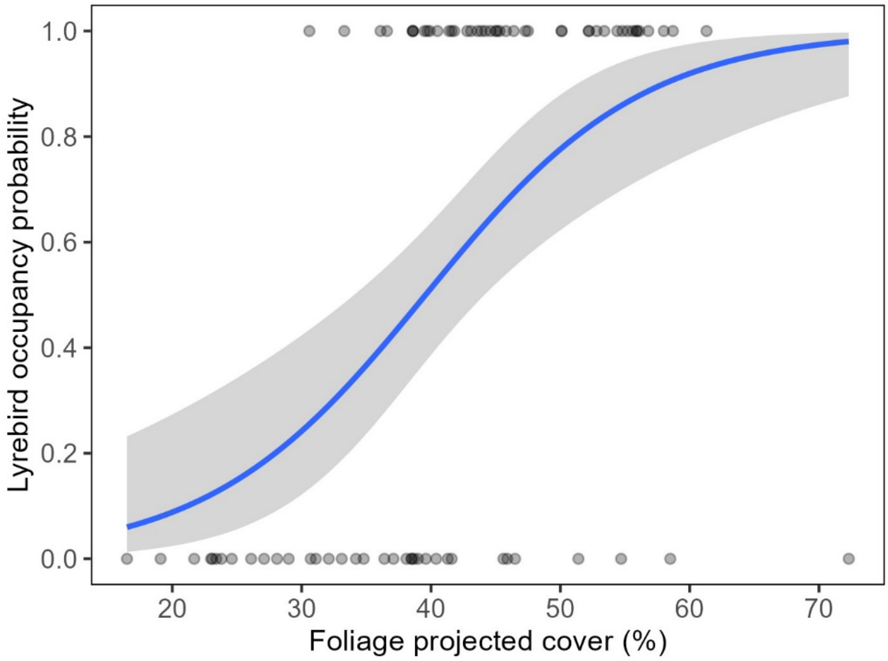


Figure 10 Modelled relationship between the probability of occupancy of superb lyrebird (y-axis) and foliage projected cover (x-axis) in Kosciuszko National Park

Shaded areas are 95% confidence intervals, small circles are actual presence records (y-axis at 1.0) or absence (y-axis at 0.0) for foliage projected cover.

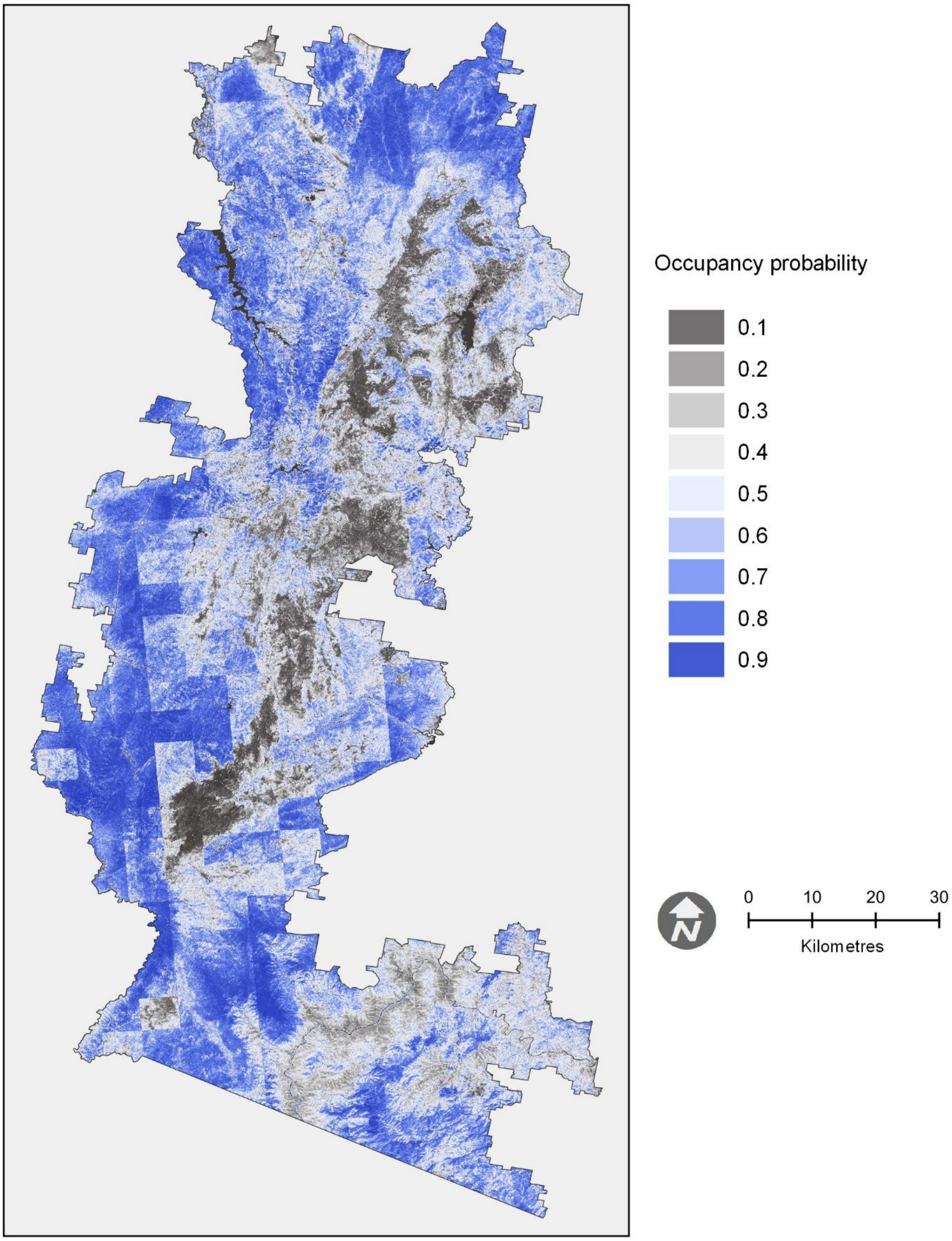


Figure 11 Predictive map of lyrebird occupancy based on foliage projected cover and presence–absence of lyrebirds from park-wide camera surveillance monitoring in Kosciuszko National Park

Figure 12 Presence and absence of gang-gang cockatoo based on acoustic recordings at park-wide surveillance monitoring sites in Kosciuszko National Park

Three nocturnal bird species were recorded incidentally on cameras: tawny frogmouth (*Podargus strigoides*), southern boobook (*Ninox boobook*), and Australian owlet nightjar

(*Aegotheles cristatus*). Two species, southern boobook and tawny frogmouth, were also recorded incidentally in the field.

Powerful owls were recorded at 14 of the 92 sites (15%) where acoustic devices were deployed (Figure 15). The majority of sites where this species was recorded were in dry sclerophyll forests (shrubby sub-formation).

Southern boobooks were recorded at 60 sites where acoustic surveillance monitoring was conducted (64% of sites) (Figure 15). They were predominantly found in dry sclerophyll forest (shrubby sub-formation) and wet sclerophyll forest (grassy sub-formation). There were very few observations of southern boobook in alpine complex vegetation (2 sites out of 12).

Ongoing analysis of acoustic data will provide occupancy estimates for other nocturnal species such as Australian owlet-nightjar, barking owl (*Ninox connivens*) and sooty owl (*Tyto tenebricosa*).

Figure 13 **Presence and absence of southern boobook and powerful owls based on acoustic recordings at park-wide surveillance monitoring sites in Kosciuszko National Park**

Discussion

The diurnal bird surveys conducted at 44 surveillance monitoring sites in 2023 provided insight into the efficacy of the survey methodology and captured a snapshot of diurnal bird species richness across the 5 major vegetation formations in KNP. The surveys detected 77 bird species, representing 41% of the total number of species recorded in the last 5 years (ALA, BioNet and eBird records, June 2018 – June 2023). Of these, 8 were listed as threatened, white-throated needletail, scarlet robin, pilotbird, gang-gang cockatoo, flame robin, diamond firetail, dusky woodswallow and brown treecreeper (eastern subspecies). An additional 32 species were detected incidentally from outside the 20-min/2-ha diurnal bird surveys (14 species), and from cameras (17 species) and acoustic devices (1 species). Of these, 5 were threatened species, olive whistler, pink robin, rose robin, turquoise parrot and powerful owl. The thirteen threatened species recorded across the monitoring sites, represent 40% of the 32 threatened species known in the park from database records (BioNet, ALA and eBird).

Bird species richness was highest in wet sclerophyll forests and lowest in the alpine complex formations. Bird species richness is often related to habitat structure (MacArthur and MacArthur 1961), particularly stand structure or vertical heterogeneity (Lindenmayer et al. 2010), floristic diversity, or both (Oliver et al.1999). Therefore, the comparatively low species richness recorded in the alpine complex formations is in part due to the increased vertical heterogeneity of woodlands and forests. Unlike mammals and reptiles there are no endemic or alpine-specialist bird species in KNP. However, over 60 species of bird use the alpine and sub-alpine areas of the park during the summer months either as international or elevational migrants (NSW NPWS 2003a). Differences in bird species richness between vegetation formations support increased overall bird species richness through the provision of greater resources and microhabitats (Tews et al. 2004; Tay 2019).

Species extrapolation curves indicate more species may be detected across all vegetation formations if more sites were surveyed (Figure 10). This is not surprising given that only 44 of the 100 park-wide surveillance sites were surveyed in 2023, and for 4 of the 5 vegetation formations there was an average of 6 sites in each formation. Confidence intervals for the 2 dry sclerophyll formations (shrub/grass and shrubby) were wide, indicating that many more sites are required to adequately record species richness in these formations. The number of sites required to enumerate species richness for wet sclerophyll formation did not asymptote, due to the relatively high number of different species observed across sites. Only 5 sites were sampled in the alpine complex and the average number of species detected at each site was only 6. This is not unexpected as other observers have noted that the number of species in the alpine zone is generally half the number in the sub-alpine zone, and significantly lower outside the summer period (Osborne and Green 1992).

Seven species of robin were recorded in the last 5 years from a possible 8 species, (Appendix 2). Of the 7 species of robin, only the pink robin and flame robin are considered to be summer residents of the sub-alpine and alpine zones. Flame robins are elevational migrants; they generally breed in the high country during spring and summer (Higgins et al. 2006) and were recorded from 3 vegetation formations: alpine complex, grassy woodland and wet sclerophyll forests (grassy sub-formation). The flame robin is listed as threatened and has been observed responding to increased warming in lower elevation areas by arriving at higher elevations earlier, before the snow melt is underway (Green 2010). Continued surveys of our park-wide surveillance sites over time will provide insights into impacts of climate change on elevation migrants such as flame robins.

Only 2 species of raptors were detected during diurnal bird surveys, with the other 6 being recorded incidentally, likely due to their behaviour. Raptors are known to occur at relatively low densities in the landscape; they are wide-ranging species, and their distribution and density are affected by their prey (Fuller and Mosher 1981; Fuller 1987). While raptors are difficult to identify based solely on acoustic cues, the higher temporal and spatial effort of the acoustic recorders may yield more species and therefore add to species records (Shonfield and Bayne 2017; Darras et al. 2018). Processing of acoustic data recorded at the park-wide monitoring sites is still under development.

The 3 species with the highest naïve occupancy, brown thornbill, white-throated treecreeper and the grey fantail, are all insectivorous and residents of sub-alpine woodland year-round. They are likely taking advantage of the diverse insect community available across the various habitats in KNP (Green and Osborne 2012), whereas other bird species that rely on the nectar and fruit of flowering plants are most common in spring and early summer.

The park-wide camera-based surveys were the most effective for detection of superb lyrebirds (53% of park-wide surveillance sites). This is likely because of the seasonal variability in their detection during diurnal bird surveys due to the difference in the frequency of their calling throughout the year. During on-ground surveys, they are detected more from their calls rather than being seen. While the ideal time for on-ground surveys of bird species at surveillance sites is likely spring and early summer, and bird surveys were conducted at the end of summer and early autumn, superb lyrebirds start calling more in autumn as their breeding begins and peaks in winter (Robinson and Firth 1981). Moreover, cameras have shown to be an effective tool in surveying for this species, with high levels of detectability obtained after a relatively short deployment period (90% probability of detection at around 11 days deployment). Lyrebird occupancy was estimated to be high in areas of dense vegetative cover, mostly in the south-west, south and far north of the park (Figure 13). Modelling indicated that occupancy in KNP is predicted to be largely absent from the alpine zone and Long Plain where vegetative and tree cover are sparse.

Gang-gang cockatoos were recorded at 15% of the diurnal bird survey sites and from 3 vegetation formations: alpine complex, grassy woodlands and wet sclerophyll forest (grassy sub-formation). Most diurnal bird surveys were conducted in early autumn and this period may not be optimal for surveying this species. However, gang-gang cockatoos were detected in late March in the alpine complex. There were perhaps enough fruit or insects in the area to draw them there, as, like the crimson rosella, they are usually attracted to higher elevations by the presence of fruit or insect galls on snow gums (Green and Osborne 2012). Acoustic recordings detected gang-gang cockatoos at 77% of the park-wide surveillance sites. Further validation and analysis of acoustic data will most likely improve this estimate, but it is clear there is potential for acoustic surveys to significantly improve estimates of species occupancy, particularly for loud and vocal species like gang-gang cockatoos.

Powerful owls were detected at just 14 of 92 sites from park-wide acoustic monitoring sites (15%). The most prevalent vegetation association was with dry sclerophyll forest (shrubby sub-formation) and no powerful owls were recorded in alpine complex vegetation. The sparsity of records is consistent with the known home range of this species, with pairs in ironbark woodland having foraging ranges of between 5.7 and 8.9 km (Soderquist and Gibbons 2007). Southern boobooks were detected at 60 of 92 sites (64%). This species is relatively common across its range so its widespread distribution within KNP is not unexpected. Its scarcity in alpine complex vegetation can be attributed to a low number of hollow-bearing trees in this vegetation formation.

The 109 native bird species recorded by the park-wide monitoring is lower than the 187 native species recorded in the last 5 years (BioNet, ALA and eBird, June 2018 – June 2023). There are several factors contributing to this:

- 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 KNP.
- The 2023 survey was conducted at 44 of the proposed 125 park-wide survey sites. Species richness extrapolation curves indicate that for all vegetation formations, a greater number of surveys, or potentially more repeat surveys, is required to adequately represent diurnal bird fauna.
- The timing of diurnal surveys coincided with elevational migration of many species to lower elevations in autumn. Results from the acoustic recorders targeting the nocturnal bird guild and dawn chorus are likely to increase the total species richness values once analysis is completed.

The average number of species detected per site during the diurnal bird surveys (10 bird species), is similar to the range of species detected from other observers in KNP and Victoria. Green and Sanecki (2006) observed an average of 11–12 resident bird species at high elevations (>1500 m above sea level) during the late winter and early spring. They also recorded an additional 10–12 migrant species at the same locations. At mountain ash sites and cool temperate rainforest sites in Victoria, the number of species detected varied from 6 to 23 species per site (Lindenmayer et al. 2010).

Park-wide surveillance: vegetation

Vegetation

Conservation context

There are 5 major vegetation formations in KNP (Table 6) classified into 8 vegetation classes and 14 individual PCTs. These range from tall moist eucalypt forests dominated by mountain gum (*Eucalyptus dalrympleana)* to montane peatlands and swamps in the high alpine plateau areas of the park. The alpine zone occupies less than 1% of Australia's landmass, however it is home to many endemic plant communities and species due to the influence of altitudinal climatic conditions. A diversity of vegetation communities persists in KNP, providing a large contiguous area of habitat linking conservation reserves across state borders. KNP contains the largest representative and protected area of alpine complex vegetation communities on the Australian mainland (Costin et al. 2000). In KNP, 9 PCTs make up the alpine complex and 8 of these form part of listed endangered or critically endangered communities under the Biodiversity Conservation Act (Table 6).

Methods and results

Vegetation was surveyed at 95 of the proposed 125 park-wide surveillance monitoring sites between February and April 2023 (Figure 2, Table 7). Vegetation surveys were undertaken as per the methods described in the park-wide surveillance monitoring section (see above). The surveys generated 3,966 plant records from the 20 × 20 m floristic plots, 23,586 records from the 50-m point-intercept transect and 10,066 tree records from the 50 × 20 m plots.

Species richness

A total of 501 native species and 55 weed species were recorded across 95 of the park-wide monitoring sites (Figure 16, Figure 17, Figure 18). The total number of native plant species recorded in each vegetation formation ranged from 303 in wet sclerophyll forest (grassy sub-formation) to 126 in dry sclerophyll forest (shrub/grass sub-formation) (Figure 16).

Rarefaction is a technique used to estimate species richness adjusting for differences in sampling effort, in this case the number of native plant species recorded at each site across the different vegetation formations (Figure 19). The extrapolation part of the curve is the predicted richness if more sites were sampled. Rarefaction and extrapolation curves (Chao et al. 2014) were calculated using the iNEXT R package. Observed native richness was greatest in wet sclerophyll forest (grassy sub-formation) and predicted plant species richness was similarly high in both the wet sclerophyll forest (grassy sub-formation) and grassy woodlands vegetation formations.

The extrapolation curve predicts that with a greater number of survey sites plant species richness would increase across all vegetation formations particularly in grassy woodland, wet sclerophyll forest, and alpine complex formations. The dry sclerophyll forest formations also have lower predicted species richness, however, this may be an artefact of smaller sample sizes (n=11 and 9) compared to wet sclerophyll forest (n=43) and grassy woodlands (n= 23), as these vegetation formations occupy smaller percentages of the park (Figure 2).

Table 6 Vegetation formations recorded in Kosciusko National Park and their listed status in the Biodiversity Conservation Act

Vegetation formation	Description in Kosciuszko National Park
Alpine complex 83,839 ha (12.4% of KNP)	The alpine complex vegetation formation is dominated by species that tolerate prolonged seasonal burial in snow or extreme temperatures on exposed slopes or in frost hollows where cold air pondage occurs. The alpine complex is made up of a mosaic of different plant communities, including low to tall alpine to sub-alpine grassy heath, alpine bogs and fens, or sometimes grassland with scattered low shrubs, on undulating treeless plains in the higher landscapes of KNP. It occurs at elevations of 1,250–2,228 m above sea level, with means of 1,450–2,400 mm rainfall and 50–120 frost days annually. Shrub species *Grevillea australis, Oxylobium ellipticum, Epacris microphylla, Asterolasia trymalioides* and *Epacris petrophila* range from common to occasional and may be locally dominant, with occasional sparse *Olearia algida, Pimelea alpina* or *P. biflora* present. The hummock-forming rush *Empodisma minus* is also common. The ground layer frequently includes grass species *Poa costiniana* and *P. hiemata* with sparse occurrences of *Rytidosperma nudiflorum, Trisetum spicatum* or *Australopyrum velutinum*. The ground layer also includes a diverse suite of alpine and more generalist forbs, very frequently including *Carex breviculmis, Ranunculus graniticola, Scleranthus biflorus, Aciphylla simplicifolia* and *Asperula gunnii*, and commonly with *Leptorhynchos squamatus, Microseris lanceolata, Oreomyrrhis eriopoda, Poranthera microphylla, Craspedia jamesii* and *Celmisia pugioniformis*. In more waterlogged parts of the landscape, wet health species that can tolerate wetter conditions may be more prevalent. The alpine complex includes the endangered ecological community listed under the Biodiversity Conservation Act as the Montane Peatlands and Swamps of the Australian Alps Bioregion, and under the Environment Protection and Biodiversity Conservation Act as Alpine Sphagnum Bogs and Associated Fens. Also listed under the Biodiversity Conservation Act in this vegetation formation are 3 critically endangered ecological communities including Snowpatch Feldmark, Windswept Feldmark and Snowpatch Herbfield in the Australian Alps Bioregion.
Grassy woodlands 156,023 ha (23.2% of KNP)	The grassy woodlands vegetation formation is characterised as a sub-alpine low shrubby sclerophyll open woodland found on low rounded hills along the high plateau of KNP. It is associated with granitoid and sandstone substrates, at elevations from 1,350–1,900 m above sea level, with mean annual precipitation of 1,450–2,400 mm. It is characterised by a low open canopy of *Eucalyptus niphophila* above a dense to patchy layer of diverse shrubs, commonly including *Olearia phlogopappa, Hovea montana, Bossiaea foliosa, Ozothamnus secundiflorus* and *Tasmannia xerophila* subsp. *xerophila*, with less common species including *Oxylobium ellipticum, Grevillea australis, Prostanthera cuneata, Acrothamnus hookeri* or *A. maccraei*. The ground layer is often dominated by grass species *Poa ensiformis* or *P. hiemata* with a diverse suite of herbaceous species including *Stellaria pungens, Asperula gunnii, Viola betonicifolia* and *Oreomyrrhis eriopoda*. Grassy woodland vegetation formation varies across the landscape at lower elevations and rainfall patterns. On the gentle lower slopes on the margins of treeless frost-hollow valleys in the lower south-western slopes of the high plateau of KNP, at elevations of 1,000–1,500 m above sea level with lower

Vegetation formation	Description in Kosciuszko National Park
	rainfall, the grassy woodland formation includes a sparse to mid-dense canopy of *Eucalyptus stellulata*, occasionally with scattered *E. pauciflora* or rarely *E. rubida* or *E. dalrympleana*. A sparse shrub layer commonly includes scattered low *Acrothamnus hookeri*, taller *Hakea microcarpa* and *Pimelea pauciflora*. A ground layer of grass species *Poa sieberiana, Anthosachne scabra* and *Themeda triandra*, and forbs *Stellaria pungens, Acaena novae-zelandiae, Senecio gunnii, Asperula scoparia, Poranthera microphylla, Viola betonicifolia, Leptorhynchos squamatus, Scleranthus biflorus, Acaena ovina, Arthropodium milleflorum, Geranium solanderi, Oreomyrrhis eriopoda, Ranunculus lappaceus* and the sedge *Carex breviculmis*. This formation is commonly replaced by wet sclerophyll forest (grassy sub-formation) formations on nearby moist slopes or by grassy woodlands dominated by *E. pauciflora* on dry exposed sites. On valley floors subject to cold air ponding, it may grade into alpine complex formations.
Wet sclerophyll forests (grassy) 319,904 ha (47.3% of KNP)	Wet sclerophyll forest vegetation formations in KNP are a tall to very tall moist grassy sclerophyll open forest, occurring at elevations of 900–1,660 m above sea level, with means of 650–1,750 mm precipitation and 13–104 frost days annually, on a variety of substrates including sedimentary, acid volcanic and granitic rocks. At higher altitudes, this formation typically occurs on moist plateaus and crests of ranges, while at lower, drier altitudes it is increasingly restricted to sheltered moist slopes. A mid-dense canopy very frequently includes *Eucalyptus dalrympleana* and *E. pauciflora*, with *E. robertsonii* occasionally present. A sparse to mid-dense shrub stratum commonly includes scattered *Coprosma hirtella, Platylobium formosum* and *Acacia dealbata*, with occasional *Daviesia latifolia, Olearia erubescens, Cassinia aculeata* or *Persoonia chamaepeuce*. The mid-dense to dense ground layer is very frequently dominated by *Poa sieberian*a, interspersed with a diverse suite of herbaceous species including *Stellaria pungens, Viola betonicifolia, Lomandra longifolia, Asperula scoparia, Glycine clandestina, Clematis aristata, Acaena novae-zelandiae, Wahlenbergia stricta, Veronica calycina, Stylidium graminifolium, Luzula flaccida, Poranthera microphylla, Craspedia variabilis, Lomandra filiformis, Lagenophora stipitata, Gonocarpus tetragynus* and *Ranunculus lappaceus*. At higher elevations and on sheltered moist slopes the forests are dominated by *Eucalyptus delegatensis* subsp. *delegatensis*, commonly with *E. dalrympleana* or *E. pauciflora*. With decreasing elevation, the forests are dominated by *E. robertsonii* with *E. viminalis* in deep gullies, while on drier warmer slopes the forest grades into dry sclerophyll forest (shrubby sub-formations).
Dry sclerophyll forest (shrubby) 99,509 ha (14.8% of KNP)	Different forest types make up the dry sclerophyll forest (shrubby sub-formation) vegetation formation in KNP, separated geographically in the upper north-west, central-west, lower south-west and lower south-east sections of the park. The distribution of this formation is driven by aspect, rainfall and soil types. The dry shrubby sclerophyll forest type of the ridges and upper slopes in the north-west, central-west and the exposed slopes in the lower south-western part of KNP occurs at elevations around 500–1,250 m above sea level, with means of 850–1350 mm annual precipitation and 40–85 frost days annually. It is found on a range of substrates including sedimentary, metasedimentary, acid volcanic and granitic rocks.

Vegetation formation	Description in Kosciuszko National Park
	The tree canopy almost always contains *Eucalyptus dives*, occasionally with *E. mannifera* or *E. dalrympleana*. A diverse, mid-dense to sparse layer of low to tall shrubs commonly includes *Hibbertia obtusifolia, Monotoca scoparia, Platylobium formosum, Tetratheca bauerifolia, Persoonia chamaepeuce* and *Mirbelia oxylobioides*. The ground layer very frequently includes moderate cover of *Poa sieberiana*, commonly interspersed with herbaceous species such as *Rytidosperma pallidum, Lomandra longifolia* and *Dianella revoluta*, the sprawling subshrubs *Hovea linearis* and *Hardenbergia violacea*, and *Gonocarpus tetragynus, Stylidium graminifolium* and *Lomandra filiformis*. On adjoining more-sheltered aspects, in the south-western part of the park, this formation may grade into the closely related wet sclerophyll forest formations. In the lower south-eastern corner of KNP, a mid-high to tall dry shrubby sclerophyll open forest associated with dry, cold rugged ranges is found predominantly on dry exposed north- and west-facing slopes and ridges formed from sandstones, and occasionally on granitic and metasedimentary rocks. It occurs at elevations around 500–1,200 m above sea level, with means of 500–950 mm rainfall and 35–70 frost days annually. A mid-dense canopy very frequently includes *Eucalyptus dives* and/or *E. rubida*, occasionally with *E. bridgesiana* or *E. macrorhyncha*. The sparse shrub layer commonly includes *Hibbertia obtusifolia, Melichrus urceolatus, Bossiaea buxifolia, Pultenaea procumbens, Acacia dealbata, Cassinia longifolia* and *Brachyloma daphnoides.* A sparse to mid-dense ground layer is very frequently dominated by large tussocks of *Rytidosperma pallidum*, commonly with scattered smaller *Poa meionectes*, the subshrub *Hovea linearis*, and herbaceous species including *Gonocarpus tetragynus*, *Hypericum gramineum* and *Lomandra multiflora* subsp. *multiflora*.
Dry sclerophyll forest (shrub/grass) 14,600 ha (2.2% of KNP)	Dry sclerophyll forest (shrub/grass sub-formation) vegetation formation in KNP is a mid-high to tall sclerophyll and Callitris woodland with a dry mid-stratum and a mid-dense, grassy groundcover restricted to the Lower Snowy River valley and Byadbo areas in the southern part of the park. It occurs at elevations <700 m above sea level, with a mean annual rainfall typically below 660 mm. It is floristically distinct formation with the canopy dominated by *Eucalyptus albens* and *Callitris glaucophylla*, however *E. melliodora, E. bridgesiana* or *E. nortonii* can also be present. The shrub to small-tree layer is sparse with *Acacia deanei* and *Brachychiton populneus,* with the most frequent and abundant shrub species including *Lissanthe strigosa, Bursaria spinosa*, and *Astroloma humifusum*. The mid-dense ground layer is mainly comprised of herbaceous species including *Anthosachne scabra* and very frequently *Senecio quadridentatus, Austrostipa scabra, Grona varians, Dichondra repens, Glycine tabacina* and *Einadia nutans*.

Table 7 Proposed and final number of sites sampled in 2023 in the 5 main vegetation formations and plant community types recorded in Kosciusko National Park

Vegetation formation	Plant community type (PCT ID)	Proposed sites	Final sites sampled 2023
Alpine complex		**16**	**14**
	Kosciuszko Alpine Wet Heath (3890)	2	2
	Kosciuszko High Plateau Grassy Open Heath (3879)	14	12
Dry sclerophyll forests (shrubby)		**15**	**9**
	Bondo Slopes Dry Peppermint Shrub Forest (4126)	6	3
	Bondo Slopes Dry Stringybark Forest (3730)	4	4
	Monaro Ranges Exposed Shrub Forest (3743)	4	1
	Snowy Gorge Grassy Box Woodland (3745)	1	1
Dry sclerophyll forests (shrub/grass)		**11**	**9**
	Snowy Gorge White Box-Pine Woodland (3538)	11	9
Grassy woodlands		**30**	**22**
	Kosciuszko Alpine Sally Woodland (3381)	17	13
	Kosciuszko Sub-alpine Hollows Black Sally Woodland (3383)	13	9
Wet sclerophyll forests (grassy)		**53**	**41**
	Bondo Slopes Peppermint Moist Grassy Forest (3292)	11	8
	Kosciuszko Snow Gum-Mountain Gum Moist Forest (3297)	24	22
	Kosciuszko Western Flanks Moist Shrub Forest (3309)	11	6
	Kosciuszko-Namadgi Alpine Ash Moist Grassy Forest (3307)	7	5
Total		**125**	**95**

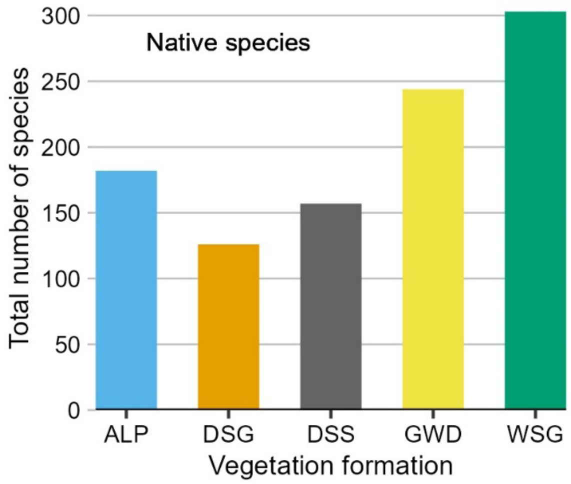


Figure 14 Total number of native species recorded from park-wide surveillance monitoring sites in each vegetation formation in Kosciusko National Park

ALP = alpine complex, DSG = dry sclerophyll forest (shrub/grass sub-formation), DSS = dry sclerophyll forest (shrubby sub-formation), GWD = grassy woodland, WSG = wet sclerophyll forest (grassy sub-formation).

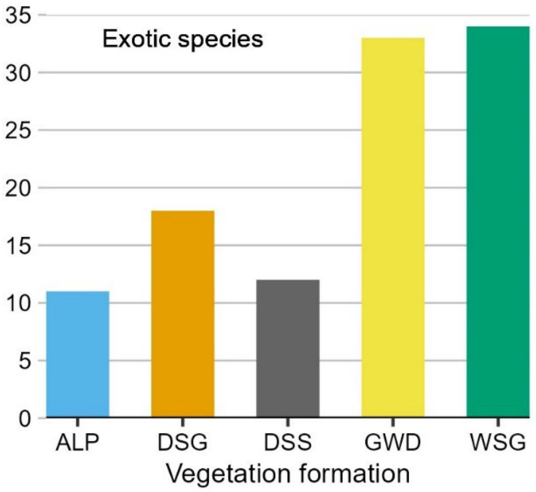


Figure 15 Total number of weed species recorded from park-wide surveillance monitoring sites in each vegetation formation in Kosciusko National Park

ALP = alpine complex, DSG = dry sclerophyll forest (shrub/grass sub-formation), DSS = dry sclerophyll forest (shrubby sub-formation), GWD = grassy woodland, WSG = wet sclerophyll forest (grassy sub-formation).

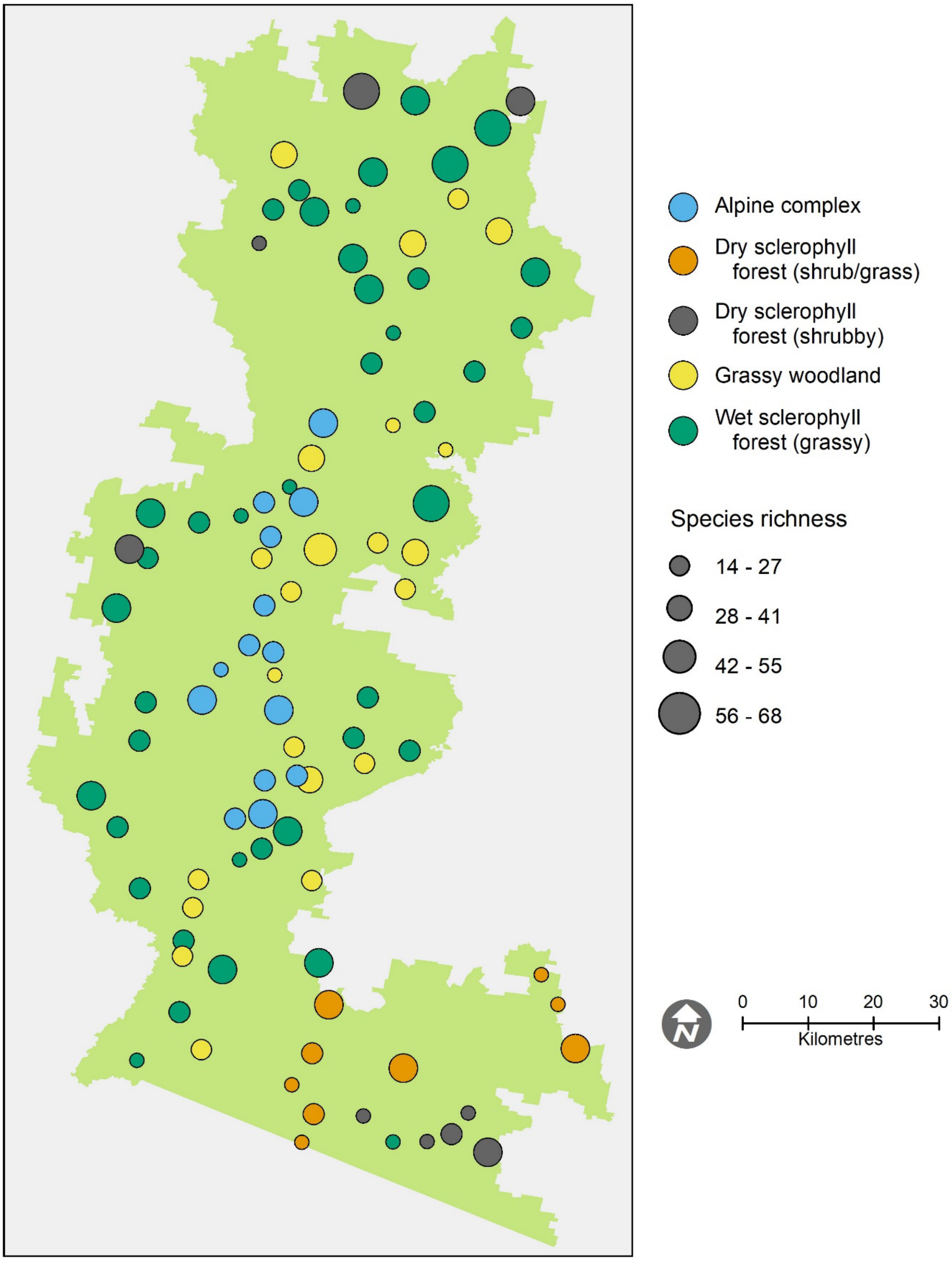


Figure 16 Number of native plant species from park-wide surveillance monitoring sites in each vegetation formation in Kosciusko National Park

Symbol sizes are graduated by the number of native plant species recorded at each site, with the larger symbols representing more diverse sites.

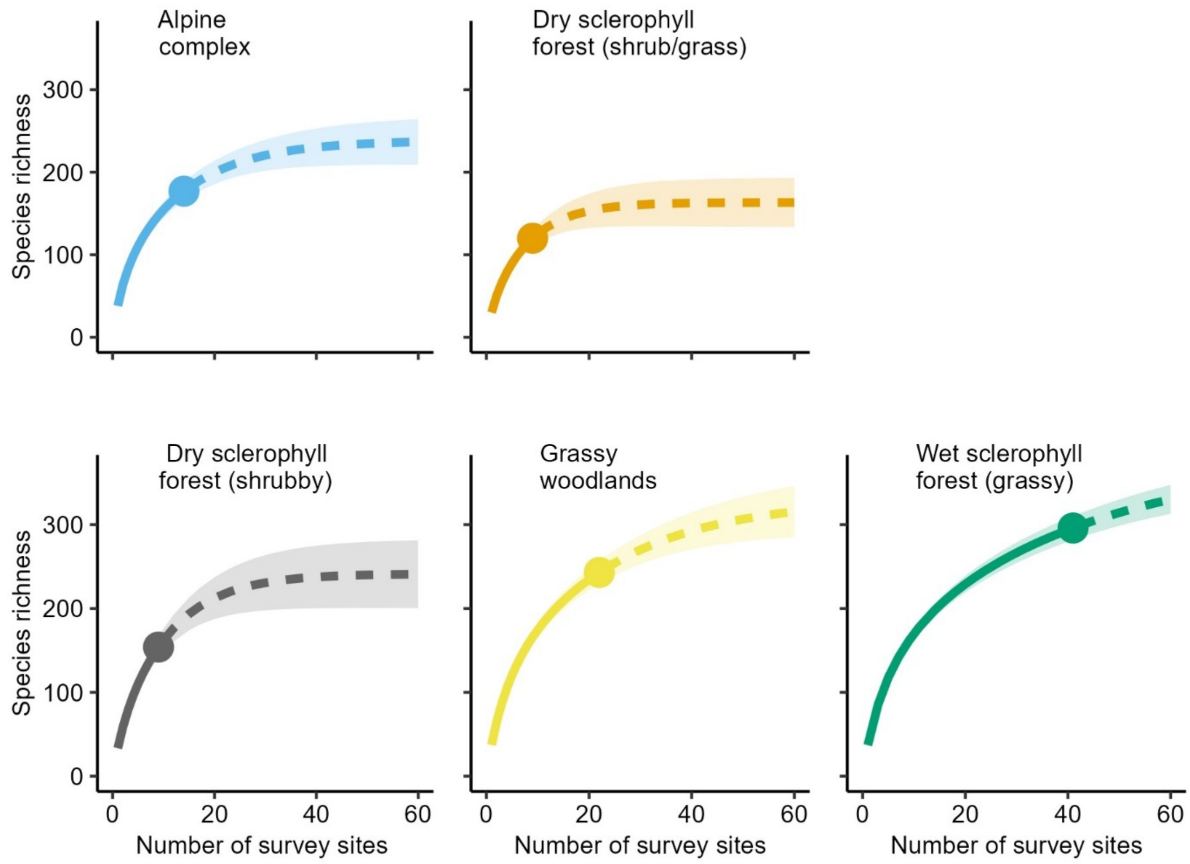


Figure 17 Native plant species richness from park-wide surveillance monitoring sites in each vegetation formation in Kosciusko National Park

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 illustrate changes in vegetation community due to age, or environmental events like fire, drought, dieback, or long-term impacts of climate change.

Native vegetation cover at different heights varied between sites within and between vegetation formations (Figure 20), however the average values were generally consistent with what is expected from the vegetation formation with a range of fire histories (from recently burnt to long unburnt).

In general, percent native vegetation cover was greatest in the lowest vegetation strata (<1 m in height) for most vegetation formations indicating the extent of understorey species. Alpine complex (91%) and grassy woodland (79%) had most vegetation in the ground stratum (<1 m). Wet sclerophyll forest (grassy sub-formation) had the most vegetation (24%) in the 1–3 m stratum. Dry sclerophyll forest (shrub/grass sub-formation) had the most vegetation (23%) in the 3–5 m stratum. Dry sclerophyll forest (shrubby sub-formation) recorded the greatest litter cover (65%) and the lowest was recorded in the alpine complex

(26%) and the grassy woodlands (33%) formations (Figure 20). Litter cover was highest in the dry sclerophyll forest (shrubby sub-formation; 64%) and lowest in the alpine complex (26%) vegetation formation (Figure 20, Figure 21).

Also, vegetation cover in the <1 m class was not collected at 17 sites during the 2022–23 survey period: at all 9 dry sclerophyll forest (shrub/grass sub-formation) sites, 5 dry sclerophyll forest (shrubby sub-formation) sites, 2 wet sclerophyll forest (grassy sub-formation) sites, and one grassy woodland site).

Data quality was not considered accurate for the >5 m stratum due to the data collection methods not being repeatable and this data has been omitted from this report.

Foliage projective cover (FPC) was 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 4 Landsat images from 8 January 2023 – 30 January 2023. The highest FPC values were found in wet sclerophyll forests (grassy sub-formation) (47.2%) and the lowest in alpine complex (31.9%).

To compare various measures of vegetation strata across the 5 main vegetation formations, plots were generated comparing all 5 main vegetation formations (Figure 21). These are the same data as depicted in Figure 20, but grouped by each of the 3 strata: <1 m, 1–3 m, 3–5 m, litter and FPC (Figure 21). Trends and patterns in cover estimates for the different measures between the vegetation formations are difficult to ascertain. Litter cover was greatest (but variable) in dry sclerophyll forest (shrubby sub-formation) and wet sclerophyll forest (grassy sub-formation). For the <1 m cover class, alpine complex vegetation was consistently high. Grassy woodlands were also high for this stratum, but more variable than alpine complex. Derived values of FPC showed differences between the vegetation formations with alpine complex and dry sclerophyll forest (shrub/grass sub-formation) recording the lowest values. Wet sclerophyll (grassy sub-formation) recorded the highest values with exception of an outlier in grassy woodland.

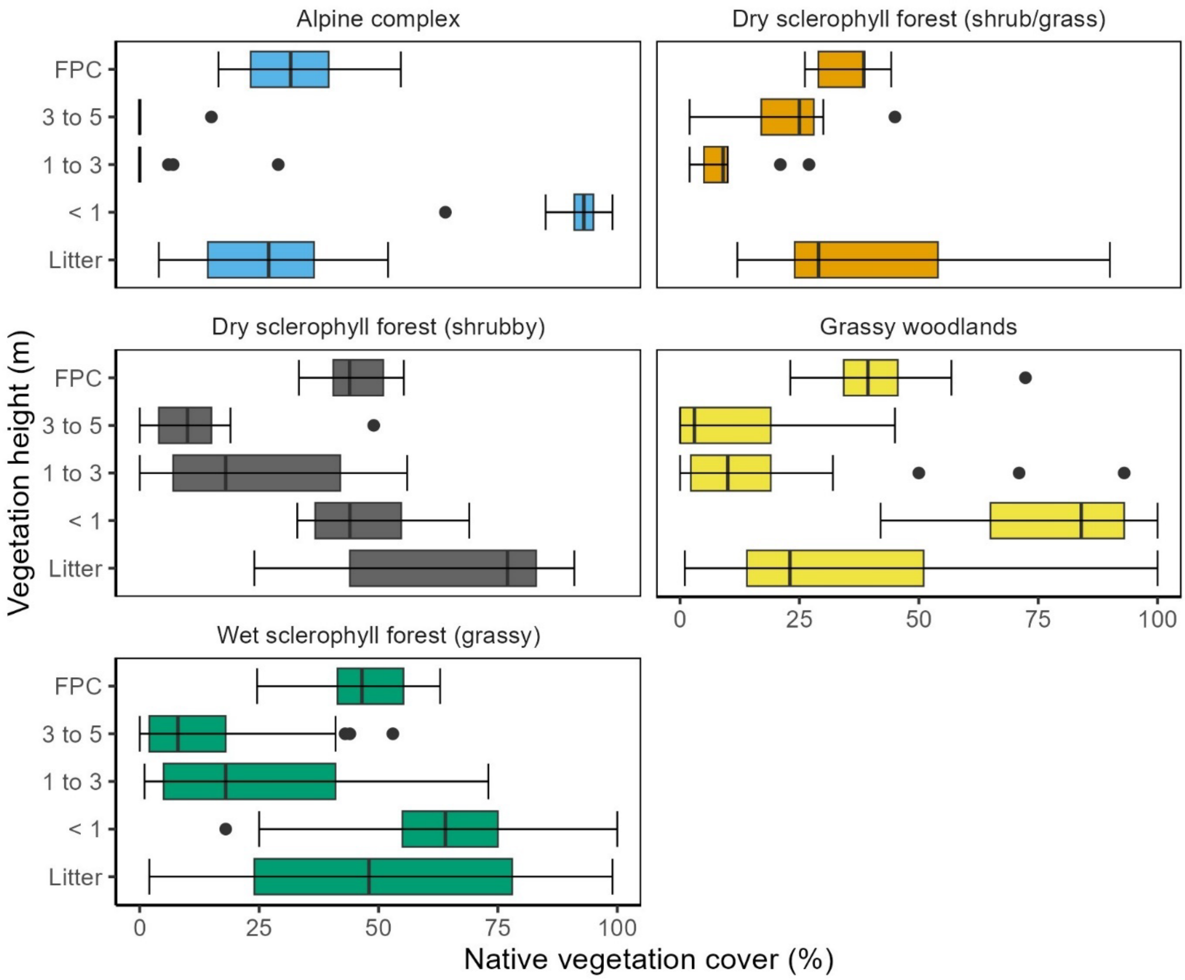


Figure 18 Boxplots showing native vegetation cover from park-wide surveillance monitoring sites by vegetation formation in Kosciusko National Park

Lower and upper bounds of each coloured box 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 the coloured box are outliers >1.5 and <3 times the interquartile range.

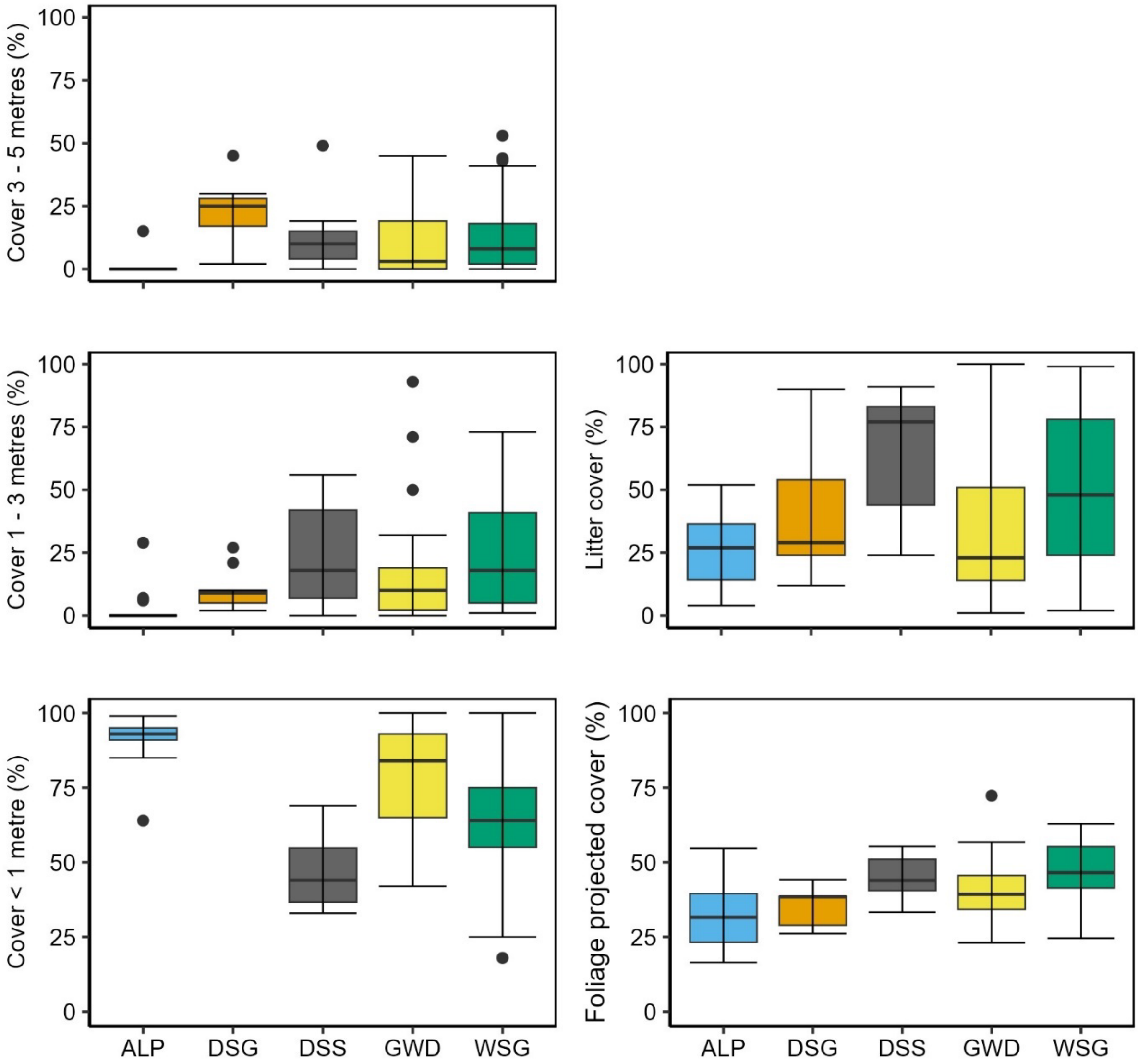


Figure 19 Boxplots showing native vegetation cover from park-wide surveillance monitoring sites by each vegetation strata in Kosciusko National Park

Lower and upper bounds of each coloured box 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 the coloured box are outliers >1.5 and <3 times the interquartile range. ALP = alpine complex, DSG = dry sclerophyll forest (shrub/grass sub-formation), DSS = dry sclerophyll forest (shrubby sub-formation), GWD = grassy woodland, and WSG = wet sclerophyll forest (grassy sub-formation).

Tree size and density

The number of alive and dead trees per ha was measured in each vegetation formation. The alpine complex vegetation formation recorded the least number of trees compared with the 4 other formations, reflecting the treeless nature of this complex. For the more forested formations, wet sclerophyll forests (grassy sub-formation), followed by grassy woodlands had the overall highest density of trees, however most were mainly small trees (<20 cm DBH; Table 8). Wet sclerophyll forests (grassy sub-formation) sites had the highest density of large trees (>50 cm DBH), followed by dry sclerophyll forests (shrubby sub-formation) and grassy woodlands. Dry sclerophyll forests (shrub/grass sub-formation) had a low number of large trees. The number of standing dead trees was highest in the small size class (<20 cm DBH) and very low in the medium and the large size classes (Table 8). Wet sclerophyll forests (grassy sub-formation) and grassy woodlands had the highest number of standing large dead trees. Neither the alpine complex nor the dry sclerophyll forests (shrub/grass sub-formation) recorded any large dead trees (>50 cm DBH; Table 8).

In the alpine complex sites, the 2 most common tree species were *Eucalyptus pauciflora* and *E. stellulata*. In dry sclerophyll forests (shrub/grass sub-formation) the most common tree species were *Callitris glaucophylla*. In dry sclerophyll forests (shrubby sub-formation), 3 tree species were the most common including *E. dives, E. robertsonii* and *E. dalrympleana.* In grassy woodlands the most common tree species were *E. pauciflora, E. stellulata, E. dalrympleana, E. robertsonii, E. delegatensis* and *E. rubida*. In the wet sclerophyll forests (grassy sub-formation) the most common tree species were *E. pauciflora, E. robertsonii, E. rubida, E. dalrympleana, E. dives, E. delegatensis* and *E. stellulata.* Tree numbers were based on the total number of stems recorded across all sites in each vegetation formation (Table 9).

Table 8 Tree diameter and density at Kosciuszko National Park park-wide monitoring surveillance sites

Vegetation formation		Stem density per ha: mean (range)			
		<20 cm	20–49 cm	>50 cm	Total
Alpine complex	Alive	84 (0–620)	16 (0–230)	0	100
	Dead	4 (0–40)	0	0	4
Dry sclerophyll forests (shrub/grass)	Alive	677 (20–1,340)	133 (30–220)	3 (0–10)	813
	Dead	180 (0–620)	7 (0–50)	0	187
Dry sclerophyll forests (shrubby)	Alive	659 (130–1,180)	262 (100–530)	42 (0–100)	963
	Dead	51 (0–100)	9 (0–30)	2 (0–20)	62
Grassy woodlands	Alive	916 (50–4,840)	79 (0–330)	24 (0–100)	1,019
	Dead	64 (0–210)	29 (0–100)	8 (0–40)	101
Wet sclerophyll forests (grassy)	Alive	1083 (80–4,570)	152 (0–600)	52 (0–140)	1,287
	Dead	67 (0–1,120)	14 (0–100)	8 (0–50)	89

Table 9 Total number of individual stems of the most frequently recorded tree species in the 50 x 20 m plots in each vegetation formation in Kosciusko National Park

Species	Alpine complex	Dry sclerophyll forests (shrub/grass)	Dry sclerophyll forests (shrubby)	Grassy woodlands	Wet sclerophyll forests (grassy)	Total
Callitris glaucophylla	0	329	0	0	0	329
Eucalyptus dalrympleana	0	0	17	120	412	549
E. delegatensis	0	0	0	39	333	372
E. dives	0	0	244	0	347	591
E. pauciflora	142	0	0	1,695	2,738	4,575
E. robertsonii	0	0	174	78	713	965
E. rubida	0	0	6	34	456	490
E. stellulata	4	0	0	396	154	550
Other tree species	0	571	473	101	456	1,601

Discussion

The park-wide surveillance monitoring sites indicate that KNP has a diverse range of flora. Vegetation communities were found to have high diversity of native species and abundance. It also shows that weed incursion is high across all major vegetation formations. This result may reflect the long history of disturbance, including the widespread grazing of feral herbivores across the park which contribute to the spread of many weed species. The presence of weed species is of concern if they impact native plant species diversity, and their cover is substantial or increases over time. Three significant environmental weed species were detected at the park-wide monitoring sites including blackberry, ox-eye daisy and sweet vernal grass.

Large standing living trees were mostly found in the wet sclerophyll forests (grassy sub-formation) and grassy woodlands. The number of standing dead trees was highest in the small size class (<20 cm DBH) for both dry sclerophyll forest types, grassy woodlands and the wet sclerophyll forests, indicating the low survival of tree seedlings or saplings in these formations. Over time, the lack of new individuals may impact the structure and condition of these formations.

Targeted monitoring

Fifteen fauna species, 4 flora species and 2 habitats have been identified initially for targeted monitoring based on conservation status and vulnerability to key threatening processes and represent species that cover a range of elevations across the KNP landscape. These conservation assets require specialised monitoring techniques and/or protocols which are beyond the scope of the park-wide surveillance monitoring program. Where possible, data from the park-wide surveillance monitoring will be used to augment specialised targeted monitoring.

Some of these conservation assets are currently monitored as part of existing threatened species or management programs, for example, Saving our Species. However, the monitoring objectives of those programs do not always meet the requirements of the Scorecards program – for example, these programs do not measure the status of the species at a park-wide scale.

A review of all existing species monitoring will be undertaken in accordance with the NPWS Threatened Species Monitoring Protocol. This aims to ensure each species or habitat has a detailed, and scientifically robust monitoring plan aimed at detecting change in the park-wide population and/or condition over time. Where necessary existing plans will be updated, or new monitoring plans will be established. These will use the most relevant population metric/s and sampling design to ensure consistent, ecologically informed monitoring is undertaken, specifically for the purposes of the Scorecards program, to evaluate population change and inform decision-making.

Five of the Scorecards' targeted species and an ecological community (broad-toothed rat, smoky mouse, alpine tree frog, alpine she-oak skink, booroolong frog and alpine bogs and fens) have been identified in the Kosciuszko Offset Strategy as impacted by Snowy 2.0 hydroelectricity project and consequently eligible for offset funds to: (i) quantify the impacts, (ii) offset the impacts by implementing cost-effect conservation actions, and (iii) measure and report on biodiversity benefits (State of New South Wales and Department of Planning and Environment 2023a, 2023b, 2023c). Monitoring generated from the Kosciuszko Offset Strategy should align with existing or proposed park-wide and targeted monitoring programs, and the NPWS Threatened Species Monitoring Protocol.

Targeted monitoring: fauna

Alpine she-oak skink

Conservation context

The alpine she-oak skink (*Cyclodomorphus praealtus*) is a tussock grassland specialist that relies on understory complexity (Sato et al. 2014) and is endemic to sub-alpine and alpine grasslands in NSW and Victoria (Swan et al. 2004). This species has a restricted distribution due to specific habitat preferences and has only been detected within KNP above 1,200 metres in grasslands and lightly wooded areas. The species has low genetic diversity and small population sizes making it vulnerable to habitat loss or severe disturbances (Hartley et al. 2023). The alpine she-oak skink is listed as endangered under the Biodiversity Conservation Act and the Environment Protection and Biodiversity Conservation Act. Habitat (11,816 ha) of exceptional value has been declared an Asset of Intergenerational Significance (AIS) for this species in KNP under section 153G of the National Parks and Wildlife Act 1974.

There has been a substantial reduction in alpine she-oak skink habitat resulting from the development of ski resorts and construction of dams. Current threats include trampling, grazing, and browsing from feral herbivores (pigs, deer and horses); direct and indirect effects from bushfires (individuals killed, habitat change and fragmentation); and predation by cats, foxes, rats and dogs. Potential threats include habitat alteration from invasive weeds such as orange hawkweed and climate change causing migration of shrubby vegetation into favoured tussock grassland habitat at higher elevations.

Background

The alpine she-oak skink has been the subject of park-wide surveys in recent years. Hartley et al (2023) undertook the first broadscale assessment of alpine she-oak skink distribution in KNP which resulted in an extension of the known range of the species. From 2018 to 2022 surveys were undertaken at 120 sites across an area ranging from Long Plain in the north to Cascades Trail in the south, and from Snakey Plain in the west to Nungar Plain in the east. Sites were selected based on elevation (>1200m) and habitat (grassland). The alpine she-oak skink was detected at 52 of the 120 sites (43%) that were surveyed.

Long term monitoring has been established at 9 sites (27 grids, 3 grids per site, Figure 22) and has been informed by surveys conducted by Hartley et al. (2023). Sites were surveyed between November 2022 to March 2023 and the alpine she-oak skink was recorded at 21 of the 27 grids (78%).

Discussion

The distribution of this species across KNP is relatively well-known from work undertaken by Hartley et al. (2023). While the distribution of alpine she-oak skink extends over a significant proportion of KNP, within this range the extent of preferred habitat (sub-alpine and alpine grasslands) represents only a small proportion of the available area (less than 15%). Ongoing surveys to monitor the distribution and occupancy of the alpine she-oak skink are planned to be undertaken every 2 years across the known extent of the species in KNP. A review of the monitoring data will be undertaken to ensure there are an adequate number of sites (and grids within sites) to robustly track changes in occupancy.

Figure 20 Alpine she-oak skink targeted monitoring grids (blue circles) and records (grey circles) from Hartley et al. (2023)

Alpine tree frog

Conservation context

The alpine tree frog (*Litoria verreauxii alpina*) is a small frog which occurs at elevations above 1,100m in the NSW and Victorian high country. Historical records indicate that it has undergone a dramatic decline in range and abundance (Osborne et al. 1999). The species is listed as endangered under the Biodiversity Conservation Act and vulnerable under the Environment Protection and Biodiversity Conservation Act. Threats include habitat modification due to feral horse impacts, changes to water flows from groundwater extraction, climate change, habitat alteration from fire as well as direct impacts from fire, and chytrid fungus.

Background

The alpine tree frog occurs across a wide variety of habitats throughout KNP with the majority of records from the Tantangara and upper Murrumbidgee catchments in northern KNP. Across the geographic range of the alpine tree-frog in KNP, up to 17 sites have been monitored since 1997 (Figure 23). The relative abundance of adult frogs is estimated from static call surveys after dark at each site, this involves listening for male calling frogs. Surveys undertaken between 2017 and 2019 estimated a relative abundance of 25 alpine tree frogs, and 20 alpine tree frogs in 2022 surveys.

Discussion

Occupancy and the relative abundance of alpine tree frogs across the 17 monitoring sites is believed to be stable. However, currently population estimates are only obtained from a limited number of sites. Broadscale surveys across the known historical range of the species is a monitoring priority to identify the current distribution of the species within KNP and trends in population abundance. Monitoring aimed at integrating bog and fen rehabilitation and sampling frogs for chytrid fungus has been recommended (Commonwealth of Australia 2014).

Additional monitoring sites have been identified for the alpine tree frog, and up to 30 additional sites will be included in future monitoring. Real-time monitoring by human observers is still the preferred survey technique for this species as abundance indices can be easily derived due to the regularity and reliability of calling male alpine tree-frogs. However, with the future advancement of automated acoustic processing and call analysis, acoustic methods may improve species detection in the future.

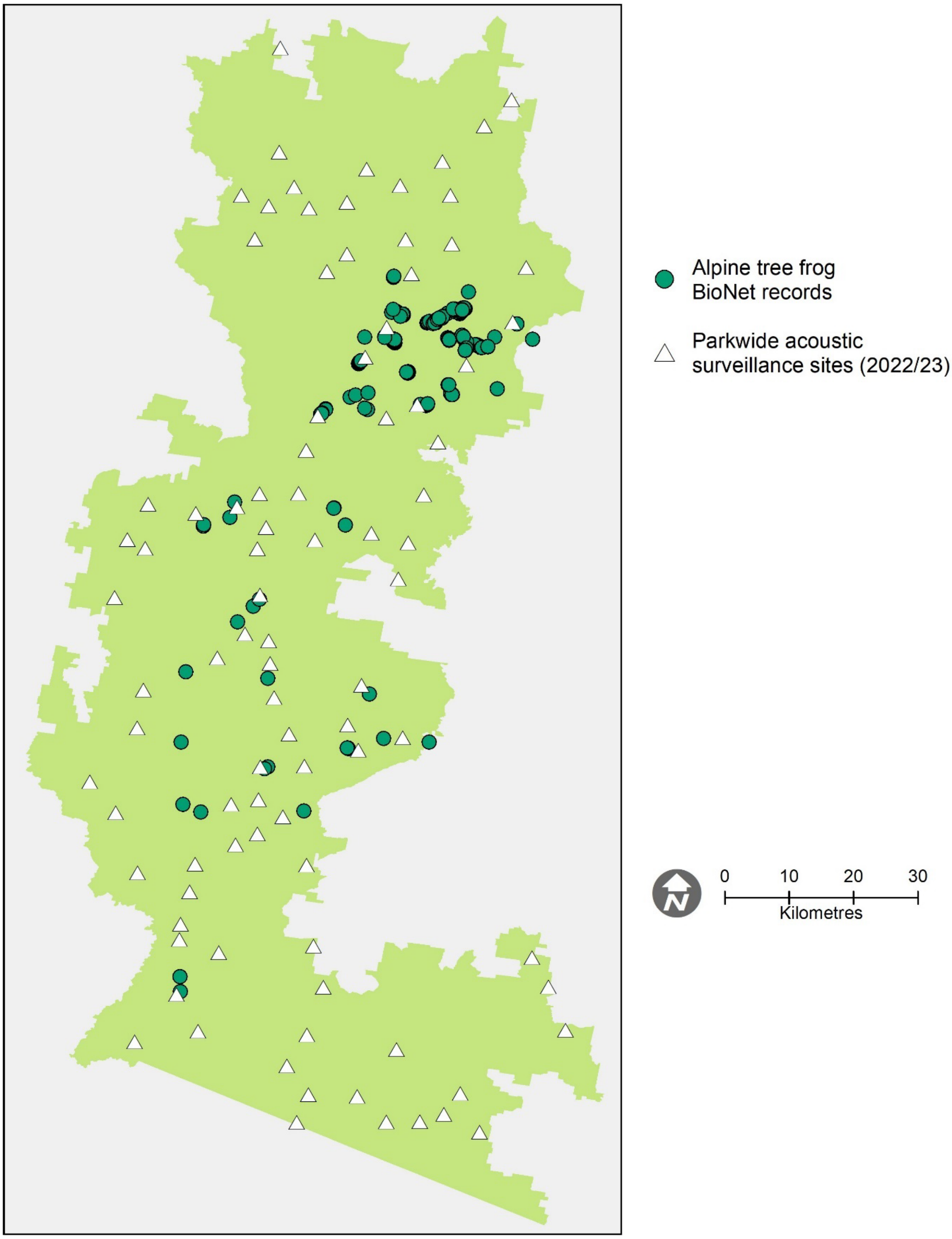


Figure 21 **Alpine tree-frog distribution based on BioNet records since 1993 (green circles). Location of park-wide acoustic surveillance sites surveyed in 2022–23 shown as white triangles**

Booroolong frog

Conservation context

The booroolong frog (*Litoria booroolongensis*) is a medium-sized frog that lives along permanent rocky streams. The species is listed as endangered under the Biodiversity Conservation Act and the Environment Protection and Biodiversity Conservation Act. The species occurs on the inland slopes and ranges of NSW and north-eastern Victoria. Previously common, the species range has declined by more than half since the 1970s. Now only a small part of the distribution range is occupied, and the species is only found in low abundance at most remaining sites (DCCEEW 2021a). Key threats include modification and loss of critical habitat, predation of their eggs by invasive fish, stream disturbance by feral horse activity, drought and stream drying, and the amphibian chytrid fungus (*Batrachochytrium dendrobatidis*) (DCCEEW 2021a; Scheele et al. 2019).

Background

The distribution of the species in KNP is restricted to the western flowing streams in the Tooma and Tumut catchments. Within these catchments, targeted monitoring surveys have been conducted for booroolong frogs since 2015 at 8 sites on 4 streams to estimate the relative abundance (counts of individuals) and occupancy at breeding sites (Figure 24). Spotlight searches are conducted at night in the breeding season (November–December) along a 500 m section of stream to search for the frogs within 4 m of the water's edge. Sites and survey methodology are based on Hunter and Smith (2013). In 2019, the average relative abundance of adult booroolong frogs during the breeding season per site (500 m transect) was 19 and 100% of breeding sites within the survey area were occupied.

Discussion

The booroolong frog is only known to remain in a small number of streams in KNP (Hunter and Gillespie 1999; Hunter and Smith 2013) and annual presence within streams can be variable due to stream dynamics (Hunter and Smith 2013). Since 2015, occupancy across breeding sites has remained constant, however, the average relative abundance across sites has declined over the same period. This observation may be consistent with natural fluctuations in abundance for this species. The booroolong frog population generally exhibits large annual fluctuations in abundance likely related to a high annual adult mortality and variable recruitment (DCCEEW 2021a) and may be strongly influenced by factors operating at the broader landscape, such as drought (Hunter 2007).

Long-term monitoring is critical for this species as the number of locations it occurs at are restricted and the number of individuals can fluctuate annually. Further surveys at the 8 monitoring sites are planned for 2025 in collaboration with Buugang Bila Indigenous Ranger Program. Monitoring will continue to use relative abundance, using raw counts by spotlighting, to monitor shifts in the abundance of individuals. However, mark-recapture studies may need to be considered in the future to identify which external factors are contributing to changes in abundance.

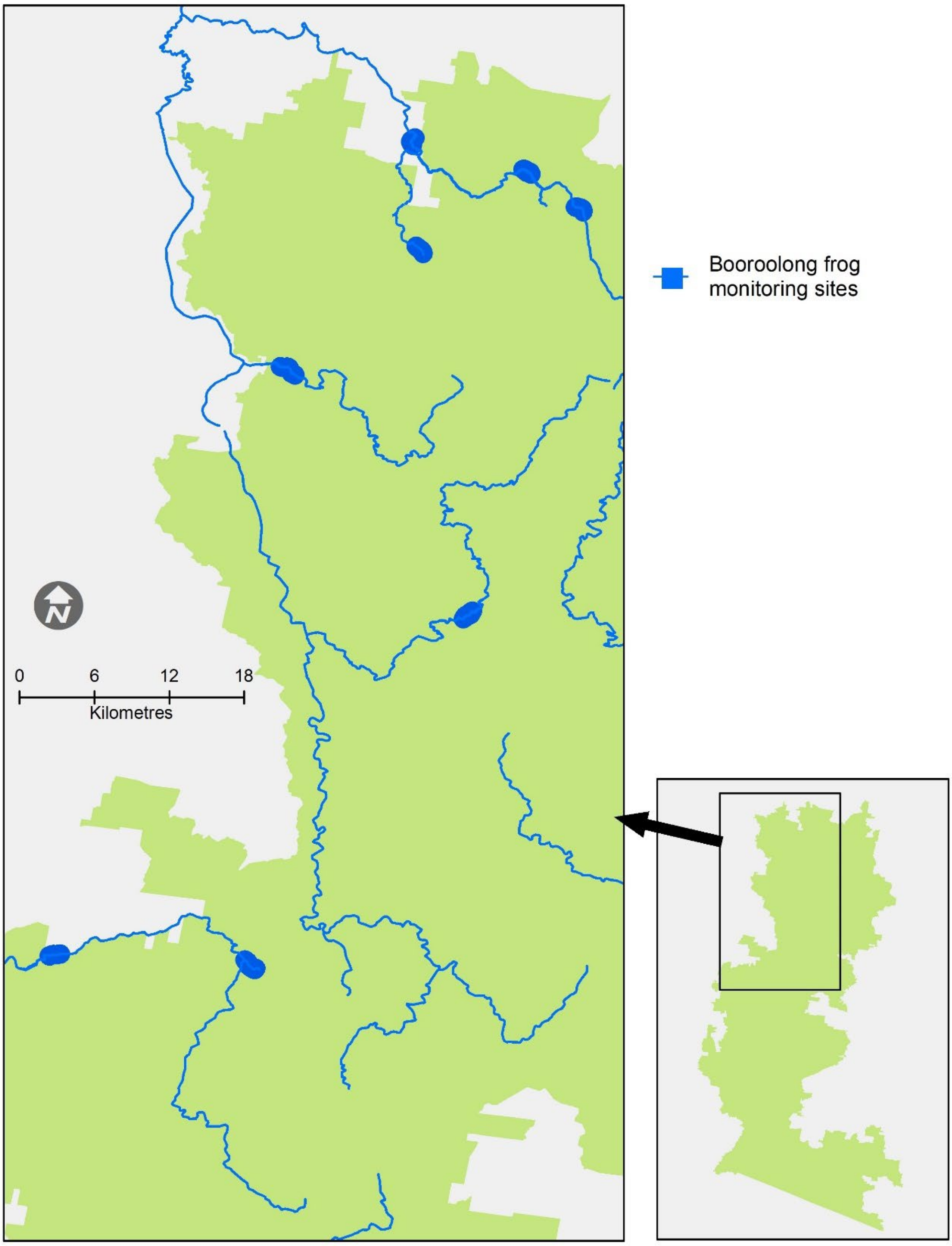


Figure 22 Booroolong frog monitoring sites (solid blue polygons) and major streams and rivers (solid blue lines). Small map at right shows the location of the booroolong frog monitoring sites in Kosciuszko National Park

Broad-toothed rat

Conservation context

The broad-toothed rat (*Mastacomys fuscus*) is a small, ground-dwelling mammal with a fragmented distribution in south-east Australia, occurring primarily in alpine and sub-alpine regions. In NSW they are known from 2 disjunct subpopulations, Kosciuszko National Park and Barrington Tops National Park. The largest subpopulation occurs in KNP, where it is confined to elevations above 1,000 m with an average annual rainfall greater than 1,000 mm. The occurrence of this species increases above 1,500 m where the species is protected by winter snow cover (Green and Osborne 2003). The species is listed as vulnerable under the Biodiversity Conservation Act and the Environment Protection and Biodiversity Conservation Act. Habitat (13,279 ha) of exceptional value has been declared an AIS for this species in KNP under section 153G of the National Parks and Wildlife Act 1974.

The broad-toothed rat is strictly herbivorous and occupies a range of habitats including heathlands, grasslands adjacent to boulder fields, swamps, sedgeland and sometimes forests with a grassy understorey. Habitat suitability is often determined by vegetation structure and the availability of grasses which are its primary food source (Carron et al. 1990; Happold 1995; Green and Osborne 2012). Mapping of suitable habitat in KNP indicates the species could occur across 200,000 ha (approximately 30%) of the park. The main threat to this species is habitat degradation by large feral herbivores, including horses, and inappropriate fire regimes (OEH 2020). Feral predators are also a known threat, with diet studies indicating the broad-toothed rat is a preferred prey species of both the fox and cat (Green 2002; Green and Osborne 2003; Broome et al. unpublished data 2022).

Background

Current and past targeted surveys of broad-toothed rats have been conducted across KNP either by scat survey or trapping (K. Green unpublished data 2017; Green and Osborne 2003; Happold 2015; Milner et al. 2015; Shipway et al. 2020). Park-wide scat surveys were conducted in 2017 and 2021 at 180 sites in KNP (Schulz et al. 2019) (Figure 25). Between 2017 and 2021, occupancy at these sites declined by 54% (from 113 to 52 sites). The decline was primarily attributed to wildfire (Schulz et al. 2023) due to the significant absence of scats at 62 sites impacted by the 2019–20 bushfires (recorded at 5 of 62 sites). Follow-up surveys conducted from 2021 to 2023 at the 62 fire-affected sites indicate an increase in occupancy to 66% (41/62) in 2023 (Schulz et al. 2023).

Trapping surveys have been conducted to study the demographics of local populations of broad toothed rats at 5 sites spanning a 20-km range within the central area of the species known distribution in KNP (Figure 25). The 5 sites occur in the species' optimum sub-alpine habitat, at Smiggins Holes which has been monitored since 1978 (Happold 2015; K. Green unpublished data 2017) and the other 4 sites, since 2002 (K. Green unpublished data 2017). In 2023, local population monitoring was completed at 4 of the 5 sites (early snow prevented one of the sites from being monitored). An average of 1.7 animals were recorded per 100 trap nights. Forty years of monitoring at these survey sites indicate that the broad-toothed rat population is in decline at these sites, likely from climate change causing reduced snow depth and duration over this time (Happold 2015). However, there has been an increase in abundance in the last 5 years most likely due to increased rainfall and subsequent increase in food resources. Fox and cat control programs near these monitoring sites may have also assisted in the short-term recovery of the species.

In 2022–23, broad-toothed rat was detected at 7 of 100 Scorecard park-wide surveillance monitoring sites (Figure 25). Animals were predominately detected at low frequency as park-wide surveillance sites are not specifically located at higher elevations to target this species.

Discussion

Monitoring conducted to date for the species does not generate an estimate of the broad-toothed rat population (or similar metric) for KNP. Thus, it is not known whether demographic changes observed at the 5 intensively monitored sites in KNP are representative of the broader population across KNP.

NPWS, in collaboration with the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and University of Canberra, is designing a new survey technique that uses genetic markers to identify broad-toothed rat individuals from their scats. Already the project has successfully generated genotypes from tissue collected across the species' range in New South Wales and Victoria. Surveys to collect scats from targeted survey sites for occupancy and population genetics commenced in 2023 at 111 sites and the study will be completed by mid-2025. This new method provides a promising non-invasive survey method for assessing population size, dispersal and genetic diversity across the species range in KNP.

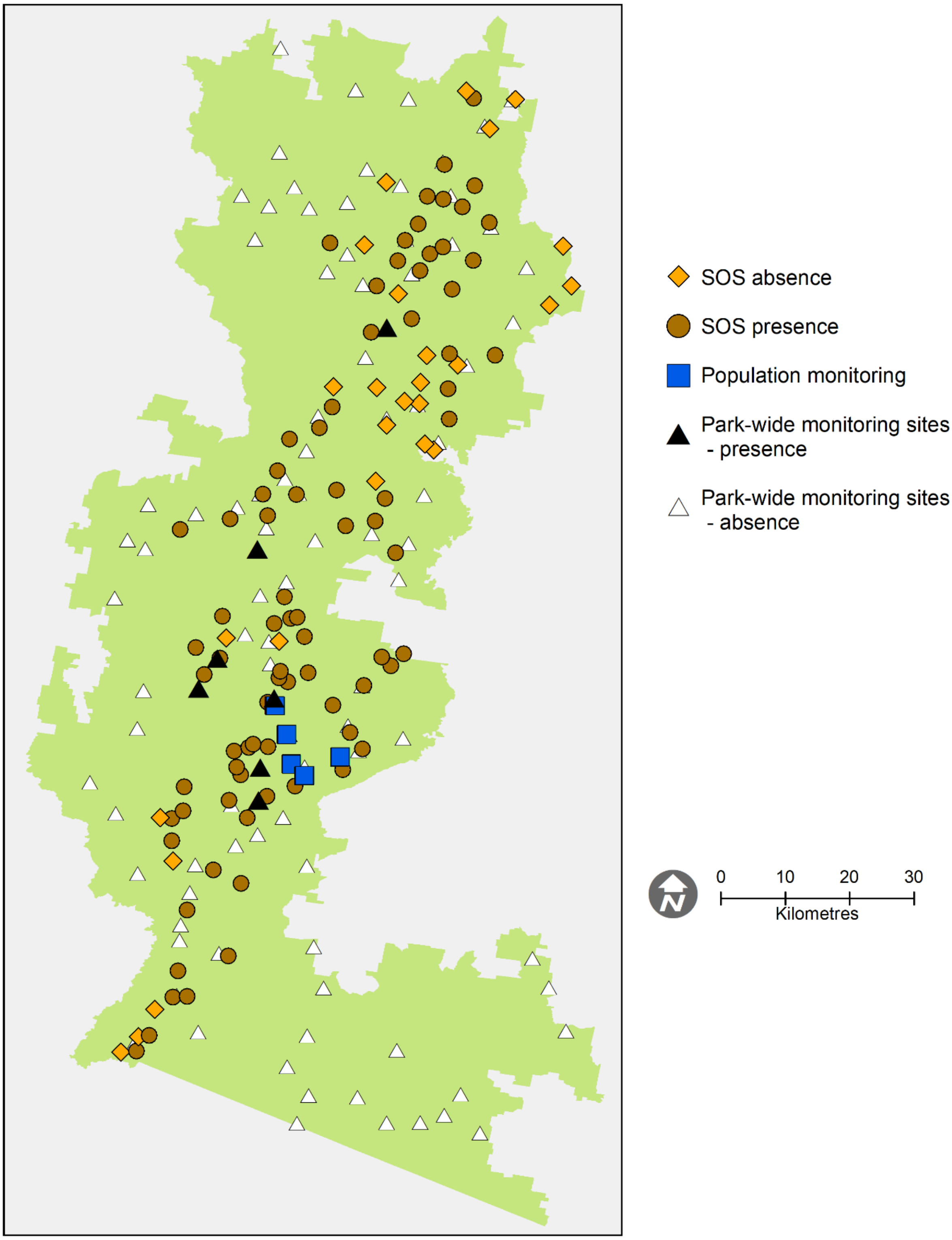


Figure 23 Broad-toothed rat records from park-wide surveillance monitoring sites (triangles), targeted monitoring sites (circles) and population demography sites (squares) in Kosciuszko National Park

Eastern false pipistrelle

Conservation context

The eastern false pipistrelle is a large microbat (c. 25 g) found on the south-east coast and ranges of Australia and is listed as vulnerable under the Biodiversity Conservation Act. It is associated with tall, wet eucalypt forests (Law et al. 2023) and known threats include disturbance and loss of roosting and breeding sites, including hollow-bearing eucalypts, as well as loss and fragmentation of foraging habitat. It is larger than most other microbat species thus occupies a roosting niche between that of most Australian microbats (5–15 g) and small arboreal hollow-dependent mammals, such as sugar gliders (c. 100 g).

Background

Systematic, broadscale surveys for most microbat species are rare. Until recently, the cost of ultrasonic recorders was prohibitive to enable such surveys. The distribution of the eastern false pipistrelle within KNP is not well understood. Park-wide surveillance monitoring detected the eastern false pipistrelle at 81% of all monitoring sites across KNP (60 of 74 sites). This figure belies its status within the park as there were just a few sites (14%) where activity levels were elevated.

The eastern false pipistrelle had an average activity index of 0.8 ± 0.1 detections (Figure 26). Activity was calculated as the number of unique detections (passes separated by at least 30 minutes) per site per night. Activity was significantly higher in wet sclerophyll forest (grassy sub-formation) than the other major vegetation formations surveyed.

Discussion

Further analysis of park-wide surveillance monitoring will also be undertaken to investigate habitat correlates with eastern false pipistrelle activity in KNP and to improve monitoring outcomes. Analyses will also be undertaken on various temporal components of eastern false pipistrelle call data to determine optimal sampling times, effort and duration. In addition, targeted ultrasonic acoustic surveys will be undertaken in alpine ash communities in March 2025 to improve understanding of eastern false pipistrelle habitat associations in KNP. These surveys will be stratified on fire history and aim to identify activity of the eastern false pipistrelle in relation to fire severity and fire history.

Figure 24 Distribution and activity indices (number of passes per night separated by more than 30 minutes) of eastern false pipistrelle at park-wide surveillance monitoring sites in Kosciuszko National Park

Symbol sizes are graduated by activity levels per site, with the larger symbols representing higher levels of activity.

Guthega skink

Conservation context

The Guthega skink (*Liopholis guthega*) occurs only in the alpine region of KNP and the Victorian Alps (>1,600 m above sea level); the highest elevation recorded for a skink in Australia (Figure 27). In KNP the population is restricted to an area of 30 × 5 km. It is listed as endangered under the Biodiversity Conservation Act and the Environment Protection and Biodiversity Conservation Act. Habitat of exceptional value (2.966 ha) has been declared an AIS for this species in KNP under section 153G of the National Parks and Wildlife Act 1974.

The Guthega skink lives in colonies, and adults show considerable site fidelity to burrow networks (Atkins 2018). The species is negatively impacted by ground disturbance, often caused by grazing and trampling by feral herbivores, which can affect the species' burrow network as well as basking and foraging areas. A large proportion of its population occurs in areas which overlap with recreational infrastructure which may impact habitat quality.

Background

The distribution, biology, and genetic diversity of Guthega skink is relatively well known and has informed the location of 5 permanent monitoring sites, which are across its known range and genetic diversity (Atkins 2018; Atkins et al. 2020; Figure 27). Targeted surveys were carried out at these sites, each 625 m² in area, from February to March 2022 and 2023 to estimate the abundance of the species in KNP. Each site was systematically searched to count individuals and locate active burrows (Brown et al. 2020). Burrow activity can be used as a surrogate for abundance due to high burrow fidelity.

In 2021, a total of 291 burrows were located (an average of 58.2 active burrows per site), 236 burrows were located in 2022 (an average of 47.2 active burrows per site), and 206 in 2023 (an average of 41.2 active burrows per site). The number of individual skinks identified was 18 in 2022, and 22 in 2023.

Discussion

While a decline in the number of active burrows has been observed across years, it's unclear whether this represents a decline in the species' population. An increase in the presence of deer was recorded at monitoring sites in 2022 which may have impacted burrow integrity and hence negatively affected skink populations. Additional data is required to assess population trends and impacts from feral herbivores.

Recently, 12 new sites were identified for monitoring, extending the geographic extent of intensive monitoring a few kilometres west and north of the current footprint. These new sites will be incorporated into a future monitoring program and improve knowledge of the species' population. In addition, surveys in remote areas in the northern part of the species' modelled habitat will be undertaken (Figure 27).

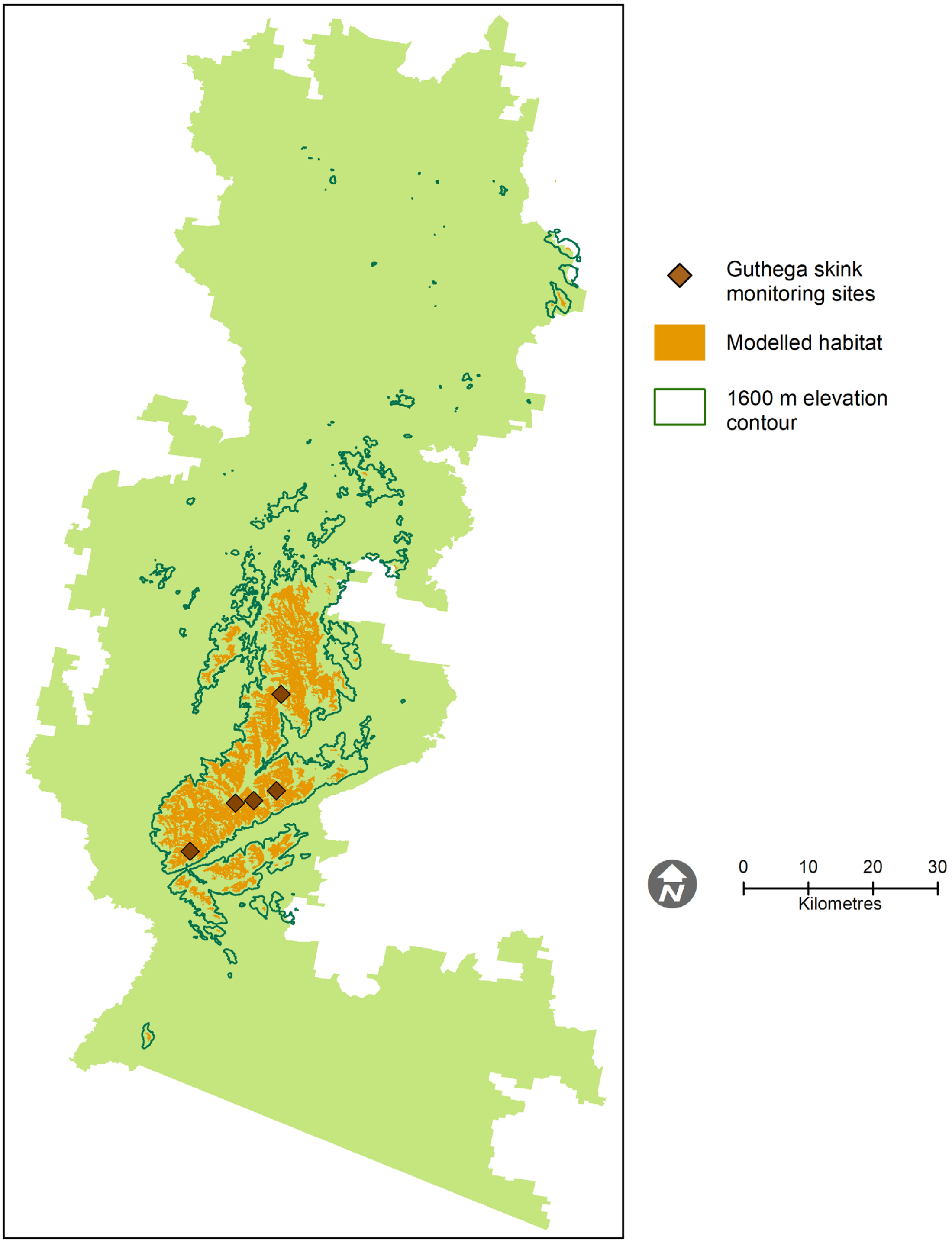


Figure 25 Location of Guthega skink targeted monitoring sites in Kosciuszko National Park. Targeted monitoring sites (brown diamonds) with 1600 m elevation contour for reference to its distributional limit (dark green polygons) and modelled potential habitat (orange shaded area)

Koala

Conservation context

The koala (*Phascolarctos cinereus*) is an iconic species which faces numerous threats across New South Wales, including habitat loss, disease, predation by dogs, inappropriate fire regimes, and climate change. The species is listed as endangered under the Biodiversity Conservation Act and the Environment Protection and Biodiversity Conservation Act.

Background

Koalas have historically been detected in the southern tableland and montane forests of KNP and the data suggest they occur in low densities in these areas. Between 2021–23, acoustic surveys were conducted across KNP by the Australian National University (ANU) (Marsh et al. 2022, 2023) to assess habitat associations with koala presence. Koalas were detected at about 10% of sites (21 of 203 sites, Figure 28) in areas that had been modelled as having lower quality habitat in the NSW koala tree index and habitat suitability models. This may suggest that available models do not reliably predict koala habitat characteristics in KNP.

Discussion

The distribution of koalas across KNP is currently thought to be restricted to the south-east section of the park (Figure 28), consistent with historical records in BioNet from the past 30 years. However, scats have been identified in a small area just north of Jindabyne, although koalas were not detected in acoustic surveys. Further work is required to clarify vegetation associations with koala occurrence in the park. Passive acoustic devices will be used to improve our understanding of the occurrence of koalas across the landscape and refine a species habitat model for KNP. Thermal drones will be used to monitor koalas at representative sites to derive population abundance estimates informed by robust modelling.

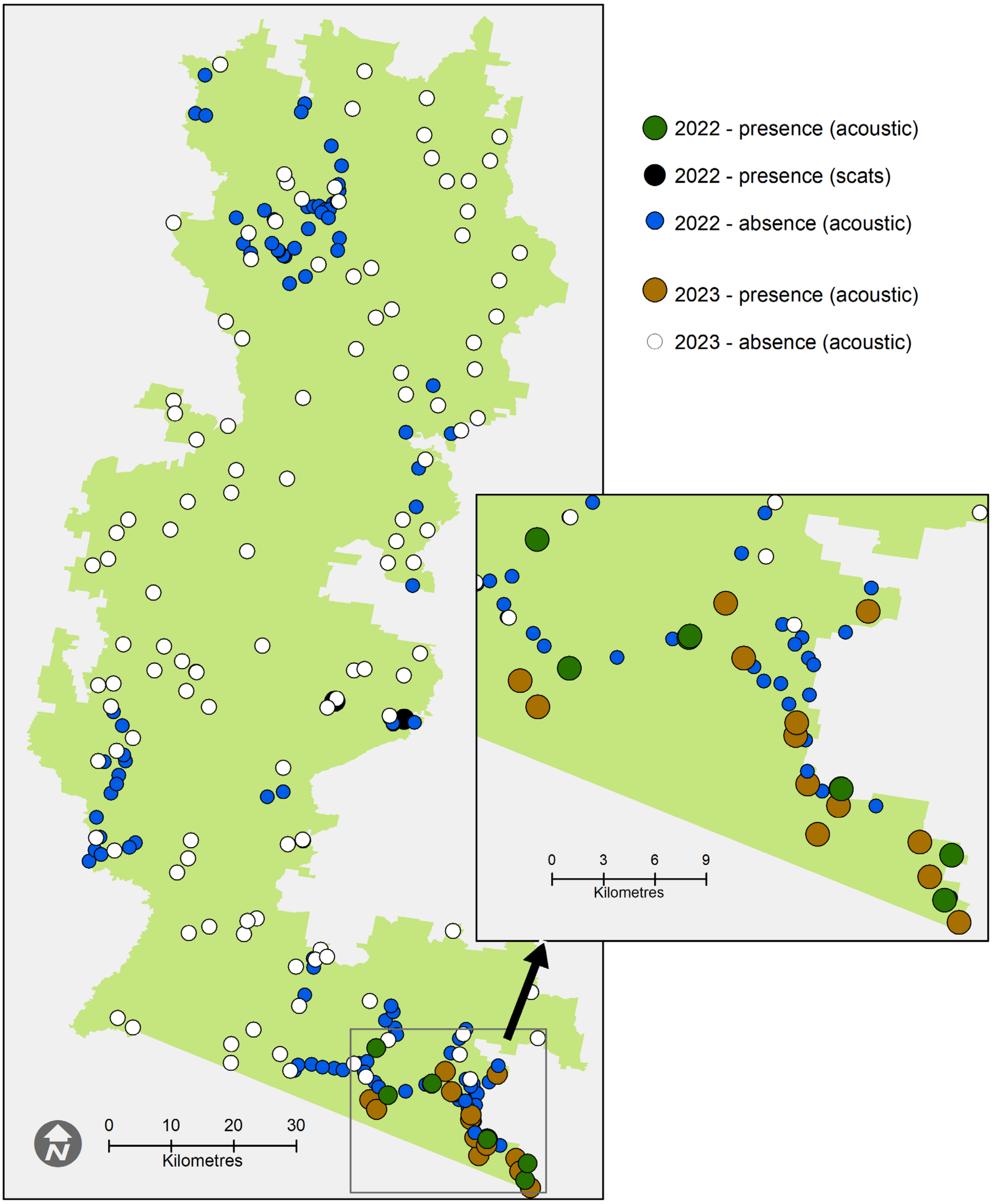


Figure 26 The presence of koalas at targeted monitoring sites based on acoustic recordings in 2022 (green circles) and 2023 (brown circles), and scats (black circles)

Mountain pygmy-possum

Conservation context

The mountain pygmy-possum (*Burramys parvus*) is endemic to the alpine and sub-alpine regions of south-eastern Australia. Snow-covered boulderfields at higher elevations are the preferred habitat for the mountain pygmy-possum (Broome et al. 2013; Bates 2017). In New South Wales, the entire known range of the mountain pygmy-possum occurs in less than 400 ha of cumulative habitat in KNP, between Thredbo in the south of the park and Cabramurra in the north (Broome 2001; OEH 2022). These populations are separated geographically and at a distance that has led to genetic differentiation (A. Weeks, unpublished data).

It is listed as endangered under the Biodiversity Conservation Act and the Environment Protection and Biodiversity Conservation Act. Habitat of exceptional value (6,773 ha) has been declared an AIS for this species under section 153G of the National Parks and Wildlife Act 1974. Key threats to this species are habitat loss and fragmentation, climate change, and predation by foxes and cats (Hoffman et al. 2019; OEH 2022).

Background

More than 30 years of research has been undertaken on the mountain pygmy-possum including microhabitat use, hibernation behaviour (Smith and Broome 1992; Koertner and Geiser 1998; Shi et al. 2015), and diet (Gibson et al. 2018; Hawke et al. 2019).

The southern population of the mountain pygmy-possum has been monitored in KNP for 36 years (Broome et al. 2013), and monitoring of the northern population commenced in 2012 (Figure 29). Small mammal trapping has been used to collect mark-recapture data across 7 monitoring plots. Population metrics such as density (number of individuals per hectare) and trapping rates, reported as the number of captures per 100 trap nights, have been used to track changes in population accounting for survey effort. In 2022 this figure was 10.4 individuals per 100 trap nights, and in 2023 it was 11.1. Long-term trapping surveys of mountain pygmy-possum populations suggest the overall population is stable (estimated at 800–1100 individuals [DPIE 2021a; L. Broome pers. comm. 27 September 2024]), however numbers fluctuate due to drought, wildfire and impacts of feral predators.

Discussion

A continuous ecological monitoring program of 36 years is rare and invaluable in Australian ecology providing valuable insights on both long-term population trends and population fluctuations. Long-term population monitoring of the mountain pygmy-possum has shown that populations have fluctuated over a 30-year period, a phenomenon not uncommon due to natural variation. Since 2019, the relative abundance across these sites has remained reasonably constant despite drought, fire and the decline in one of their major food sources, the bogong moth. Twenty percent of the species' northern habitat was severely impacted in the 2019–20 bushfires although populations in these localities have recovered following supplementary feeding (L. Broome unpublished data 2022).

Further analyses of the mark-recapture data are required to provide robust density estimates of the population and to provide understanding into the impacts of climate change and feral predators on the population. Future monitoring will also include camera-based surveys in suitable boulder field habitat to improve our knowledge of the distribution of mountain pygmy-possum across KNP and monitor any changes in their distribution. These insights will help prioritise management actions to more effectively ensure persistence of the mountain pygmy-possum in KNP.

Figure 27 Location of mountain pygmy-possum sites in Kosciuszko National Park (solid green circles)

Northern corroboree frog

Conservation context

The northern corroboree frog (*Pseudophryne pengilleyi*) is a small frog with distinctive colouring of bright yellow, or lime green, with black stripes. It has a highly restricted distribution, occurring only in the high montane and sub-alpine bog environments in the northern Australian Alps of NSW and high country around the ACT. It is a habitat specialist requiring temporary pools and seepages in sphagnum bogs, wet tussock grasslands and wet heaths to breed. Threats to the species include loss and modification of habitat and infection with the amphibian chytrid fungus. Drought, weeds, and feral herbivores are also contributing to the ongoing decline of this species (OEH 2012). For example, feral pigs (*Sus scrofa*) and horses (*Equus equus*) can cause considerable disturbance and damage to breeding sites.

The species is listed as critically endangered under both the Biodiversity Conservation Act and the Environment Protection and Biodiversity Conservation Act. Habitat of exceptional value (5,967 ha) has been declared an AIS for this species in KNP under section 153G of the National Parks and Wildlife Act 1974.

Background

The historic distribution of the species in KNP is in the northern section of the park, with most extant populations occurring in the Bogong Peaks wilderness area. The species population continues to be impacted by the amphibian chytrid fungus and was further impacted by the 2019–20 bushfires in the park.

Targeted monitoring of the species has been undertaken for several years across the species' range in KNP and on adjoining state forests, collectively known as the Fiery population. In 2022 and 2023, surveys were carried out at 40 sites in KNP. Monitoring the abundance of northern corroboree frog involves counting the number of calling males at breeding sites during the peak calling period of the summer breeding season using the shout-response technique (Osborne 1989). The number of calling males recorded in 2022 was 187, and in 2023 was 149.

Discussion

It's unclear whether the species is continuing to decline in KNP due to the partial impact of the 2019–20 bushfires to the species' known range and uncertainty about population recovery. Ongoing surveys to monitor the relative abundance of breeding males will be undertaken and visual inspections of nests and pools should be used to monitor egg and tadpole development.

Due to the precarious state of the species' population, a robust insurance population is being established at Taronga Zoo. A reintroduction program is currently being developed which will include *in-situ* disease-free field enclosures. Post reintroduction monitoring will be undertaken to assess the success of the program.

Smoky mouse

Conservation context

The smoky mouse is a small rodent (c. 50 g) that has a restricted distribution in the south-east of NSW. It occurs in a wide range of vegetation communities, ranging from coastal heath to dry ridgeline forest, sub-alpine heath and, occasionally, wetter gullies (Menkhorst and Seebeck 1981). It has undergone a contraction in range since European settlement, due to loss of habitat because of vegetation clearance.

It is listed as critically endangered under the Biodiversity Conservation Act and endangered under the Environment Protection and Biodiversity Conservation Act. Habitat of exceptional value (6,226 ha) has been declared an AIS for this species in KNP under section 153G of the National Parks and Wildlife Act 1974. Key threats to the species are predation by foxes and cats, which may be magnified where too frequent or high-intensity fire occurs, and during periods of drought; and loss of habitat from browsing by feral herbivores and *Phytophthora* dieback.

Background

Smoky mouse was first identified in KNP in 1994 in the far south of the park and then again in 1998 from an opportunistic discovery of 3 animals from a cat kill at Yarrangobilly Caves (northern KNP). It wasn't until 2015 that more occurrences were identified. In 2018−19, during surveys for the Snowy 2.0 development, the species was found north of Cabramurra in KNP. Subsequent live trapping and camera-based surveys have revealed the species to be widespread throughout the northern section of the park. While smoky mouse has been observed on camera in southern KNP, its status in the southern section of the park is unclear.

A 3-tier classification system has been developed to prioritise survey sites for smoky mouse by the SoS program. This approach aims to refine the species' habitat associations and distribution in KNP. Priority 1 sites are based on vegetation formations where the species has previously been recorded. Priority 2 and 3 sites are based on similar vegetation formations but are sites where smoky mice have not previously been recorded (Figure 30). Between 2021 and 2023, 215 Priority 1 sites were surveyed, and the species was detected at 10 sites.

In addition, of the 100 park-wide surveillance sites surveyed in 2022–23, 36 sites overlapped with Priority classified sites; 15 were in Priority 1 sites, 12 in Priority 2 sites, and 9 in Priority 3 sites. Smoky mouse were detected at 2 surveillance sites, one detection was just outside of a Priority 1 site, and the other detection was within a Priority 2 site.

Discussion

Camera-based surveys are an effective method for surveying smoky mice and to improve knowledge of the species' habitat associations, distribution and abundance across KNP. Further camera-based surveys are planned for 2024 and 2025 at 403 Priority 2 sites and 125 Priority 3 sites (Figure 30). These data will be used to assess detection probabilities to optimise survey design and to develop habitat models using appropriate statistical techniques. This information will be used to design a long-term camera-based monitoring program to determine where and whether smoky mouse populations persist in KNP – smoky mouse colonies are thought to be ephemeral in nature, with their occurrence varying both spatially and temporally across the landscape (Menkhorst and Broome 2006). Long-term monitoring will be critical to track changes in species' distribution and abundance, and to assess the effectiveness of management actions on reducing impacts on the population.

Figure 28 Smoky mouse records in Kosciuszko National Park (solid green circles), Priority 1 (dark grey polygons), Priority 2 (orange polygons) and Priority 3 (light grey polygons) survey sites. Park-wide camera-based surveillance sites are shown as solid white triangles

Southern corroboree frog

Conservation context

The southern corroboree frog (*Pseudophryne corroboree*) was historically restricted to sphagnum bogs entirely within Kosciuszko National Park, from Smiggin Holes in the south, and northwards to the Maragle Range. The species occupies a relatively narrow altitudinal strip between 1300 and 1760 m above sea level. However, the occupied range has greatly contracted over the past 25 years, with the species now only occurring at a small number of remnant populations along the north-western edge of its former range (OEH 2012).

The southern corroboree frog is listed as critically endangered under both the Biodiversity Conservation Act and the Environment Protection and Biodiversity Conservation Act. Habitat of exceptional value (862 ha) has been declared an AIS for this species in KNP under section 153G of the National Parks and Wildlife Act 1974. Threats to the species include climate change, weeds, habitat degradation and soil loss due to grazing and trampling from feral herbivores (including historic impacts from cattle), habitat loss due in part to ski resort expansion, and infection with the amphibian chytrid fungus (OEH 2012).

Background

The southern corroboree frog currently occupies only a small number of sites within or immediately adjacent to the Jagungal Wilderness Area of Kosciuszko National Park. It has been the focus of a population monitoring program since 1986 assessing ongoing trends in abundance and occupancy (OEH 2012). Due to the very small population size, and high risk of extinction, a captive breeding program including Taronga Zoo, Zoos Victoria, and the Amphibian Research Centre in Victoria was established. The program maintains a genetically robust population of southern corroboree frogs and provides large numbers of progeny for management and research actions, including for release back into the wild at reintroduction sites in KNP.

Southern corroboree frog eggs and tadpoles bred in captivity have been reintroduced in areas with steep topography and permanent water to promote the establishment of wild colonies. In addition, in-situ artificial habitat field enclosures, free of amphibian chytrid fungus, are maintained and supplemented with captive-bred eggs and tadpoles.

Targeted surveys are carried out annually at field enclosures and at reintroduction sites to estimate the relative abundance of male southern corroboree frogs using the shout-response technique described in Osborne (1989). The number of male frogs heard calling across 40 monitoring sites in 2022 was 35, and 29 in 2023.

Discussion

The relative abundance of the southern corroboree frogs at the surveyed sites remains stable, despite the decrease in the number of males identified between years. However, the species now only occurs at managed sites where captive-bred individuals are released. Without a captive breeding program and species' reintroductions in KNP, the southern corroboree frog would be extinct in the wild.

Southern myotis

Conservation context

The southern myotis (*Myotis macropus*) is a medium-sized microbat (c. 10 g). It is unusual amongst Australian microbats in that it forages over waterbodies and feeds on aquatic invertebrates and small fish. It is regarded as a habitat specialist although it is widely distributed along the eastern seaboard of Australia. It is thought to be sensitive to changes in water quality due to its dietary reliance on aquatic biota. The southern myotis is listed as vulnerable under the Biodiversity Conservation Act. Threats to the species include disturbance and degradation of foraging sites.

Background

Little is known of the historical or current distribution of southern myotis across KNP. However, the southern myotis was detected on ultrasonic acoustic recorders at 2 of 74 (3%) surveyed park-wide surveillance monitoring sites. However, this may be an underestimate due to current difficulties in identifying the species from echolocation calls. Ongoing improvements in call identification techniques means it is likely that a much-improved estimate of the park-wide occupancy can be obtained in the future.

Discussion

While park-wide surveillance monitoring sites provide some insight into southern myotis occurrence across KNP, given its preference for foraging over water bodies (Campbell 2009); a more meaningful assessment of its status will be obtained from targeted surveys along riparian corridors and waterbodies. Targeted surveys are planned for December 2024 at 25 sites where water quality monitoring is undertaken. The use of ultrasonic acoustic recorders and analysis of call activity levels will be used to identify correlates with habitat and water quality measures, particularly macroinvertebrate diversity.

Spotted-tailed quoll

Conservation context

The spotted-tailed quoll (*Dasyurus maculatus*) is a medium-sized marsupial carnivore endemic to eastern Australia. It occurs across a range of different habitat types and occupies large home ranges, and is often solitary. The species is listed as vulnerable under the Biodiversity Conservation Act and as endangered under the Environment Protection and Biodiversity Conservation Act. Key threats to spotted-tailed quoll include habitat loss and degradation, inappropriate fire regimes, and competition with feral predators. For these reasons the species is a useful indicator to understand the effects of disturbance and possible shifts in prey species abundance (Dawson et al. 2007).

Background

The current distribution of spotted-tailed quolls in KNP is not well understood, outside of their known stronghold in the Lower Snowy and Byadbo areas of the park. The Lower Snowy and Byadbo area population has been studied for over 20 years and has provided valuable information on their diet, breeding ecology and home range in a rain-shadow woodland

(Claridge et al. 2005; Dawson et al. 2007; Claridge et al. 2021). Since 2017, systematic camera-trap monitoring has been in place, covering an area of approximately 5,000 ha, to track changes in the spotted-tailed quoll population. Population estimates have been derived from the individual identification of quolls using their unique spot patterns. Monitoring indicates that the population has been steadily increasing over the past 7 years. In 2017, 21 individuals were identified and increased to 31 in 2019, and to 49 in 2023. Increases observed in this population have coincided with higher-than-average rainfall over the past 4 years.

In addition, of the 100 park-wide surveillance sites surveyed in 2022–23, the spotted-tailed quoll was recorded at 5 sites on camera-traps, all in the south-east section of KNP (Figure 31).

Discussion

While historically spotted-tailed quoll has been recorded more broadly across KNP, most records of the species are concentrated in the south-eastern section of the park. The Lower Snowy and Byadbo area contains a high-density population, which cannot be extrapolated to the rest of KNP. While continued monitoring of this high-density population is important to help understand the species' response to threats such as climate change, and competition with other predators (e.g. cats, foxes and dingoes); a broader understanding of quoll distribution and/or density is required across KNP.

In areas where spotted-tailed quoll occurs in low densities, targeted placement of cameras in suitable habitat at latrine sites, dens, and rocky outcrops may be required to improve detection of the species, as well as extended camera deployment durations (e.g. greater than 40 days). Further, the distribution of the spotted-tailed quoll may be mediated by elevation and future surveys in KNP will consider this as a stratification variable in surveys. This will permit more robust estimates of quoll distribution across KNP and assist in the design of a long-term monitoring program.

Figure 29 Spotted-tailed quoll records from park-wide surveillance monitoring sites and BioNet surveys in Kosciuszko National Park

Dashed square denotes the area of targeted population monitoring.

Spotted tree frog

Conservation context

The spotted tree frog (*Litoria spenceri*) is known from just a single population in KNP and approximately 15 locations in Victoria, having disappeared from 50% of its known historic sites. The species inhabits naturally vegetated, rocky, swift-flowing north-west draining mountain streams in dissected country. The spotted tree frog is listed as critically endangered under the Biodiversity Conservation Act and the Environment Protection and Biodiversity Conservation Act. Habitat of exceptional value (659 ha) has been declared an AIS for this species under section 153G of the *National Parks and Wildlife Act 1974*. It is susceptible to amphibian chytrid fungus and predation from introduced trout.

Background

Historically, the spotted tree frog was known from 2 streams in New South Wales – the Upper Murray and Upper Swampy Plains catchments in KNP. By 1998 one of these populations had completely disappeared, and the other population had been reduced to a single mature individual (DCCEEW 2021b). The last remaining frog was removed and used in a captive breeding program at the Amphibian Research Centre in Melbourne to repopulate wild spotted tree frogs into their former habitat. However, ongoing impacts from the chytrid fungus occur in their former habitat, therefore new habitats have been identified for species translocations with a thermal regime that is within the species distribution, does not favour chytrid infection, and where there are low abundances of other frog species that could be reservoir hosts for the disease (DCCEEW 2021b).

Mark recapture surveys are undertaken at translocation sites three times per year to estimate population size, survivorship, recruitment, body condition, and to swab for chytrid infection. In 2021, after monitoring indicated the 2019–20 bushfires had a marked effect on the population causing a 95% reduction in numbers, 80 one-year-old frogs were released. Monitoring results in 2022–23 show a high survivorship of released juvenile frogs, and a large number of tadpoles and metamorphs have naturally recruited into the system, suggesting that the population may recover from the recent decline.

Discussion

Despite the species being at critically low numbers, it is persisting with the aid of captive breeding. Identification of new sites for reintroduction is critical for the future survival of the spotted tree frog. Appropriate chytrid-resilient sites have been identified and a ‘wild to wild’ translocation is planned for January 2025 (D. Hunter pers. comm. Sept 2024). Ongoing monitoring of species survivorship will be conducted at translocation sites and is being undertaken in collaboration with Buugang Bila Indigenous Ranger Program.

Yellow-bellied glider

Conservation context

The yellow-bellied glider (*Petaurus australis*) is a nocturnal gliding marsupial with a widespread but patchy distribution from south-eastern Queensland to far south-eastern South Australia. In NSW, it predominantly occurs in forests along the eastern coast but also extends inland to the western slopes of the Great Dividing Range. The species requires floristically diverse eucalypt forest, which are dominated by winter-flowering and smooth-barked eucalypts, so it can forage year-round and is dependent on mature living hollow-bearing trees for denning and breeding (Goldingay 2008). It is likely that the yellow-bellied glider has been significantly affected by the combined effects of climate change (and pronounced drought periods) and extensive severe fires.

The yellow-bellied glider is listed as vulnerable under the Biodiversity Conservation Act and the Environment Protection and Biodiversity Conservation Act. It is primarily threatened by climate change, inappropriate fire regimes, and habitat fragmentation. In particular, altered fire regimes may degrade existing habitat, in the short term, and reduce the availability of suitable tree hollows in the long term which are vital for population persistence.

Background

The distribution of yellow-bellied gliders in KNP is not well understood and there have been few dedicated surveys for the species. Despite being a vocal and visible species there are relatively few records in the park with only 43 records reported in the past 30 years (Figure 32). Yellow-bellied gliders have been recorded incidentally about every 2 to 3 years mostly along the western side of the park where there is a dominance of tall, wet eucalypt forests.

Spotlight surveys were conducted by the Australian National University in 2022 at 26 sites but were only detected at 2 sites. In addition, acoustic devices were deployed at 92 park-wide surveillance sites in 2022-2023. However, no confirmed records of yellow-bellied gliders have yet been recorded from these sites. Collaborative work has commenced with the Ecoacoustics Research Group at Queensland University of Technology to build a suitable recogniser for the species and improve automated identification of yellow-bellied glider calls from the audio recordings.

Discussion

Systematic and stratified surveys are required to identify where yellow-bellied gliders occur in KNP. Passive acoustic recording devices have been used effectively elsewhere to survey yellow-bellied gliders as the species has a distinctive call (Whisson et al. 2021); however, a suitable acoustic recogniser for the species is required for efficient automated identification. Targeted acoustic surveys have been planned for March 2025 in the alpine ash community and sites will be stratified on fire history. Results from this survey and data from park-wide surveillance sites will be used to inform a monitoring design to assess distribution and abundance of yellow-bellied gliders in KNP. Acoustic devices will be used to monitor changes in distribution and thermal drone technology can be used to derive population abundance estimates at representative sites (Vinson et al. 2020) across its range in KNP.

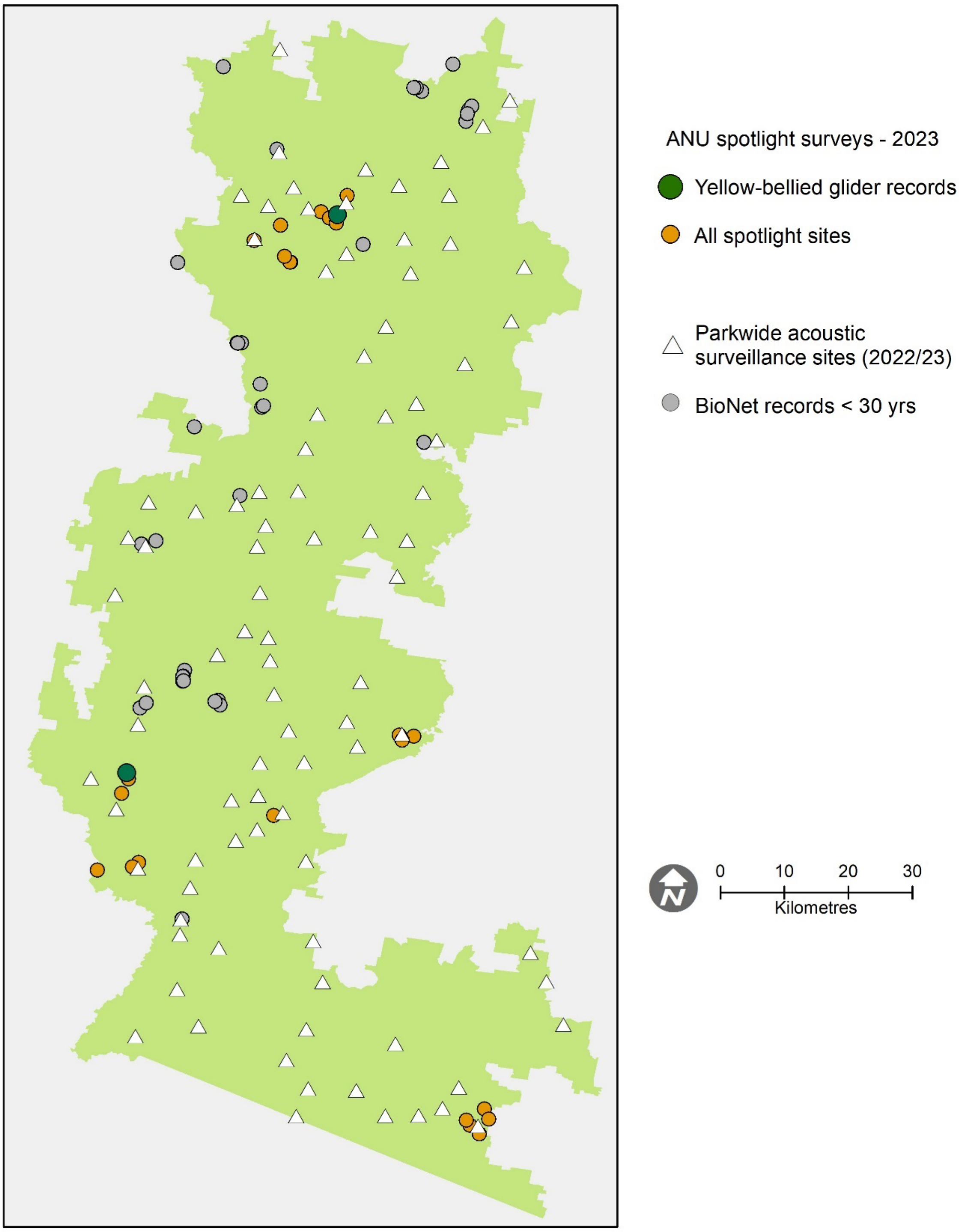


Figure 30 Spotlight surveys conducted by ANU in 2022 and presence of yellow-bellied gliders in Kosciuszko National Park. Spotlight surveys are depicted as orange solid circles and presence of yellow-bellied gliders as large green circles. Past records (30 year) of yellow-bellied gliders are shown as grey solid circles, acoustic park-wide surveillance sites from 2022–23 are shown as white triangles

Targeted monitoring: flora

Kosciuszko National Park contains many endemic flora species and plant communities which are restricted to the Australian Alps bioregion. These communities are vulnerable to the direct and indirect threats from climate change which can lead to a loss of species richness, movement of native and weed species up-slope from lower elevations resulting in changes in community composition and structure (McDougall and Walsh 2007).

A range of flora and vegetation communities have been identified for targeted monitoring based on conservation status or vulnerability to key threatening processes and cover a range of elevations across the KNP landscape. These conservation assets require specialised monitoring techniques which are beyond the scope of the park-wide surveillance monitoring program. Each will have a tailored monitoring program aimed at monitoring changes in population and health over time. The data presented below are intended as interim reporting. Each monitoring program will, as required, be revised to meet the requirements of the Scorecard program, an estimate of the park-wide population or similar metric.

Monitoring results of 4 threatened plant species have been included in this report. These are the anemone buttercup, leafy anchor plant, Suggan Buggan mallee and Max Mueller's burr-daisy. These species are all monitored as part of Saving our Species program and Assets of Intergenerational Significance (AIS) and are largely restricted to KNP (Figure 33).

Two vegetation communities have also been identified for further monitoring and reporting: alpine ash forests and montane peatlands. The next round of monitoring for these 2 communities is planned for early 2025.

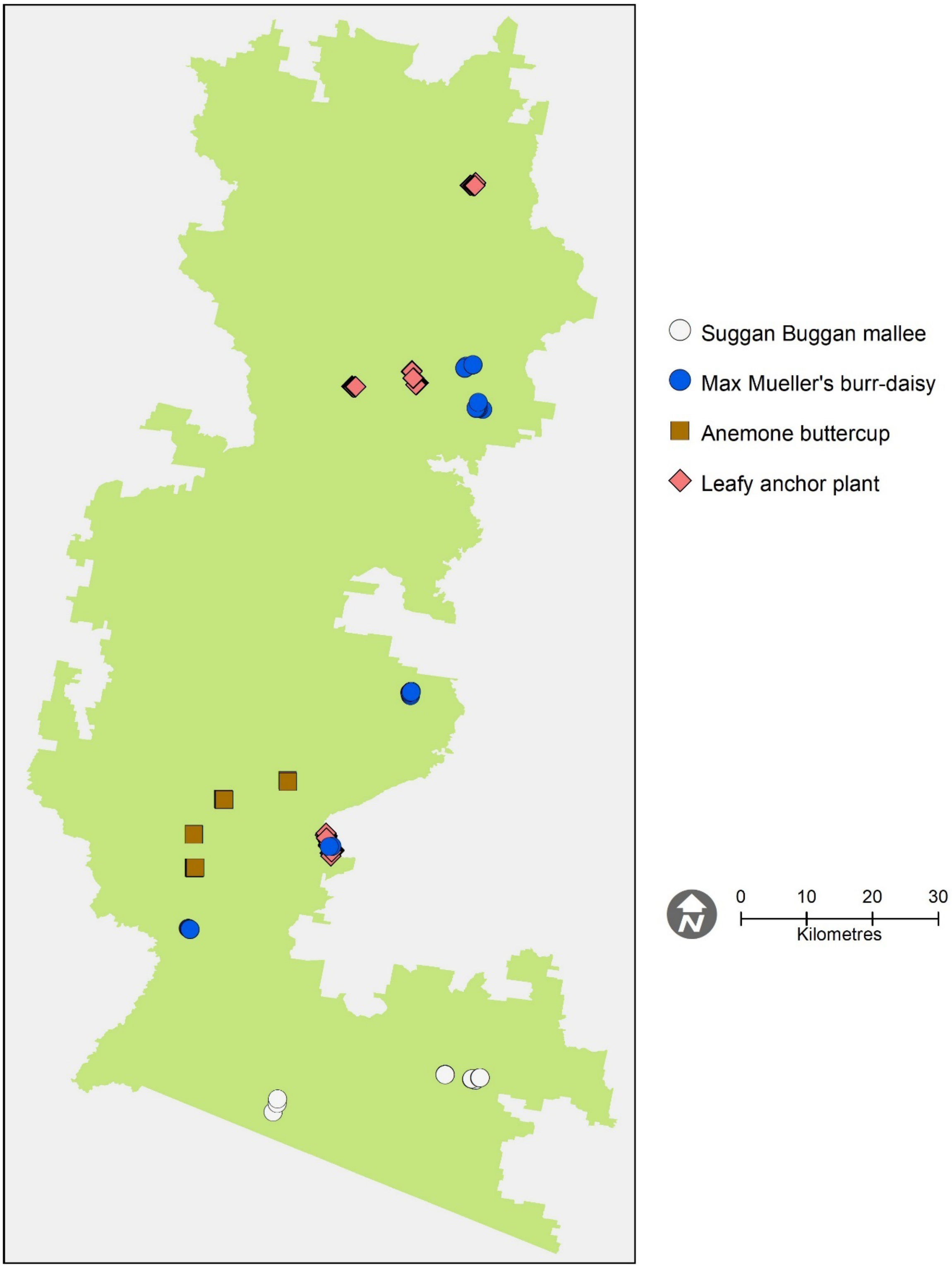


Figure 31 Map of targeted flora monitoring sites for 4 threatened species in Kosciuszko National Park

Anemone buttercup

Conservation context

The anemone buttercup (*Ranunculus anemoneus*) is a perennial herb listed as vulnerable under the Biodiversity Conservation Act and the Environment Protection and Biodiversity Conservation Act. The species is endemic to KNP and is confined to a narrow area (8 km × 32 km) above 1,600 m. The anemone buttercup usually grows in areas with late melting snow and along watercourses, on grassy slopes, in rock crevices or alpine herbfields. The distribution of this species has significantly declined due to cattle and sheep grazing in the alpine areas and populations are still recovering since grazing was removed from these areas in the mid-1960s (Costin et al. 2002). The species is one of the first to flower following snow melt making plants vulnerable to grazing, as herbivores are attracted to the flower buds.

Background

Four monitoring sites which span the known distribution of the anemone buttercup in KNP have been monitored for several years. Within each monitoring site 5 permanent plots (10 × 10 m) have been established. Stem counts, fixed photo points and feral animal sign are recorded in each plot. Between 2019–20 and 2021–22, monitoring of the anemone buttercup identified 2,904 stems in 2019–20 and 5,308 stems in 2021–22. These results indicate a 45% increase in the number of stems between years. However, an increase in the occurrence of feral animal scats (deer, pig, fox and hare) and browsing damage have also been observed across sites and between monitoring seasons (DCCEEW 2024a).

Discussion

The overall monitoring design will be reviewed to generate a metric relevant to the overall KNP population. While short-term changes in stem counts are positive, future surveys are required to determine long-term trends. Short-term changes may be influenced by La Niña climatic conditions. Further, surveys in areas with suitable habitat are needed to increase knowledge on the current distribution of the species in KNP. Future surveys will revisit sites with historical records to determine if populations are persisting. In addition, a review of the monitoring approach will be undertaken to enable an estimate of the relative abundance of the species.

Leafy anchor plant

Conservation context

The leafy anchor plant (*Discaria nitida*) is a deciduous shrub listed as vulnerable under the Biodiversity Conservation Act. The species occurs at elevations above 900 m along riparian corridors in woodlands or treeless grassy plains. In New South Wales it is primarily confined to KNP (DPE 2022c, Appendix 3). Fire is a key threat to this species as plants are generally killed by even low intensity fires, and post-fire recruitment is very low. Herbivory by deer is also a major threat. Other threats to this species include competition from weeds, and flood damage to stream banks.

Background

Annual monitoring is conducted at 4 sites (Boggy Plain, Little Thredbo River, Peppercorn Creek and Racecourse Creek). At each site 30 tagged individuals are monitored for survival, flowering success, and damage from herbivores. One site (Racecourse Creek) was impacted by fire in 2019–20 resulting in a 70% decrease in the number of plants. Other sites have recorded 3–13% declines in the number of plants since the 2019–20 fires.

Survey results from 2020–21 found that of the original 120 tagged plants, only 100 were alive with the greatest loss occurring at the site impacted by the 2019–20 fires (Racecourse Creek). Monitoring in 2022–23 found a similar result, with survey results suggesting that individuals at the Racecourse Creek site continue to be impacted because of fire (2019–20) and post-fire grazing, threatening the persistence of this population. During this monitoring period an increase in feral horse activity was observed in the general area, with associated streambank damage and browsing along streambanks and in wetland areas. This increased activity, particularly along the edges of Racecourse Creek will compromise any recruitment of this threatened species. At the other 3 sites flowering was observed at 50–90% of tagged plants. Overall, 97 of the original 120 tagged plants were alive.

Discussion

The overall monitoring design for this species will be reviewed. It is expected to include annual surveys and seed collection consistent with the current methodology. Monitoring will track changes in plant numbers and recruitment so as to generate a metric relevant to the overall KNP population.

Max Mueller’s burr-daisy

Conservation context

Max Mueller’s burr-daisy (*Calotis pubescens*) is a perennial herb listed as endangered under the Biodiversity Conservation Act. The species has a restricted distribution and was previously known from 4 locations in KNP and one outside of the park (OEH 2021). The species occurs in sub-alpine treeless plains and herb-rich grasslands. Habitat of exceptional value (4,327 ha) has been declared an AIS for this species under section 153G of the National Parks and Wildlife Act. Threats to this species include weed invasion, browsing by feral herbivores, and damage by feral pigs. Dung mounds from horses have the potential to smother patches of this mat-forming forb.

Background

The Max Mueller’s burr-daisy is known to persist at 6 sites in KNP – 4 sites where annual monitoring has been established (Figure 33) and 2 recently discovered sites. The 4 monitoring sites (Botherum Plain, Cascade Plain, Kellys Plain and Nungar Plain) are monitored annually to determine species survival, flowering success and damage from herbivores and pigs. Within each site between 6 and 12 quadrats (10 × 10 m) are established depending on the area the population occupies. Population density is measured using the presence or absence of the species in each 1 × 1 m cell within each quadrat (a frequency out of 100).

In 2021–22, the density of plants across quadrats was 45% and 40% in 2022–23. Survey results from 2020–21 and 2022–23 suggest that populations at the 4 monitoring sites appear to be stable (DPE 2022d). Cascade Plain had an area severely degraded by horses from trampling and dung deposits. In 2021–22 an exclosure fence was established to protect this area from further damage. This fencing also protected an area of montane peatlands which is habitat for the broad-toothed rat, alpine she-oak skink and Max Mueller's burr-daisy.

Horses had previously been identified as a threat in 2020–21 at Nungar Plain. Subsequent monitoring has indicated a decrease in the detection of horse dung at this site. Ox-eye daisy is out-competing Max Mueller's burr-daisy at Kellys Plain and has also been detected sporadically at Nungar Plain.

Discussion

Despite weed incursions impacting some sites where Max Mueller's burr-daisy occur, the population is considered stable and able to maintain a viable population. The 2 newly discovered sites, where the species occurs, will be incorporated into the existing monitoring program which will improve estimates on the number of individuals in the population.

Suggan Buggan mallee

Conservation context

The Suggan Buggan mallee (*Eucalyptus saxatilis*) is a small multi-stemmed tree listed as endangered under the Biodiversity Conservation Act. The distribution of this species in New South Wales has been surveyed and is known only from KNP (AVH accessed 16 January 2024), where it appears to be restricted to the Lower Snowy area (Figure 33). Habitat of exceptional value (1,239 ha) has been declared an AIS for this species under section 153G of the National Parks and Wildlife Act. Threats to this species include inappropriate fire regimes, browsing by feral herbivores and herbivory from native species (especially beetles) resulting in dieback (DPE 2023a).

Background

In KNP Suggan Buggan mallee appears to be restricted to rocky outcrops in remote dry eucalypt forests the Lower Snowy area (Figure 33). The population is currently monitored at 4 locations in KNP – Windmill Hill, Iona, Pilot, and Blackjack. At each site between 30 and 60 individual plants are tagged and monitored for survival, evidence of dieback, seed production, and damage from deer. Survey results from 2020–21 indicated 191 tagged plants persisted, and in 2022–23, 174 tagged plants persist.

Discussion

Current monitoring of this species has been inconsistently applied across sites and across years making it difficult to ascertain population trends. Regular monitoring of species abundance, extent and condition at each site is required to determine population trends through time. Future surveys are planned to be undertaken every 2 years across all sites. The extent and severity of threats should also be monitored to assess the effectiveness of any management actions.

Targeted monitoring: habitat

Montane peatlands (including bogs and fens)

Conservation context

Montane peatlands are listed under the Biodiversity Conservation Act as the *endangered ecological community Montane peatlands and swamps of the New England Tableland, NSW North Coast, Sydney Basin, South-East Corner, South-Eastern Highlands and Australian Alps Bioregions*. Montane peatlands are also listed under the Environment Protection and Biodiversity Conservation Act as *Alpine sphagnum bogs and associated fens*. Montane peatlands cover 6,037 ha in KNP. Sphagnum bogs comprise 61% (3,656 ha) of montane peatlands and are important for carbon sequestration and their water holding capacity. The peat soils that accumulate provide an archive of past change in vegetation and fire regimes and were formed over 17,000 years ago (Hope et al. 2012). Their range has significantly contracted because of previous land use, periodic or long-term drying, inappropriate fire regimes and habitat changes associated with the presence of large feral herbivores, particularly deer and horses.

One of the most important components to protecting peatlands is ensuring sufficient vegetation cover. Peatlands are vulnerable to hydrological changes as they are near their climatic limit and are threatened by declining rainfall and increasing frequency and severity of droughts due to a changing climate (BOM and CSIRO 2022). Increased drying of montane peatlands increases the risk of habitat destruction from wildfire. Over 1,900 ha (26%) of this community was burnt by the 2019–20 bushfires and is at various stages of recovery.

Background

Twenty-six monitoring plots were established in KNP (Figure 34) in 2018 to record ground disturbance, vegetation damage and herbivore presence (native and feral). Eleven of these sites were burnt by the 2019–20 bushfires and were subsequently re-surveyed in 2020. All 26 sites were surveyed again in 2021. Across all 26 sites there were 83 transects (50 × 5 m) with each transect containing 10 quadrats measuring 5 × 5 m. These were established in peatlands spread across the broader distribution of the alpine bog and fen community with a focus on sub-alpine and montane areas. At 2 locations (Big Boggy and Cascades), 14 transects overlapped with known feral horse activity.

The average native vegetation cover across all 26 sites was 87%. The average exotic vegetation cover was 3%. Additional information collected during the monitoring but not reported in the Scorecard metrics include evidence of feral herbivores (scats and tracks), damage to vegetation (herbivory) and features of the landscape (e.g. rocks and bare ground).

Vegetation recovery at fire-impacted sites was generally good. Vegetation condition varied across sites, depending on the presence of feral herbivores, weed species, and the recovery of ground cover post-fire (DPIE 2022a). An increase in feral animal presence was observed. This was expected, as animals colonised the burnt areas where fresh pick was available from regenerating vegetation. The presence of weeds declined, with the early-colonising weeds being outcompeted by slower growing yet more robust native plant species. Significant rehabilitation works were undertaken at the Happy Jacks site with funding provided through the Commonwealth post-bushfire recovery program.

Discussion

Vegetation condition varies across peatland sites in relation to the presence of feral vertebrates, weed species, native fauna and regeneration of ground cover at sites impacted by bushfire. Future work will continue to monitor changes in vegetation cover and the presence of feral herbivores, including feral horses. Surveys will be undertaken every 3 years (in autumn) or immediately following severe impacts such as fire and trampling from feral herbivores. This monitoring will be augmented by satellite and/or aerial imagery to confirm the extent of occurrence of peatlands in KNP compared to existing maps derived by Hope et al. (2012). Monitoring of the peatland sites will continue with funding from the Future Proofing Australia's Alpine Catchments (2023 to 2028) project funded by the Australian Government Natural Heritage Trust and delivered by Local Land Services. This work will compare previous mapping undertaken (Hope et al. 2012) to assess changes in occurrence and condition of this community in KNP. Additional funding will also come from the Kosciuszko Offset Strategy (State of New South Wales and Department of Planning and Environment 2023c).

Alpine ash community

Conservation context

Alpine ash (*Eucalyptus delegatensis*) is an iconic species in the alpine landscape and it is a dominate species in the wet sclerophyll forests of KNP. They are killed by high severity fires (full crown scorch), relying on canopy-held seed to regenerate post-fire and require long fire return intervals to ensure stand persistence. Based on their fire traits, they are sensitive to frequent fire and are at risk of local extinction (Noble and Slatyer 1980). Alpine ash dominated forests occupy 77,050 ha in KNP, representing 76% of the NSW extent (Doherty et al. 2021). In 2003, 64% of the total area of alpine ash in KNP was burnt and in 2020, 33% of the total area of alpine ash was burnt. Of concern is the area burnt by both fires (19,295 ha); allowing only a 17-year recovery time for the species (Doherty et al. 2021). Inappropriate fire regimes impacting alpine ash could result in changes in the structure and function to this community, and in some locations of the park the loss of this species from the landscape as it is replaced by other eucalypt species that have a faster recovery as they resprout after fire.

Background

Eighty-seven 20 × 20m monitoring plots were established between 2008 and 2013 initially to determine changes in floristics, structure and tree dynamics over time in response to the impact of the 2003 fires (Figure 34). Further monitoring was undertaken following the 2019–20 fires, particularly where different fire severities had impacted the species. Re-sampling was undertaken in 2020–21 of monitoring plots burnt by both the 2003 and 2020 fires. Survey results from 2021 observed more seedlings in the high severity sites burnt once (in 2019–20) compared to high severity sites burnt twice (2003 and 2019–20). Some recruitment was observed in the low severity sites, but as these seedlings compete with the intact mature canopy for light and water, they are unlikely to survive and develop into saplings or mature trees.

Discussion

Post-fire monitoring needs to document initial post-fire dynamics in structure and composition. To understand alpine ash regeneration, more information is required on the relative growth rates, time to first flowering and fruiting, and time to establish a canopy seed bank. Ongoing assessment for the first 10 years post-fire of plots which have burnt at high severity will provide information on stand dynamics, the timing of flowering and fruiting, and the persistence of alpine ash in KNP.

Repeat surveys are planned for March 2025 at 21 of the 87 sites established by Doherty et al. (2021). These sites were burnt once or twice in the major bushfires of 2003–04 and 2019–20. In addition, fauna monitoring using audible and ultrasonic acoustic devices will also be deployed at these sites to investigate the effects of fire history and severity on 2 targeted fauna species: the eastern false pipistrelle and yellow-bellied glider.

Figure 32 Targeted monitoring sites for the alpine ash community and montane peatlands in Kosciuszko National Park

Aquatic and biological indicators

Soil health

Conservation context

The humus soils, alpine bogs and fens of the Australian Alps are foundational to water cycling regimes in the Snowy Mountains, as well as an important carbon store (Wilson et al. 2022). Peat bogs are important for holding water and moderating runoff in sub-alpine catchments, and filter sediments through surface vegetation to release clear water (Hope et al. 2009). They are an important resource for wildlife though dry periods due to their retention of water and moist vegetation. Peat bogs are fire sensitive and vulnerable to hydrological changes caused by trampling by feral herbivores.

There is limited information available on the status of soils in KNP or an understanding of the impact of threats such as fire have on soil communities and soil health (Wilson et al. 2022). The soils of KNP are in a state of recovery from past land use such as cattle grazing. They are also vulnerable to climate change and ongoing disturbance from hoofed animals such as feral horses, pigs and deer resulting in areas of soil erosion in the park.

Methods and results

Soil samples were taken randomly from 4 to 5 plots within 95 of the park-wide surveillance monitoring sites during vegetation surveys. Soil was sampled using a soil corer (0–10-cm core with a 4-cm, 5-cm or 10-cm diameter) and combined. Four core samples were taken to measure soil composition (total nitrogen, phosphorus, pH, total organic carbon) and one core sample for bulk density (to calculate tonnes of carbon per ha). Samples were analysed by the department's Soil and Water Monitoring Laboratory, Yanco.

In general, nitrogen and phosphorus were higher in soils from the alpine complex (N = 7,686 mg/kg, P = 79 mg/kg) and the grassy woodland (N = 6,209 mg/kg, P = 44 mg/kg) vegetation formations (Figure 35), although there was considerable variability between sites (Figure 36, Figure 37, and Figure 38).

Total organic carbon and tonnes of carbon per ha were highest in the alpine complex (116 g/kg, 71 tonnes/ha) and grassy woodland (109 g/kg, 97 tonnes/ha) formations and lowest in the dry sclerophyll forest formations (shrubby sub-formation: 42 g/kg, 45 tonnes/ha; shrub/grass sub-formation: 26 g/kg, 54 tonnes/ha). However, there was greater variability in total organic carbon between sites within alpine complex, grassy woodlands and wet sclerophyll forest vegetation formations than within the dry sclerophyll forest formations (Figure 35).

Soils at 4 of the 5 vegetation formations (alpine complex, dry sclerophyll forest [shrubby sub-formation], grassy woodland, and wet sclerophyll forest [grassy sub-formation]) were slightly acidic to acid (pH<4.8). Soils in dry sclerophyll forest (shrub/grass sub-formation) had a more neutral pH (median of 5.6).

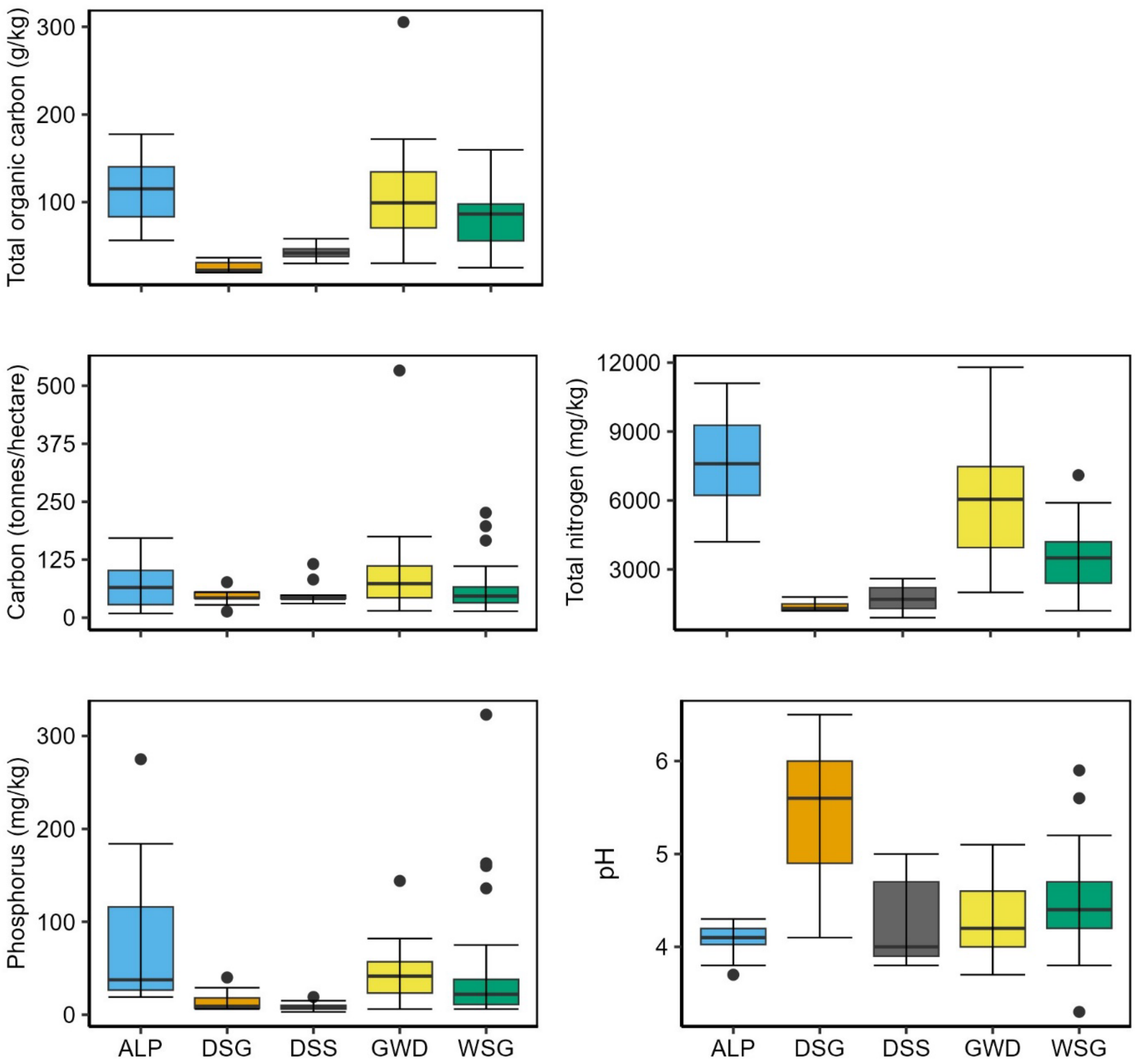


Figure 33 Boxplots summarising soil properties (total organic carbon, carbon, total nitrogen, phosphorous, and pH) by each major vegetation formation in Kosciuszko National Park in 2023

Lower and upper bounds of each coloured boxes represent the 25th and 75th percentile respectively (the interquartile range), and the thick horizontal line within the coloured box indicates the median value. Error bars represent the largest and smallest value within 1.5 times the 75th and 25th interquartile respectively. Black circles are outliers >1.5 and <3 times the interquartile range. ALP = alpine complex, DSG = dry sclerophyll forest (shrub/grass sub-formation), DSS = dry sclerophyll forest (shrubby sub-formation), GWD = grassy woodland, and WSG = wet sclerophyll forest (grassy sub-formation).

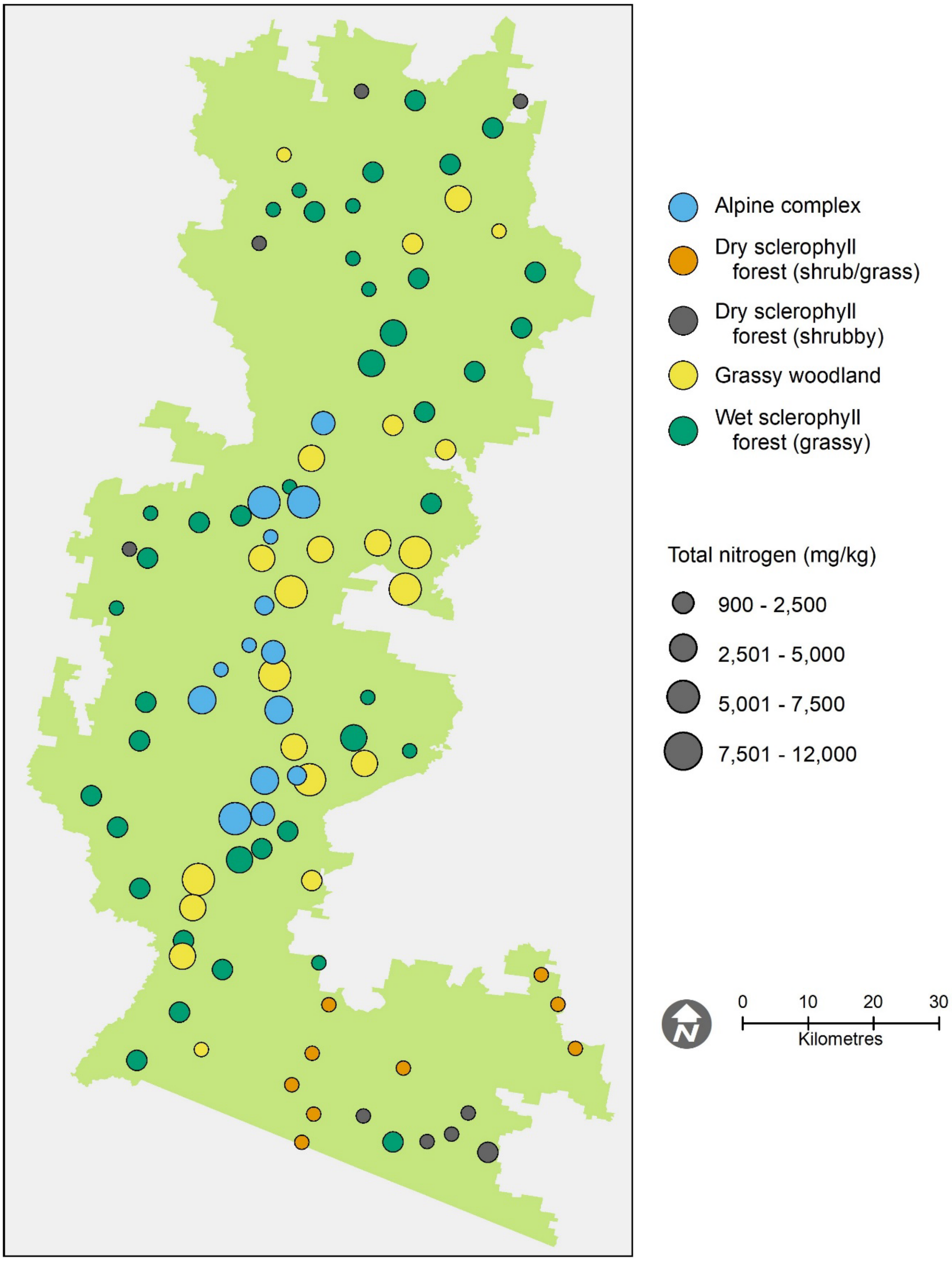


Figure 34 Total nitrogen (mg/kg) by each major vegetation formation in Kosciuszko National Park

Symbol sizes are graduated by the amount of total nitrogen recorded at each site; larger symbols indicate more total nitrogen levels present.

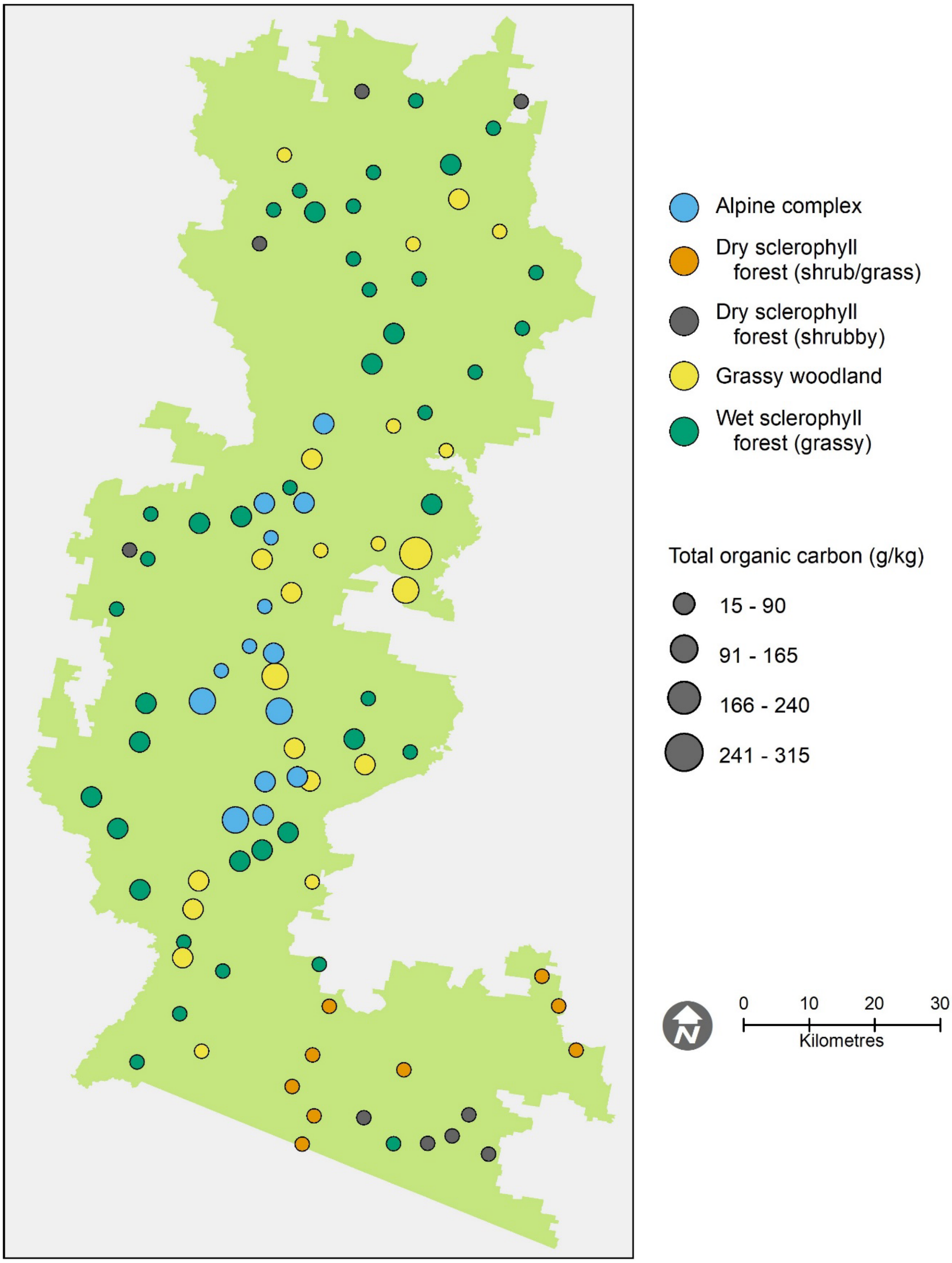


Figure 35 Total organic carbon (g/kg) by each major vegetation formation in Kosciuszko National Park

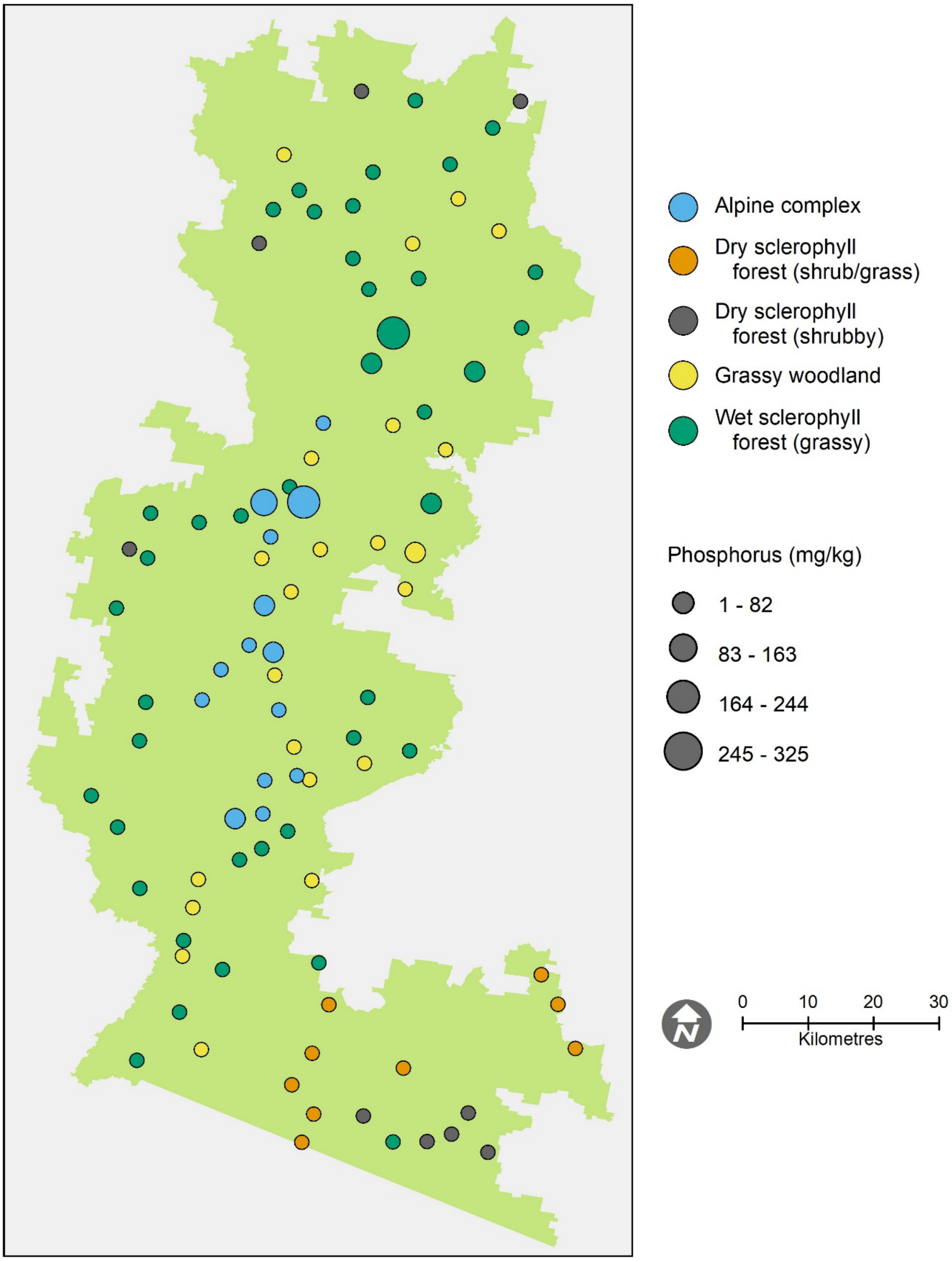


Figure 36 Total phosphorus (mg/kg) by each major vegetation formation in Kosciuszko National Park

Discussion

Total nitrogen, phosphorus and organic carbon were highest in the alpine complex sites, which tend to have humus soils developed from the breakdown of organic material (i.e. decomposing plant material). These soils are an important store of carbon and are susceptible to soil erosion by feral deer and horses. Total nitrogen, phosphorus and organic carbon were also high in grassy woodland sites. Regular monitoring of soil parameters will be undertaken to assess changes over time with respect to the removal of feral animals in KNP.

Waterway health

Conservation context

The major catchments of the Snowy, Murrumbidgee, Tumut and Murray Rivers provide important ecological services for KNP. However, the riparian areas and waterways of the park are heavily impacted by large feral herbivores, primarily horses and deer. These impacts are well documented and include changes in riparian vegetation, increased soil compaction and damage to soft structures such as sphagnum bogs (Hope and Clark 2008; Robertson et al. 2019; Scanes et al. 2021). Horses are known to favour areas associated with water, such as valley bottoms and stream-side areas with low vegetation (Dawson 2009; Scanes et al. 2021). Deer are also more likely to be detected closer to water (Hartley et al. 2022). Other activities that may impact water quality in KNP include changes to hydrology due to dams, weirs and infrastructure for hydroelectric power generation and recreational activities such as snow sports, mountain biking, hiking and horse riding.

Methods

In 2023 and 2024, water samples were collected at 54 sites across KNP (Figure 39), comprising 19 alpine stream sites and 35 upland river sites. Surveys were undertaken in autumn 2023 and 2024 and at a subset of sites (34) in spring 2023. Survey methods were based on a river health stressor-response model developed and implemented by the DCCEEW Estuaries and Catchments Science Team and followed the Standards Association of Australia (1998) protocols for water quality and NSW AUSRIVAS (Turak et.al. 2004) sampling and assessment protocols for macroinvertebrates and associated habitat. Samples were sent to the National Association of Testing Authorities (NATA) accredited laboratory for analysis of nutrients.

Trigger values are used to assess risks of adverse effects due to chemical, physical and biological attributes in different ecosystem types. Compliance against a guideline or trigger value is used to assess the status of an indicator and determine when an indicator is outside an expected range (Table 10). The default guideline values provided in Water Quality Management Framework in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018) were used for chemical and physical attributes for upland rivers (>150 <1500 m above sea level). Guideline values were obtained from Victoria for alpine streams (>1500 m above sea level). Guideline values for macroinvertebrate indicators were derived from a data set that included data across the KNP area from a number of historic monitoring programs.

Table 10 Water quality guidelines applied to upland streams are taken from the (ANZG, 2018) and ANZECC (2000) guidelines, and guidelines applied to alpine streams are taken from Victorian alpine streams. Guidelines for macroinvertebrates derived from historical data

Water quality parameter	Unit	Guideline values	
		Upland	Alpine
Ammonia	µg N/L	13	13
Dissolved oxygen	% saturation	90 - 110	90 - 110
Electrical conductivity	µS/cm	55	30
Nitrogen oxides	µg/L	15	15
Turbidity	NTU	2 (low flow) 25 (high flow)	2
Total phosphorus	µg/L	20	10
Total nitrogen	µg/L	250	100
Taxa richness		Edge: 20 Riffle: 15	Edge: 20 Riffle: 15
EPT richness		Edge: 9 Riffle: 6	Edge: 9 Riffle: 6
SIGNAL2		Edge: 5.5 Riffle: 5.7	Edge: 5.5 Riffle: 5.7

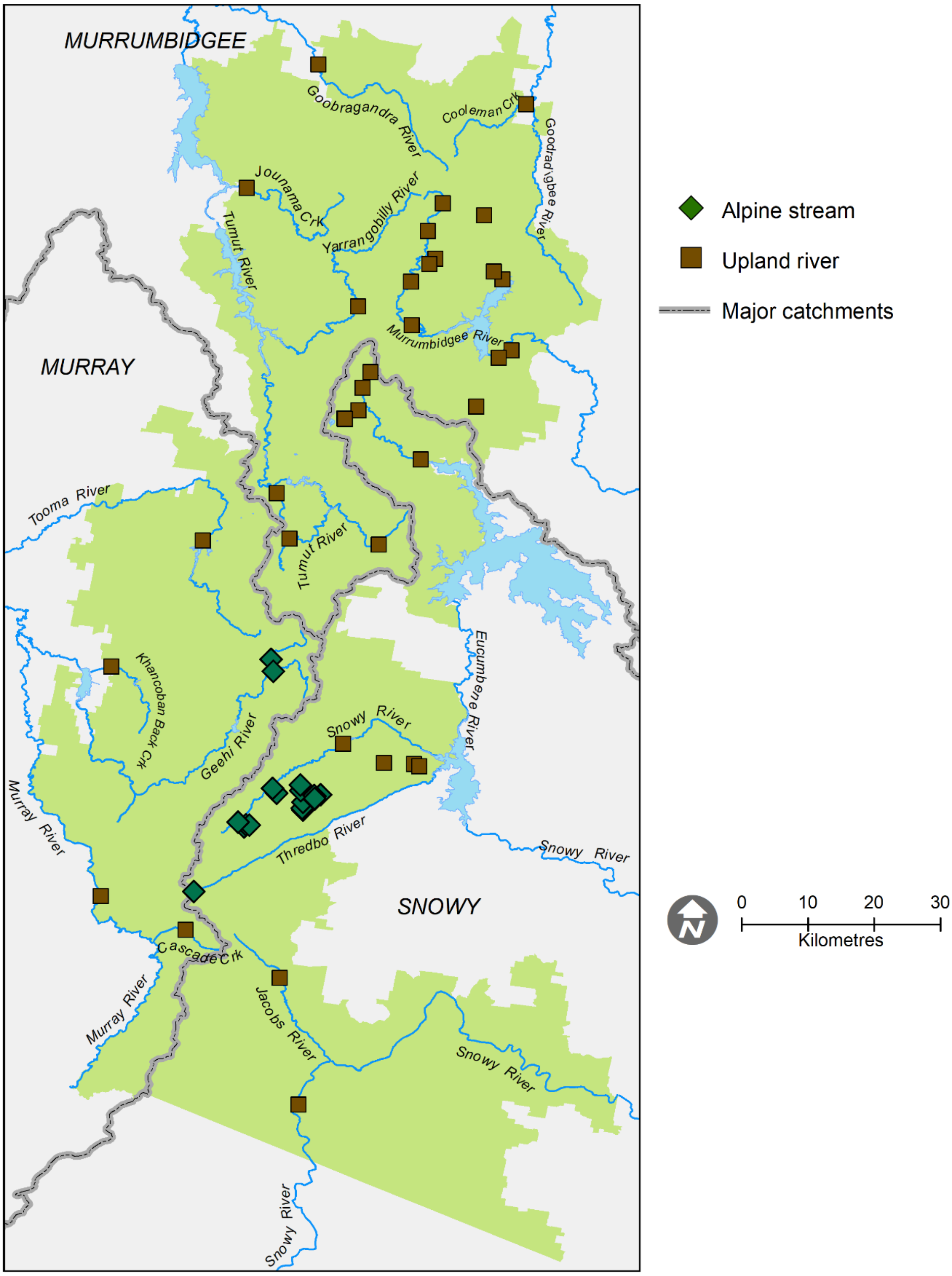


Figure 37 Water monitoring sites within Kosciuszko National Park showing the locations of alpine streams (green diamonds) and upland rivers (brown squares). Major catchments (Murray, Snowy and Murrumbidgee) are labelled in italicised capitals

Results

The water monitoring program assesses the impact of environmental stressors, measured by chemical and physical water quality attributes, on the biological condition, as determined by benthic macroinvertebrate communities. Environmental stressors include nutrients, salinity and water clarity which, in high concentrations, can cause decline in macroinvertebrate diversity and pollution-sensitive taxa, resulting in decreased stream health.

Of the 54 monitoring sites, 43 (80%) recorded one or more environmental stressor attributes outside guideline levels, of these 20 (37%) recorded 2 or more attributes outside guideline levels:

- 16 (84%) of 19 alpine streams exceeded trigger levels for one or more of the measures, and 9 (17%) exceeded 2 or more
- 27 (77%) of 35 upland rivers exceeded trigger levels for one or more of the measures, and 11 (31%) exceeded 2 or more.

Of the 54 monitoring sites, 19 sites (35%) recorded one or more biological condition attributes outside guideline levels, of these 10 (19%) recorded 2 or more attributes outside guideline levels:

- 5 (26%) of 19 alpine streams where outside one or more of the guideline levels, and one site was outside 2 or more
- 14 (40%) of 35 upland rivers where outside one or more of the guideline levels, and 9 (26%) was outside 2 or more.

Several factors within KNP contribute to water quality levels failing to meet guideline values including historical land use, feral herbivore (including horse) impacts and wastewater inputs from tourist resort areas. Sites that recorded 2 or more environmental stressor attributes outside the guidelines were observed in several areas: areas where horse abundance has been high, around resort areas, and at least 1 site where both fire and pig activity have impacted the site. Sites that recorded 2 or more biological condition attributes outside the guidelines were predominantly observed in areas with impacts from horses and tourist infrastructure.

Environmental stressor and biological condition attributes are discussed below.

Turbidity

Turbidity is a measure of the light scattered by materials suspended in water and affects the amount of light available to aquatic plants and benthic algae for photosynthesis. High measures of turbidity can indicate changes in stream bank stability, erosion, impacts from feral herbivores (horses), or impacts from humans, especially infrastructure where land surfaces become disturbed.

Acceptable guidelines for turbidity vary depending on the type of water body and whether it is sampled during periods of low or high flow. High flow events resulting from heavy rains can mobilise and transport sediments resulting in higher measures of turbidity.

Turbidity levels were at or in excess of low flow trigger levels at 26 (48%) of the 54 sites (Table 10, Figure 40a):

- 3 of 19 (16%) alpine streams
- 23 of 35 (66%) upland river sites.

Values did not exceed high flow trigger levels during high flow events (Figure 40b).

High levels of turbidity were predominately found in upland river sites. Of particular note, turbidity exceed acceptable/trigger levels at 13 of 16 sites being monitored for horse impacts in the Murrumbidgee and Snowy catchments. These measures were taken prior to substantial horse removal.

Dissolved oxygen

Dissolved oxygen is the measure of the amount of oxygen that is present in water and indicates how much is available for aquatic organisms. Both low and high values of dissolved oxygen can have implications for ecosystems.

Low values of dissolved oxygen can indicate the presence of organic pollutants (human and animal waste, decaying plant material) that consume oxygen during decomposition. Low values result in less oxygen available for cellular respiration and can lead to anoxic conditions, most likely in sediments. High values can also be an issue and are often caused by high nutrient loads, especially phosphate, that promote increased cellular respiration and algae growth which can smother aquatic habitats and force changes in macroinvertebrate community composition, as benthic fauna that graze algae may benefit while others can be smothered or trapped in filamentous algae.

Dissolved oxygen levels were outside trigger levels for 2 sites (4%) of the 54 sites (Table 10, Figure 41).

- 1 (5%) of 19 alpine streams, and
- 1 (3%) of 35 upland river sites.

Nitrogen

While nitrogen is a key nutrient for plant growth, when in excess it can lead to harmful algal blooms and eutrophication. High levels can indicate contamination from sewage or animal waste.

Total nitrogen levels were at or in excess of trigger levels at 20 (37%) of the 54 sites (Table 10, Figure 42):

- 16 of 19 (84%) alpine streams, and
- 4 of 35 (11%) upland river sites.

Total nitrogen levels were above guidelines for most alpine stream sites within the Snowy and Murray catchments. Few upland river sites exceeded guidelines with 3 sites in the Murrumbidgee catchment and one in the Snowy.

High nitrogen levels were predominately observed in the area being monitored for impacts from the ski resorts, with 87% of these sites recording levels of total nitrogen which exceed the recommended guideline for this ecosystem type (ANZG 2018). Excess nutrient loads can increase eutrophication (excessive growth of algae in water), harm aquatic life and indicate pollution.

Phosphorus

Phosphorus is another essential nutrient for plant growth but is often a limiting nutrient for their growth in freshwater systems. When in excess, high levels of phosphorus cause harmful algal blooms and eutrophication. High levels can indicate contamination from sewage or animal waste, or excessive input of organic matter due to catchment disturbance such as fire, feral herbivores and human activity.

Total phosphorus levels were at or in excess of trigger levels at 7 (13%) of the 54 sites (Table 10, Figure 43):

- 3 (16%) of 19 alpine streams, and
- 4 (11%) of 35 upland river sites.

Total phosphorus levels were above the guidelines for alpine streams in the Snowy catchment in close proximity to the ski resorts. For upland rivers, levels were above guidelines in the Murrumbidgee catchment.

Nitrogen oxides

Nitrogen oxides (nitrate (NO_3^-) and nitrite (NO_2^-)) are dissolved forms of nitrogen that are transported with flowing waters and are among the most available forms of nitrogen for uptake by plants. Elevated levels of nitrogen oxides can be an indicator of pollution from sewage treatment plant discharge or agricultural and industrial wastewater discharges.

Nitrogen oxides levels were at or in excess of trigger levels at 21 (39%) of the 54 sites (Table 10, Figure 44):

- 8 (42%) of 19 alpine streams, and
- 13 (37%) of 35 upland river sites.

High levels of nitrogen oxides were predominately observed in alpine streams in the area being monitored for impacts from the ski resorts, with some upland rivers across the Murrumbidgee, Snowy and Murray catchments also recording high levels. Excess nutrient from nitrogen oxides can increase eutrophication (excessive growth of algae in water) and harm aquatic life.

Ammonia

Ammonia is produced during the aerobic decomposition of organic matter by bacteria. High concentrations in waters can indicate pollution from human sources such as sewage treatment plant discharge, or in areas where feral herbivores may have direct access to waterways. Ammonia is toxic to aquatic life.

Ammonia levels were at or in excess of trigger levels at 3 (9%) of the 54 sites (Table 10, Figure 45):

- 2 (11%) of 19 alpine streams, and
- 1 (3%) of the 35 upland river sites.

Ammonia was above the guidelines at 3 sites in the snowy river catchment. In generally most waterways in KNP have not exceeded the guidelines for this indicator of water quality.

Electrical conductivity

Electrical conductivity is a property which is influenced by the presence of dissolved salts and other inorganic chemicals in the water. Elevated levels may be an indicator of broad-scale land disturbance or may indicate discharges from sewage treatment plants, industrial or other human sources such as salting of roads for de-icing around ski resort areas during winter. Many aquatic organisms are sensitive to changes in salinity and elevated levels may inhibit plant and animal growth. Prolonged exposure to elevated levels can lead to decline or changes in macroinvertebrate community composition and ecosystem processes.

Electrical conductivity levels were at or in excess of trigger levels at 4 (7%) of the 54 sites (Table 10, Figure 46):

- 0 of 19 alpine streams
- 4 (11%) of 35 upland river sites.

Electrical conductivity was above the guidelines for 3 upland river sites in the Murrumbidgee catchment and one in the Snowy catchment. Electrical conductivity levels did not exceed the guidelines in any of the alpine stream sites. In general, most waterways in KNP have not exceeded the guidelines for this indicator of water quality.

Macroinvertebrates

Macroinvertebrates are an important biological response variable of riverine aquatic ecosystems. Samples are typically collected at 2 locations in streams, one on the stream edge in slow flowing areas and among overhanging and instream vegetation, and the other in stream riffles, where fast flows over boulders and cobbles occur. Three indices are used to assess macroinvertebrate diversity and sensitivity to pollution, as follows:

- Taxa richness reports the number of different macroinvertebrate species in a sample,
- EPT richness measures the diversity of three orders of aquatic insects: Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). These groups are generally considered to be sensitive to changes in aquatic habitat and water quality conditions than other macroinvertebrate groups,
- Stream Invertebrate Grade Number Average Level (SIGNAL) Version 2 (Chessman 2003) is a simple scoring system for macroinvertebrates of Australian rivers. SIGNAL is a biotic index based on pollution sensitivity values (grade numbers) assigned to aquatic macroinvertebrate families that have been derived from published information on their tolerance to pollutants, such as sewage and nitrification (Chessman 1995). Each taxon is assigned a grade from 1 (tolerant) to 10 (sensitive) based on eco-toxicity assessment data. The average of the grades for each site is used as the SIGNAL2 score.

The average macroinvertebrate taxa richness was 24 (range 16–31) and EPT richness 10 (range: 6–15). The average SIGNAL2 score across sites was 6 (range: 4–7).

Guideline values for macroinvertebrate indices differ dependent on the sample type (edge or riffle) and were derived for KNP (Table 10).

- Taxa richness was outside guidelines for either edge or riffle samples at 9 sites (17%), including 2 alpine stream and 7 upland river sites (Figure 47 and Figure 48).
- EPT richness was outside guidelines for either edge or riffle samples at 11 sites (20%), including one alpine stream and 10 upland river sites (Figure 47 and Figure 48).
- SIGNAL2 scores were outside guidelines for either edge or riffle samples at 12 sites (22%), including 3 alpine streams and 9 upland river sites (Figure 47 and Figure 48).

EPT richness and SIGNAL2 scores were lowest at sites impacted by horses and those downstream of tourist infrastructure and indicate poor water quality or habitat degradation.

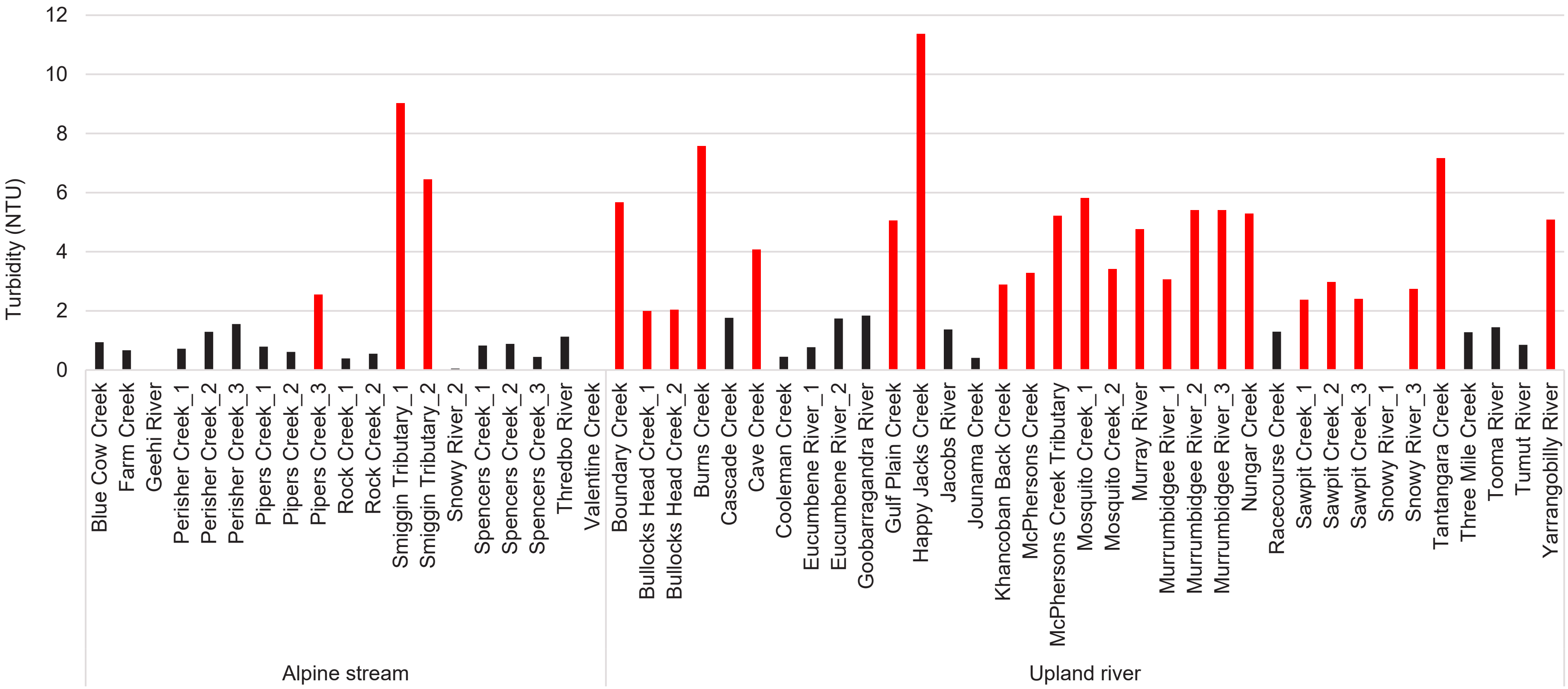
Discussion

Several waterways in KNP recorded elevated nutrient levels. Many alpine stream sites are impacted by tourist activities, stormwater and snow melt runoff from hard surfaces (carparks and roads in the resort areas), and one site downstream from the resort village and sewage treatment plant at Charlotte Pass. Elevated nutrient levels were also recorded at upland river sites downstream of Snowy Hydro infrastructure (Murrumbidgee River downstream of Tantangara Reservoir and Tooma River downstream of Tooma Dam).

Sites being monitored for horse impacts observed increased turbidity in areas under high horse activity resulting in increased stress on sensitive macroinvertebrate taxa, particularly in the edge habitat areas where horse activity leads to streambank degradation, and sedimentation.

Future analysis of water monitoring data will include statistical modelling approaches to assess changes in water quality and biological response attributes over time and in relation to environmental variables.

(a) Low flow events



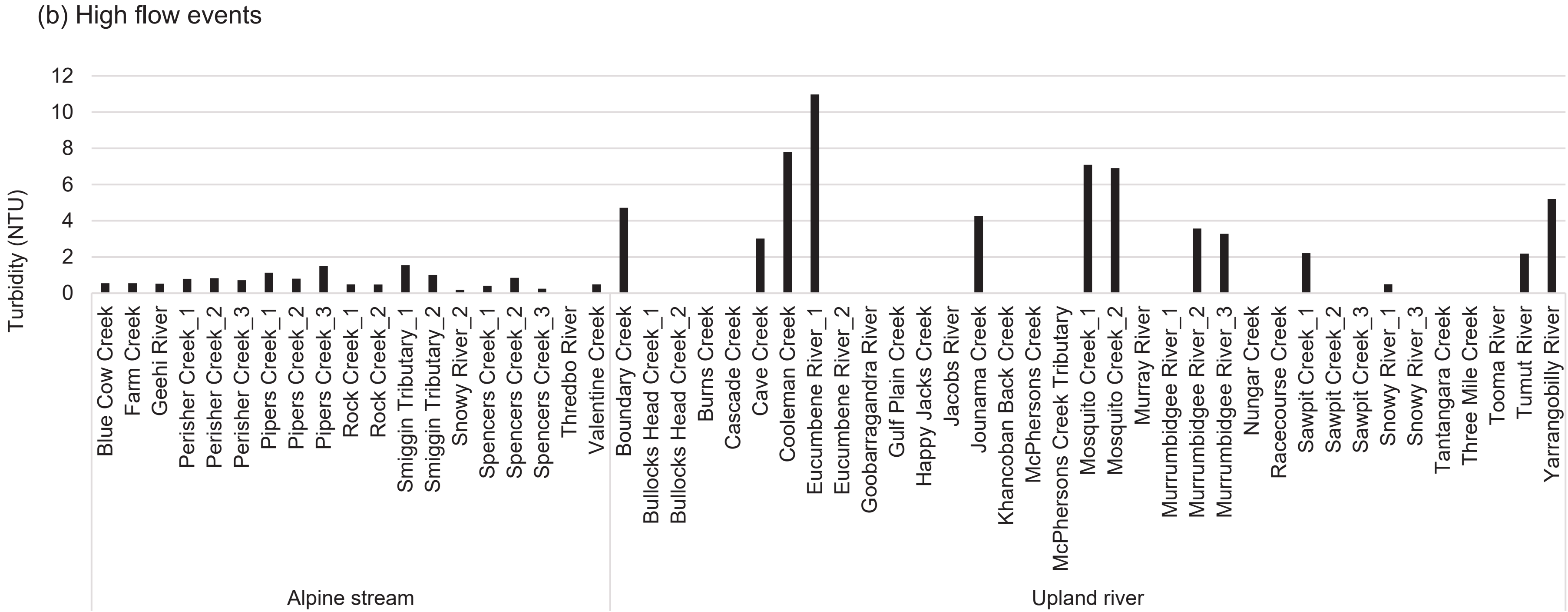


Figure 38 Turbidity for upland rivers and alpine streams in Kosciuszko National Park during (a) low flow and (b) high flow events, sampled in autumn 2023 to autumn 2024. Results (red) show sites outside the water quality guidelines (ANZG, 2018)

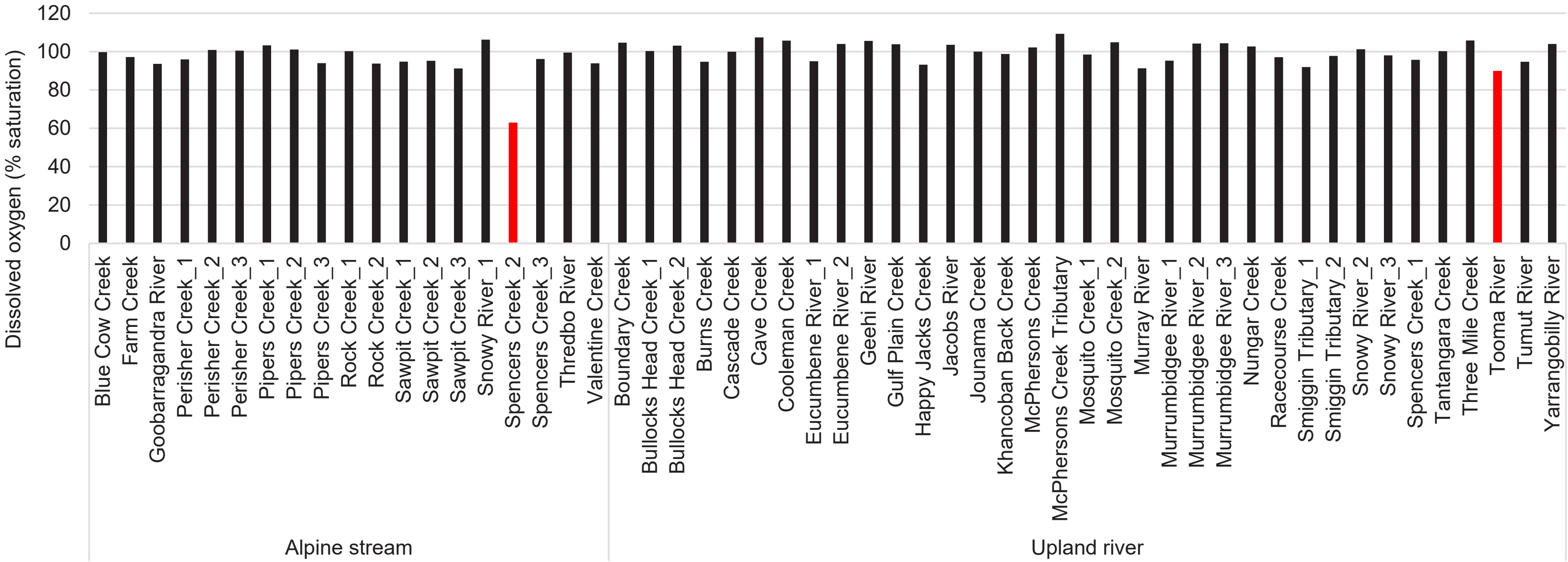


Figure 41 Dissolved oxygen for upland rivers and alpine streams in Kosciuszko National Park, sampled in autumn 2023 to autumn 2024. Results (red) show sites outside the water quality guidelines (ANZG, 2018)

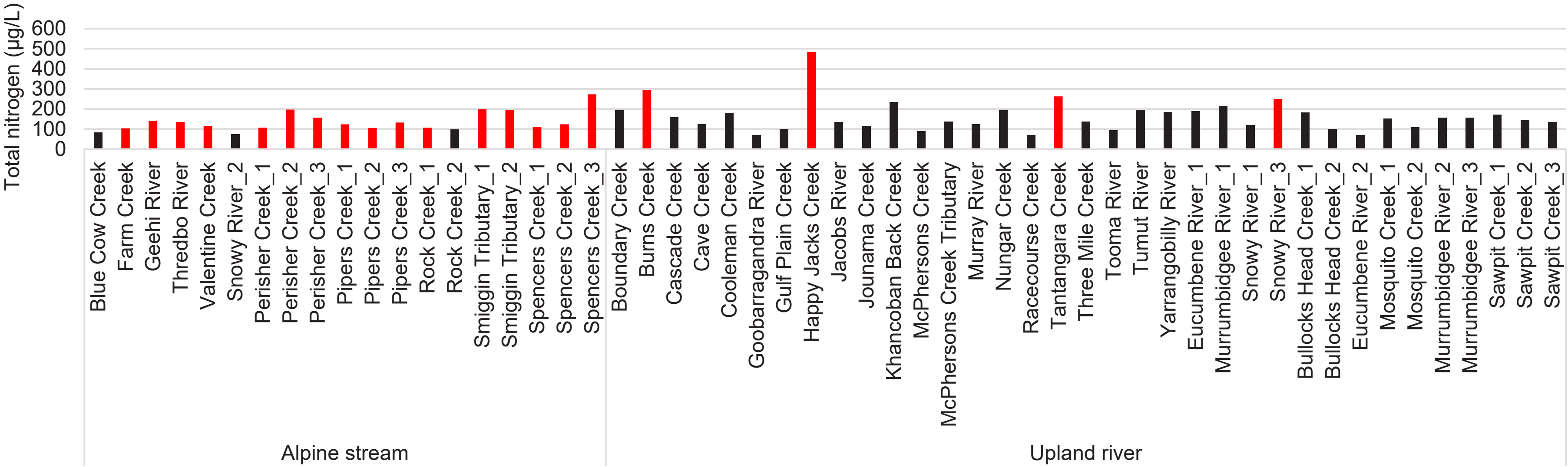


Figure 39 **Total nitrogen for upland rivers and alpine streams in Kosciuszko National Park, sampled in autumn 2023 to autumn 2024. Results (red) show sites outside the water quality guidelines (ANZG, 2018)**

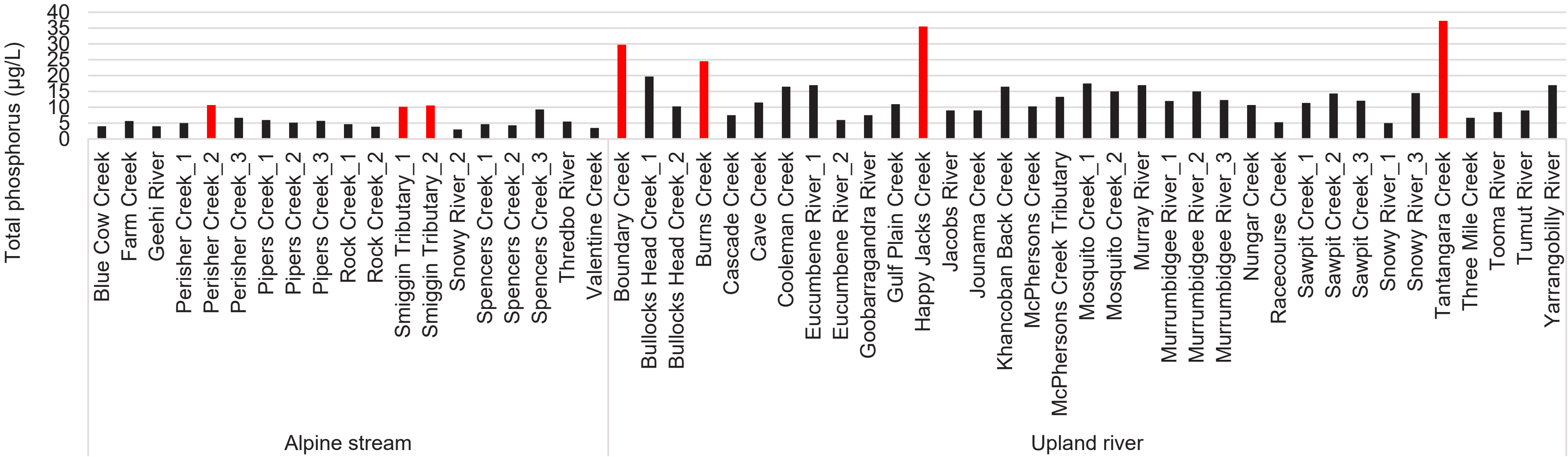


Figure 40 Total phosphorus for upland rivers and alpine streams in Kosciuszko National Park, sampled in autumn 2023 to autumn 2024. Results (red) show sites outside the water quality guidelines (ANZG, 2018)

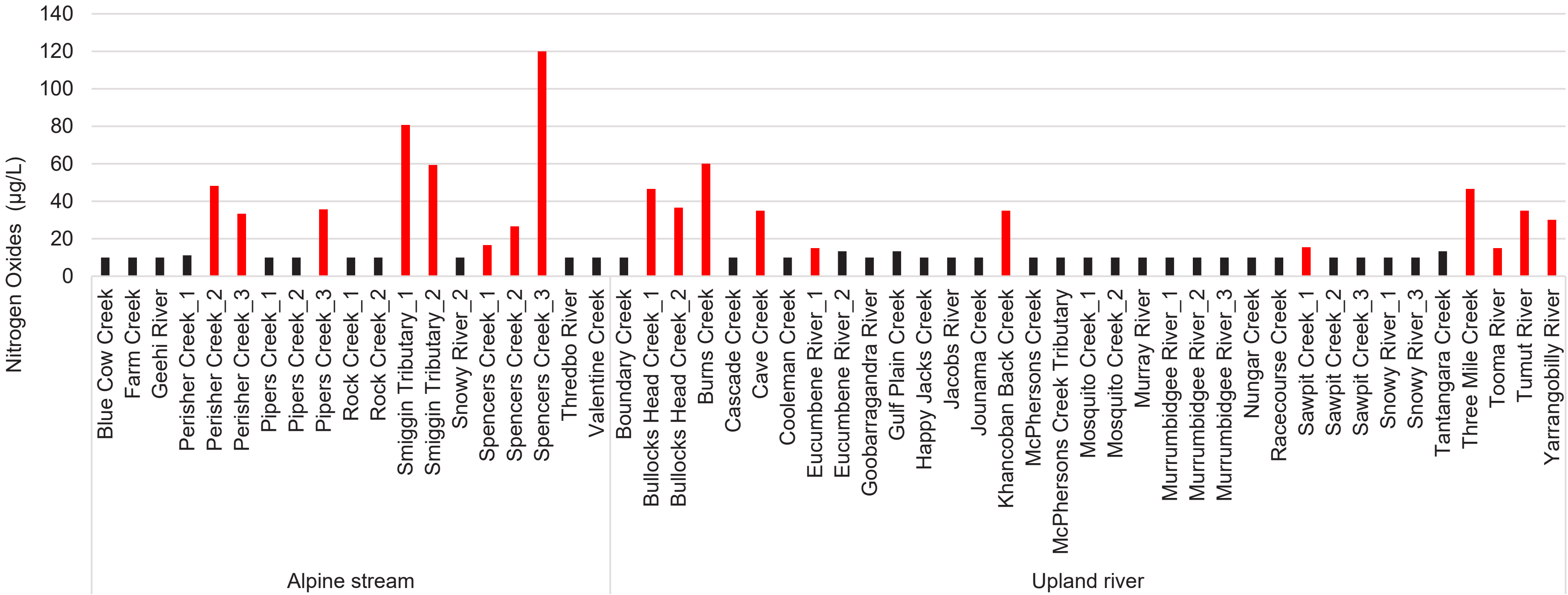


Figure 41 Nitrogen oxide levels for upland rivers and alpine streams in Kosciuszko National Park, sampled in autumn 2023 to autumn 2024. Results (red) show sites outside the water quality guidelines (ANZG, 2018)

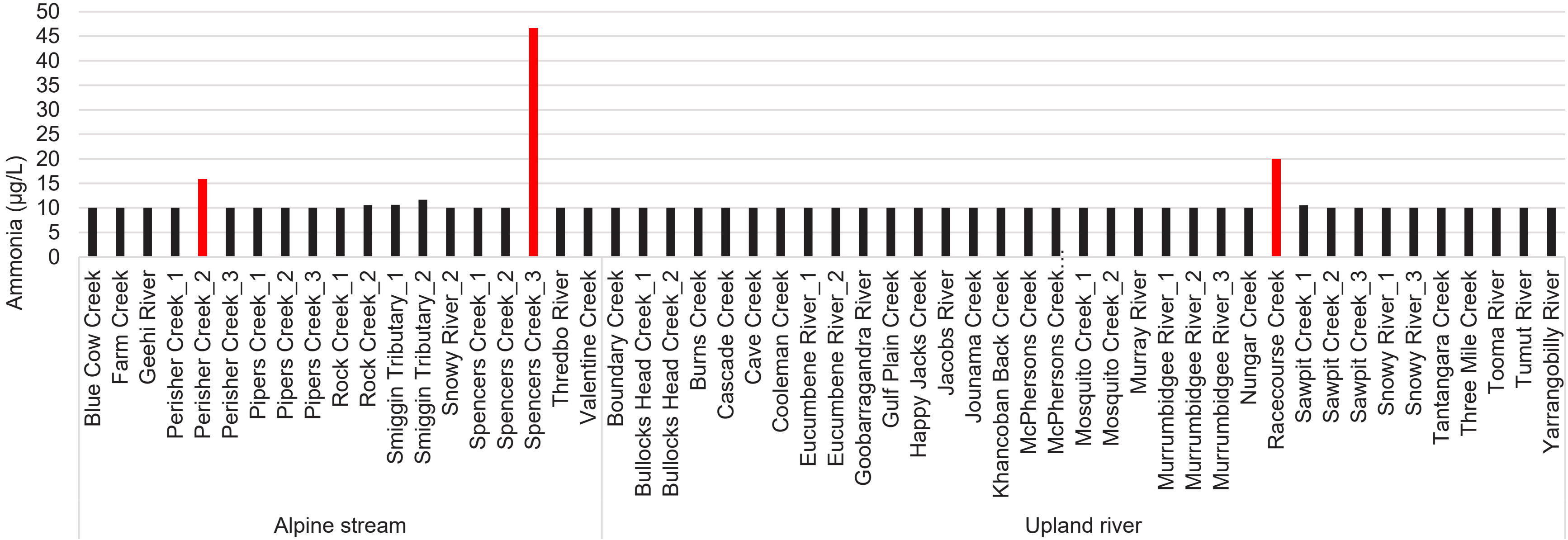


Figure 42 Ammonia levels for upland rivers and alpine streams in Kosciuszko National Park, sampled in autumn 2023 to autumn 2024. Results (red) show sites outside the water quality guidelines (ANZG, 2018)

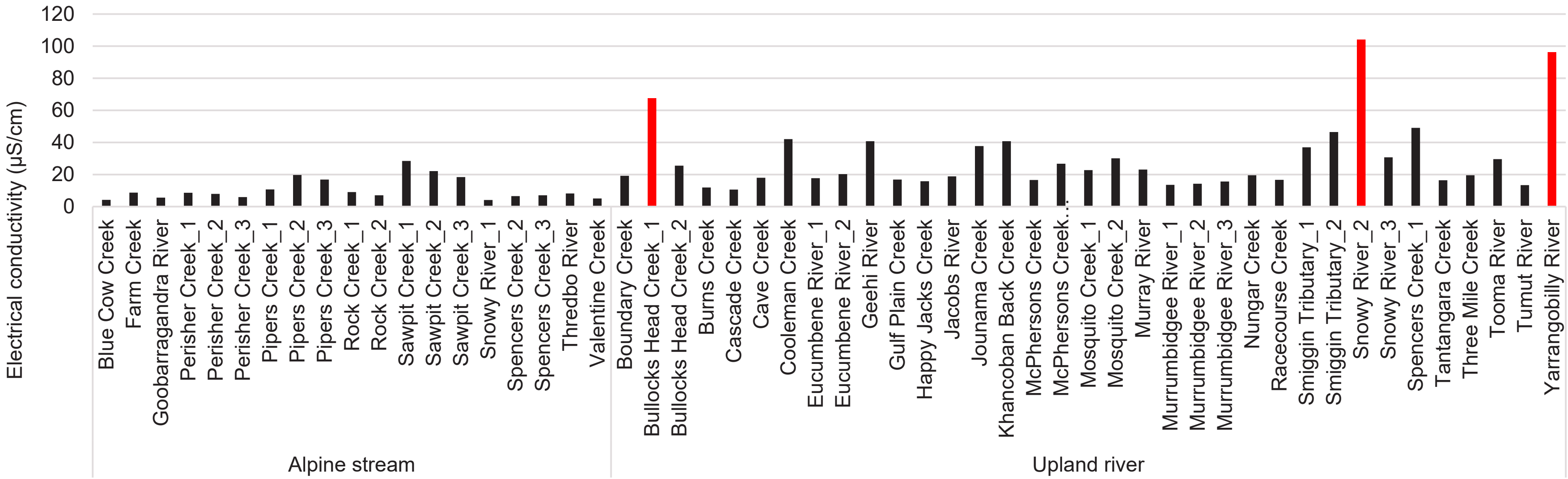


Figure 43 Electrical conductivity for upland rivers and alpine streams in Kosciuszko National Park, sampled in autumn 2023 to autumn 2024. Results (red) show sites outside the water quality guidelines (ANZG, 2018)

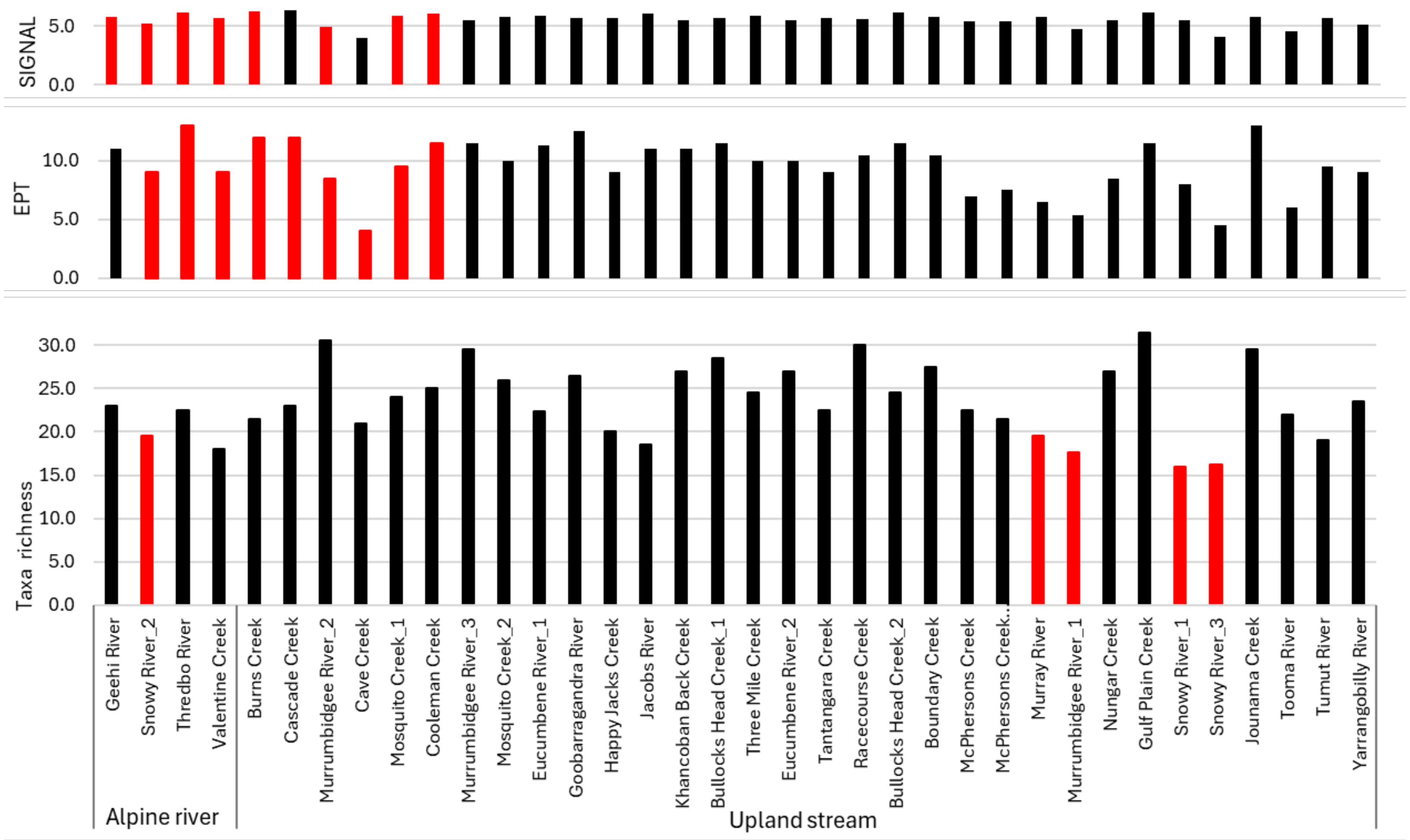


Figure 44 **Edge habitat macroinvertebrate richness, EPT and SIGNAL in Kosciuszko National Park, from autumn 2023 to autumn 2024. Results (red) show sites outside the water quality guidelines (ANZG, 2018)**

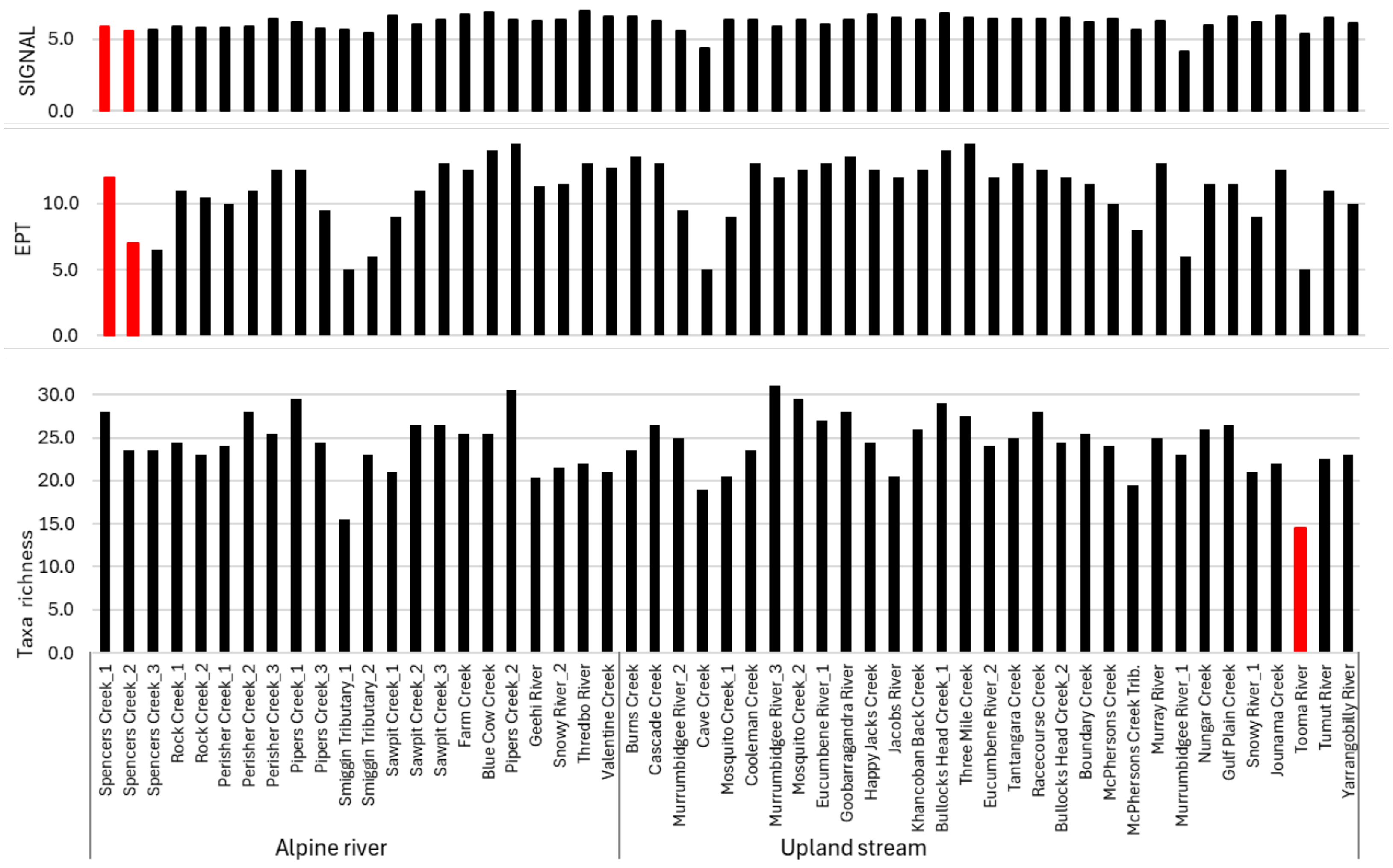


Figure 45 **Riffle habitat macroinvertebrate richness, EPT and SIGNAL in Kosciuszko National Park, from autumn 2023 to autumn 2024. Results (red) show sites outside the water quality guidelines (ANZG, 2018)**

Park-wide threats: feral animals

Feral animal species are critical to manage and monitor across NSW parks due to their impacts on native species and/or habitats. Trampling and browsing damage by feral herbivores can result in severe habitat degradation and loss, and impacts of feral predators on Australian fauna are pervasive.

Of the 11 feral animals known to occur in KNP, park-wide surveillance sites are used to monitor 10 species (Table 11). The feral goat is known to be present but at low numbers and at just a few locations in KNP. This represents a relatively high number of introduced species. By comparison, only 2 feral animal species (fox and rusa deer) were detected in the RHG Scorecard program during park-wide surveillance monitoring. Feral cats and foxes, as well as sambar deer, were widespread across KNP (>40% modelled occupancy) while fallow deer, pigs and rabbits were detected at around 20% of survey sites. Horses are also widespread, occurring across an estimated 53% of KNP (DPE 2023b).

Monitoring will be guided by protocols developed for each feral animal species to ensure a standard approach in survey design and reportable metrics across NPWS. These will ensure consistent and scientifically robust monitoring. This is important because the inability to detect a species if it is in fact present at a site increases uncertainty in reportable metrics. For example, detection probabilities based on the 4 different camera set-ups used in the park-wide surveillance monitoring program demonstrate how survey methods can influence the probability of detection of different species (Figure 49). Fallow deer and sambar deer were the only 2 species that showed evidence of an improved daily detection probability using an infra-red camera aimed 4 metres away (IR400).

Table 11 Feral animal occupancy and activity in Kosciuszko National Park, 2022–23

Species	Naive occupancy	Modelled occupancy	Activity*
Black rat	15%	-	-
Fallow deer	20%	23%	7.1 (± 1.7)
Feral cat	40%	46%	1.3 (± 0.2)
Goat	0%	-	-
Hare	14%	-	-
Horse*	-	-	-
Pig	19%	23%	
Rabbit	21%	22%	-
Red deer	1%	-	-
Red fox	38%	41%	3.6 (± 0.8)
Sambar deer	42%	45%	2.2 (± 0.4)

*horses are monitored under a dedicated targeted monitoring program

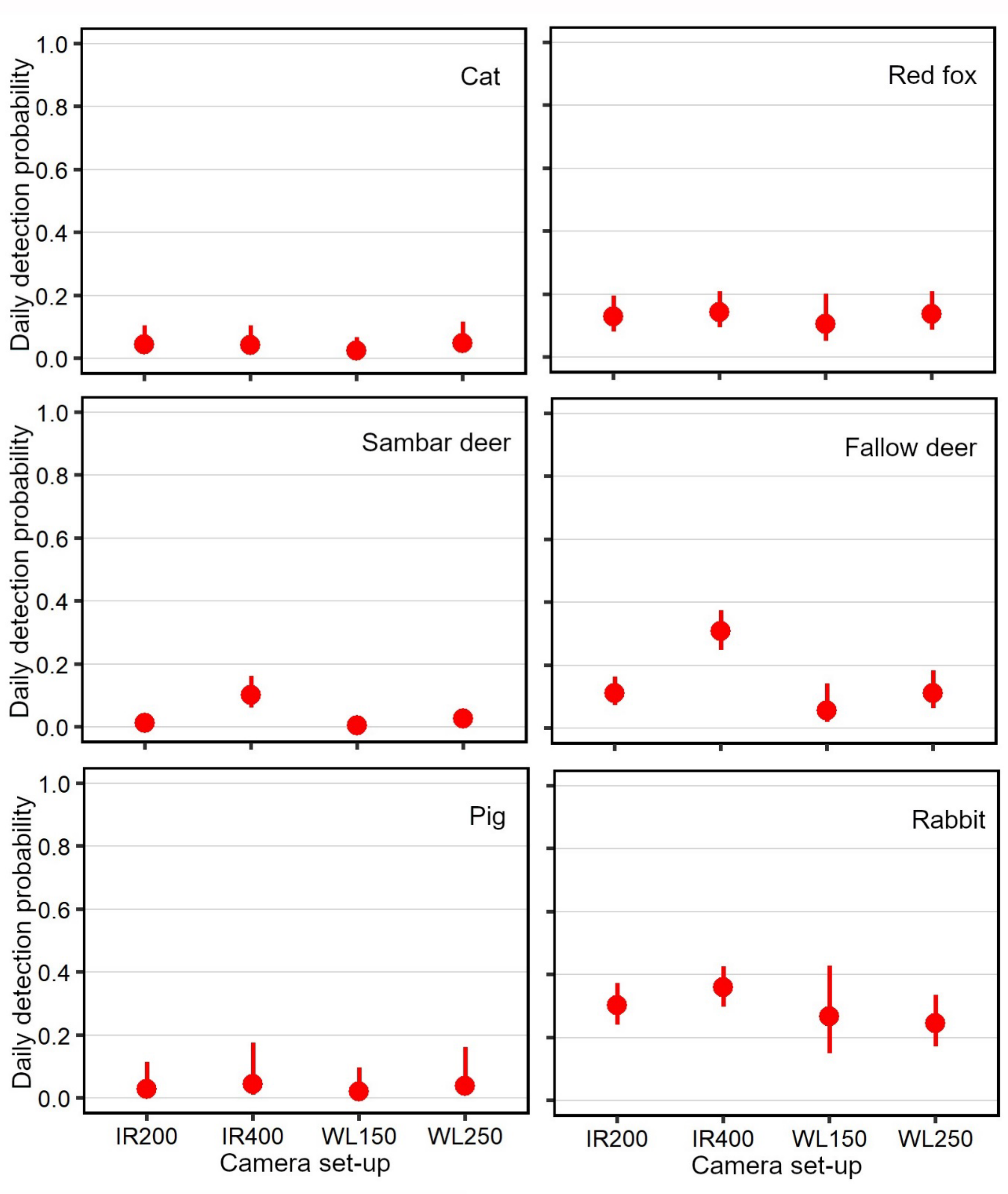


Figure 46 A comparison of detection probabilities for 4 different camera set-ups for 6 feral animal species: cat, fox, sambar deer, fallow deer, pig and rabbit in Kosciuszko National Park

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

Feral cats

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 the Environment Protection and Biodiversity Conservation Act. Cats are known to impact a wide range of vertebrate taxa such as small mammals, reptiles and birds (Doherty et al 2015, Doherty et al 2017).

In KNP, cats represent a major threat to several threatened mammal species including mountain pygmy-possum, eastern pygmy-possum, smoky mouse, and broad-toothed rat. The broad-toothed rat and mountain pygmy-possum have been detected in the scats of feral cats (Schroder and Broome, unpublished data). Cats are also likely to prey upon threatened reptiles (Guthega skink and alpine she-oak skink) and numerous species of threatened birds such as brown treecreeper, olive whistler, scarlet robin and flame robin.

Methods and results

Between November 2022 and February 2023, park-wide surveillance monitoring sites were used to assess occupancy and activity of cats. The daily detection probability and occupancy were modelled using multi-method occupancy analyses (Nichols et al. 2008).

Cats were detected at 40% of sites and had an overall activity measure of 1.3 (±0.2) detections per 100 camera days (Figure 50; Table 11). Modelled occupancy, which accounts for imperfect detection and potential false absences (sites that are occupied but in which the species was not detected during surveys) was 46%. There was little difference in detection success between the 4 camera set-ups used in the park-wide surveillance monitoring (Figure 49). Site occupancy of cats was greatest in the wet sclerophyll forest (grassy sub-formation) vegetation formation but was also prevalent in the dry sclerophyll forest (shrubby sub-formation) and grassy woodlands formations.

Management summary

Park management control programs for cats included trapping and shooting. A total of 206 cats were trapped during the 2022–23 financial year.

Discussion

Feral cats are found across KNP and currently there is no effective landscape-scale control method for managing feral cat populations. The limitations on effective control for feral cats is further complicated in KNP where snow cover occurs between 4 to 6 months of the year. During winter, cage trapping has been the preferred management method especially around ski resorts.

The continued presence of cats in the park is a key threat to many small mammal species. Their impact on native mammal species may be reduced, in part, through the reduction of feral herbivores and effective fire management. There is evidence that cats are more efficient predators when vegetation structure is simplified which may result from extensive and severe fires and feral herbivore pressures (McGregor et al. 2014, 2015, 2016). However, the extent to which measures to prevent the simplification of vegetation structure can help reduce the impact of feral cats is unknown and, in any event, unlikely to be sufficient for the effective conservation of many cat-susceptible species.

Cats are a cryptic species with low levels of detections on camera-based surveys, and long camera deployments are required for robust occupancy estimates (Stokeld et al. 2015). A preliminary survey has been employed to enumerate cat density over an area of approximately 2,000 ha in the northern section of the park. Dedicated surveys to better understand occurrence and density will be established in the 2024–25 financial year, including density of cats which will be measured by dedicated surveys in accordance with the NPWS Feral Cat Monitoring Protocol (DCCEEW 2024b).

Red foxes

Conservation context

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

Methods and results

Between November 2022 and February 2023, park-wide surveillance monitoring sites were used to assess occupancy and activity of foxes. The daily detection probability and occupancy were modelled using multi-method occupancy analyses (Nichols et al. 2008).

Foxes were detected at 38% of sites and had an overall activity measure of 3.6 (±0.8) detections per 100 camera days and modelled occupancy was 41% (Figure 50; Table 11). Fox occurrence was not confined to any one area of the park but was highest in grassy woodland sites. There was little difference in detection success between the 4 camera set-ups used in the park-wide surveillance monitoring (Figure 49).

Management summary

Control programs in 2022–23 for this feral species included ground and aerial baiting, trapping and shooting. Baiting is the primary method of fox control.

During this period, ground baiting was undertaken for foxes where 207 meat baits, each containing 3 mg of 1080 (a lethal dose for foxes), were deployed with 95 baits taken. Targeted ground baiting for foxes was conducted in priority areas of threatened species habitat, namely broad-toothed rat and mountain pygmy possum.

An additional 17,176 (aerial) and 836 (ground) baits were deployed targeting wild dogs. Each bait contained 6 mg of 1080, noting dog strength baits will also kill foxes. The aerial baiting runs amounted to 576 km in length across a 500 sq km area and focused on perimeter areas of KNP.

A total of 31 foxes were trapped and 8 were also shot during this period.

Discussion

Foxes occur across a broad range of habitats in KNP. They are highly mobile and have a flexible diet adapting to varying prey availability and alternative food sources such as seeds, berries and insects (Fleming et al. 2021).

The park-wide surveillance monitoring cameras were deliberately not placed on formed walking tracks, trails and roads, as is often the case in camera-based monitoring programs for foxes. As such, the activity index value may be less than observed on formed trail-based programs, but the approach provides an unbiased estimate of relative activity and occupancy estimation (Sollmann et al. 2013; Raiter et al. 2018). Thus, further analysis of camera data to better understand patterns of activity of foxes across the park can be used to assist control programs to be more targeted and efficient.

Of the 100 surveillance sites, only 13 sites recorded both foxes and cats (Figure 50). Further analysis is required to assess whether either spatial and/or temporal avoidance is occurring between these species. Having a better understanding of these dynamics can assist with evaluating feral animal control programs and impacts on vulnerable threatened species.

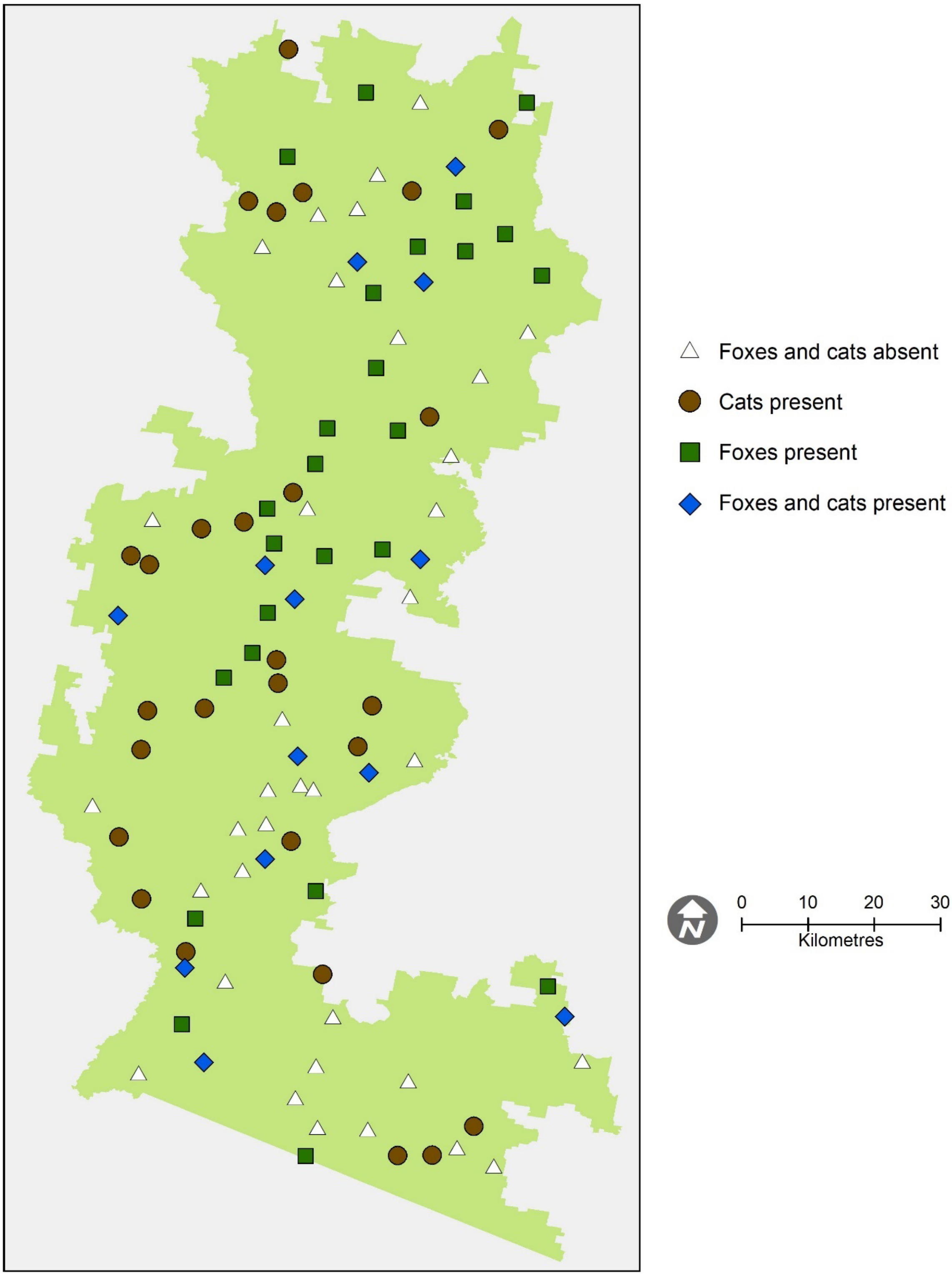


Figure 50 Fox and cat occupancy at park-wide surveillance monitoring sites in Kosciuszko National Park

Brown circles = only cats present, green squares = only foxes present, blue diamonds = both cats and foxes present, white triangles = both cats and foxes absent.

Deer

Conservation context

Deer were introduced to Australia during the 19th and 20th century for sport and farming activities (Moriarty 2004). Since the 1970s, deer populations have increased rapidly, and studies from the 2010s observed year-to-year increases in deer population estimates using harvest numbers from game licence holders (Moloney and Turnbull 2013; Claridge 2016). Deer have rapidly expanded within KNP, particularly where agricultural land meets the forest interface. The region contains some of the highest concentrations of feral deer in the state, with the relative abundance of deer species being dominated by fallow and sambar deer (DPI 2024). Trampling and herbivory by deer negatively impact vegetation cover (resulting in sparse cover) and cause soil erosion. They have a direct impact on the populations of threatened plant species in the park. Herbivory and environmental degradation caused by deer has been listed as a key threatening process under the Biodiversity Conservation Act.

Methods and results

Between November 2022 and February 2023, park-wide surveillance monitoring sites were used to assess occupancy and activity of three deer species across the 5 main vegetation formations in KNP. The daily detection probability and occupancy were modelled using multi-method occupancy analyses (Nichols et al. 2008).

Camera-based surveys detected deer at 53% of the park-wide surveillance sites (Figure 51). Sambar deer (*Cervus unicolor*) were the most detected species of deer throughout KNP with detection at 42% of sites (modelled occupancy = 45%) and had an overall activity measure of 2.2 (±0.4) detections per 100 camera days (Table 11). This species was found equally across all 5 major vegetation formations in the park. Fallow deer (*Dama dama*) were detected at 20% of sites (modelled occupancy = 23%) and had an overall activity measure of 7.1 (±1.7) detections per 100 camera days (Table 11). This species was detected most frequently in dry sclerophyll forest (shrub/grass sub-formation) at 7 of the 9 sites that were surveyed. Red deer (*Cervus elaphus*) were detected at one site.

Management summary

In 2022–23 financial year, 200 hours (8,215 km) of aerial shooting was conducted targeting multiple feral species (not including horses). Three species of deer were shot comprising 93% of all feral animals shot at this time (fallow deer 65%, red deer 1%, and sambar deer 27%). In addition, 20 days of ground shooting was also conducted targeting multiple feral species (not including horses). Two species of deer were shot by ground shooting, fallow deer (n=4) and sambar deer (n=1). Aerial and ground shooting combined removed 15 red deer, 1,206 fallow deer and 493 sambar deer.

Discussion

Park-wide camera-based surveillance monitoring detected 3 introduced species of deer in KNP: 2 species were widespread (sambar, fallow) and one (red) was recorded from just one site. Sambar deer are distributed across most of KNP and showed no discernible difference in distribution with respect to vegetation formation, being recorded in all 5 vegetation formations across KNP. Fallow deer showed a clear pattern in distribution, being found only in the south-east of KNP (Figure 51) and were strongly associated with dry sclerophyll forest (shrub/grass sub-formation) at 3 times the occupancy of the other 4 main vegetation formations. However, this association may not be directly related to any habitat preferences per se as control efforts in other parts of KNP have probably reduced the prevalence of fallow deer in other vegetation formations. The species is known to be adaptable and occurs in a wide variety of habitats elsewhere in south-east Australia and has a variable diet (Guy et al. 2024). The distribution of dry sclerophyll forest (shrub/grass sub-formation) is predominantly restricted to the south-east corner of KNP which is also where fallow deer were detected so the relationship may be correlative rather than causative.

This is potentially significant in terms of management operations – it suggests control operations are having impact in most vegetation formations but highlights the need to focus control of fallow deer in dry sclerophyll forests (shrub/grass sub-formation) and to consider other technology that can improve aerial shooting outcomes in these conditions.

While fallow deer were relatively easily detected, frequently returning to sites over the duration of a camera deployment, sambar deer were infrequently detected. A 90% detection probability using cameras-based surveys could be reached in 10 days for fallow deer, and between 25 and 30 days for sambar deer. This has implications for how site occupancy of these species can be effectively monitored using cameras. Specifically, appropriate camera set-ups and deployment durations that are required for robust occupancy estimates and quantifying changes over time.

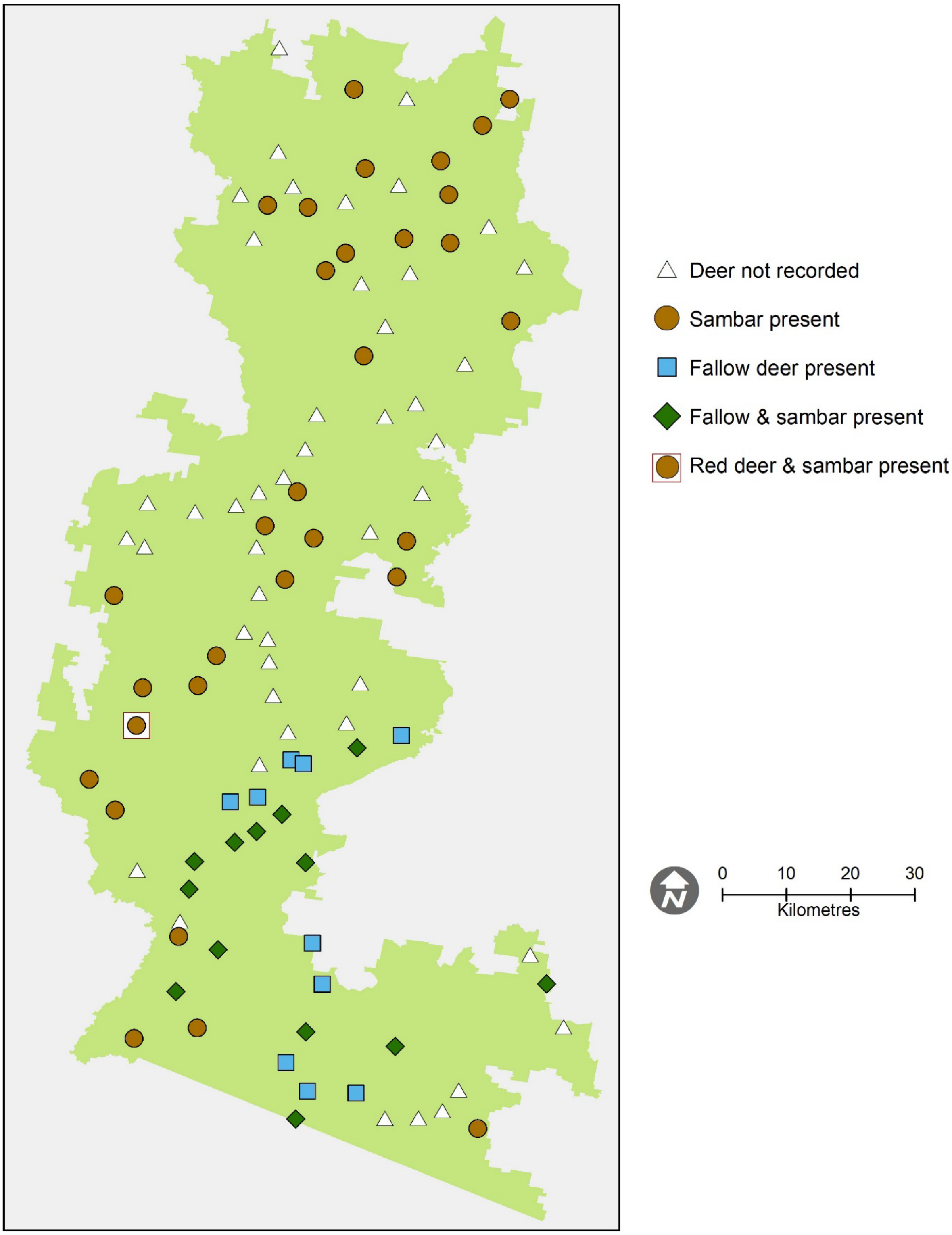


Figure 51 Deer species detection at park-wide surveillance monitoring sites in Kosciuszko National Park

Coloured symbols indicate deer detection: brown circles = sambar, blue squares = fallow deer, green diamonds = sambar and fallow deer, brown circles with white square = sambar and red deer.

Horses

Conservation context

Habitat degradation and loss by feral horses is listed as a key threatening process under the Biodiversity Conservation Act. Horses negatively impact wetlands, watercourses, and riparian systems; alter the structure and composition of vegetation; and reduce plant biomass. The distribution and abundance of feral horses is having a significant impact on the environmental values of KNP (DPE 2023b).

NPWS has an obligation to implement the *Kosciuszko National Park Wild Horse Heritage Management Plan* (DPE 2023b): see section 10 of the *Kosciuszko Wild Horse Heritage Act 2018*. The plan identifies 3 management zones: retention areas (32% of the park); removal areas (21% of the park); and prevention areas (47% of the park) (Figure 52). The plan requires the population of horses to be reduced to 3,000, confined to retention areas, by 30 June 2027 (Figure 52; DPE 2023b). The population of horses in removal areas is to be reduced to zero by 30 June 2027. Population of horses in prevention areas is also to be maintained at zero.

Methods and results

In October 2023 aerial surveys were conducted in 4 survey blocks (267,500 ha area) known to support 95% of the horse population within KNP (Figure 52). Surveys involved 2 independent observers seated on opposite sides of a helicopter flown at a ground speed of 93 km/h (50 knots) and a height of 61 m (200 ft). Over the 4 survey blocks, 144 line transects were flown covering a total transect length of 1,948 km over 22% of the survey blocks (NSW NPWS unpublished 2024). Horse sighting data was analysed using the statistical program Distance 7.5 release (Thomas et al. 2010).

The estimated number of horses in the 4 survey blocks in 2023 was 17,393 (95% CI: 12,797–21,760) (Figure 53). There was no significant change in abundance between 2022 and 2023. Surveys conducted in 2022, estimated 18,814 horses (95% CI: 14,501–23,535; DPIE 2022b).

A foal-to-adult ratio of 0.178 (18 foals per 100 adults) was estimated from the survey data across all 4 survey blocks as an indicator of population recruitment. This ratio was not significantly different from the 2022 survey results of 0.191 (19 foals per 100 adults).

Management summary

A total of 1,606 horses were removed from the park between February 2022 and June 2023.

Discussion

Horses are estimated to occur in over 53% of the park (DPIE 2022b). Overall, there has been no statistically discernible change in horse populations across the survey area between 2023 and 2022. The highest density of horses occurs in the northern survey block, with approximately 75% of the total number of horses across the 4 survey areas.

The control of horses has increased substantially in 2023–24. An aerial survey in October 2024 will generate a revised population estimate, revealing the extent to which control operations under the plan have resulted in a decrease in the estimated horse population.

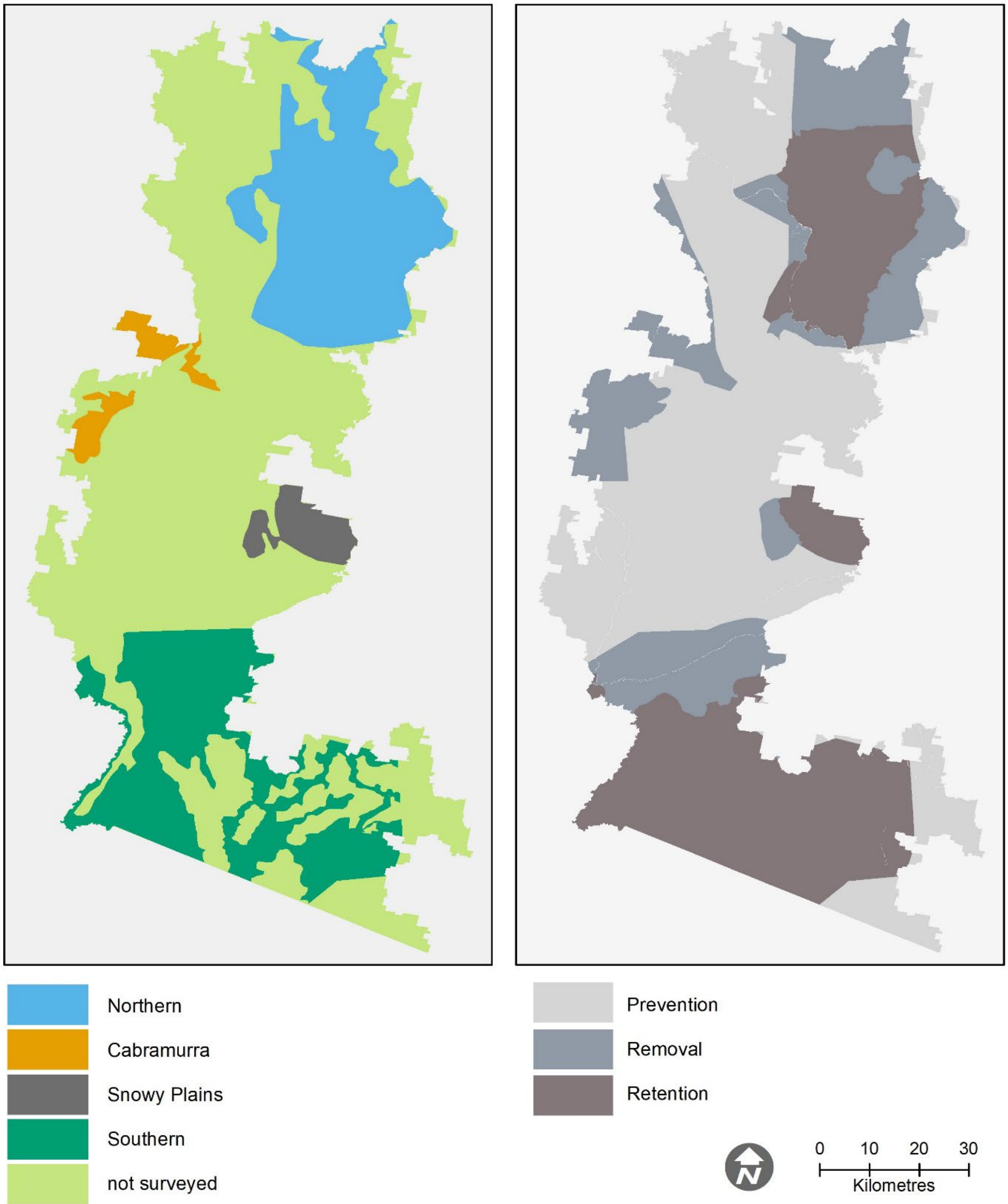


Figure 52 **Horse survey blocks (northern, Cabramurra, Snowy Plains and southern) and management zones (prevention, removal and retention) in Kosciuszko National Park**

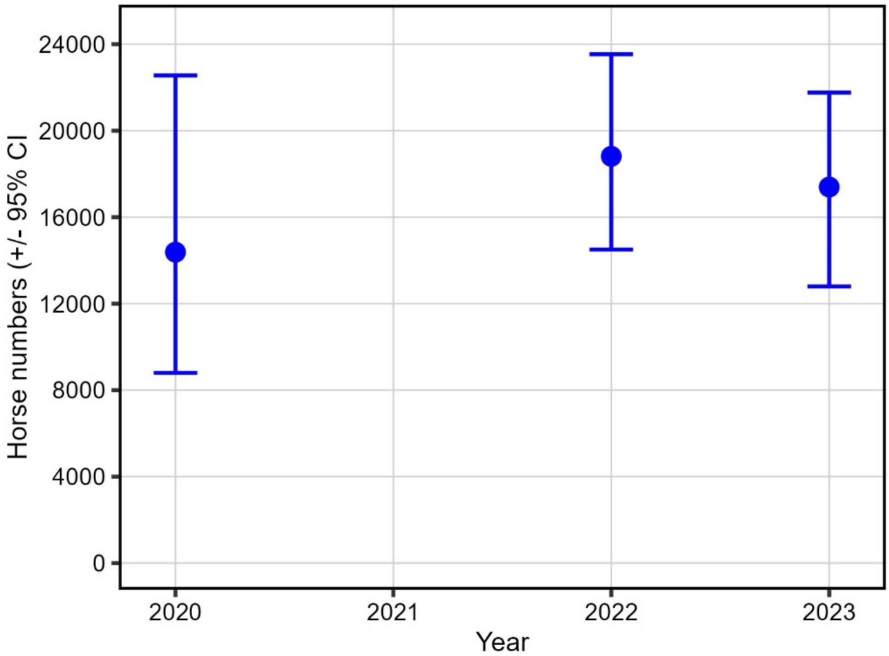


Figure 47 Estimated numbers of horses (+/- 95% confidence intervals) in KNP from 2020 to 2023

Feral pigs

Conservation context

Feral pigs can cause severe damage to the environment: they eat native flora and fauna, cause damage to native vegetation through trampling, cause soil erosion and loss of topsoil, damage watercourses and degrade water quality, and are known to spread weeds and diseases (DPIE 2021). Predation, habitat degradation, competition and disease transmission by feral pigs are listed as key threatening processes under the Biodiversity Conservation Act. Feral pig occurrence is thought to be seasonally variable in the park. While they are known to occur across the park, they are rarely observed in alpine areas.

Methods and results

Between October 2023 and February 2024, park-wide surveillance monitoring sites were used to assess occupancy and activity of pigs across KNP. The daily detection probability and occupancy were modelled using multi-method occupancy analyses (Nichols et al. 2008).

Camera-based surveys detected pigs at 19% of the monitoring sites (Table 11, Figure 54). Modelled occupancy was 23%. Daily detection probability of pigs was very low (<0.05), and no difference was observed between any of the camera set-ups (Figure 49). Pig occurrence was strongly associated with dry sclerophyll forests (shrubby sub-formation).

Management summary

In the 2022–23 financial year, control programs shot 238 feral pig. A total of 116 pigs were removed (30 shot and 86 trapped) from specific ground-based pig control programs, costing $29,241 and 511 hours of staff time. Aerial shooting conducted targeting multiple feral species (not including horses), 122 pigs were shot from a total of 200 flying hours (8,215km). Pigs made up 7% of all feral vertebrates shot in this time. Five other feral species (predominantly deer) were also shot so it is not possible to definitively breakdown the costings on a per species basis.

Discussion

Pigs were detected at a small portion of monitoring sites and the probability of capturing them on camera was low. There was little difference in the proportion of pig detections with respect to vegetation formation in KNP with the exception of the alpine complex. Pigs were recorded at between 17 and 35% of sites within each vegetation formation, and only one site out of 26 alpine complex sites.

Figure 48 Feral pig detection in Kosciuszko National Park park-wide surveillance monitoring sites

Rabbits and hares

Conservation context

In the Lower Snowy area of KNP, rabbit plagues of the 1900s caused severe disturbance and erosion (Costin 1954). The impact of rabbits includes reducing the regeneration of native flora species through grazing and ringbarking of saplings, competing with native animals for food and shelter, and creating soil erosion caused by overgrazing. Competition and grazing by the feral European rabbit are listed as key threatening processes under the Biodiversity Conservation Act. Rabbit populations occur throughout KNP but decrease as elevation increases. In recent decades the population has declined and been replaced by deer and horses (Ward-Jones et al. 2019). However, declining snow cover and earlier snow thaw is allowing rabbits to survive through winter in places they previously did not occupy (Green et al. 2017). A recent study in 90,000 ha of sub-alpine and alpine grasslands of KNP found rabbits and hares to occupy 85% of sites surveyed (Hartley et al. 2022).

Methods and results

Between November 2022 and February 2023, park-wide surveillance monitoring sites were used to assess occupancy and activity of rabbits and hares across KNP. The daily detection probability and occupancy were modelled using multi-method occupancy analyses (Nichols et al. 2008).

Camera-based surveys detected feral rabbits in 21% of the monitoring sites (Figure 55), and hares at 14% of the monitoring sites. Combined, hares and rabbit were recorded at 34% of all sites. Despite this relatively high level of occurrence, there were only 2 sites were both species were recorded. The ability of the camera-based monitoring to detect rabbits if they were present at a site was high, and no difference was observed between camera set-ups in detecting rabbits (Figure 49). Rabbits were more commonly observed in the grassy woodland, and dry sclerophyll forest (shrub/grass sub-formation) vegetation formations. Hares were most commonly observed in the alpine complex at 38% (10/26) of all sites in that vegetation complex. In the other 4 vegetation formations, hares were observed at 9% of grassy woodland sites, 5% of dry sclerophyll forest (shrubby sub-formation) and were not recorded at all in wet sclerophyll forest (shrub/grass sub-formation) or dry sclerophyll forest (grassy sub-formation).

Management summary

A control program for rabbits included ground shooting with 149 individuals shot in 2022–23.

Discussion

Rabbits were most commonly detected in grassy woodland vegetation formations. Hares were most commonly detected in the alpine complex. Management strategies in KNP need to consider how to improve the control of rabbits to contain and reduce their distribution and density. Strategies need to consider the interaction with fox control, noting rabbits are a prey species for foxes. Also noting, fox activity was also highest in grassy woodlands.

Figure 49 **Rabbit and hare detection in Kosciuszko National Park park-wide surveillance monitoring sites**

Park-wide threats: weeds

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.

Due to the sheer number of weed species, a consistent approach across the national park estate is being developed to focus weed-monitoring efforts on priority weeds. To the greatest extent 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.

A total of 357 exotic plant species have previously been recorded within KNP (DPE 2023c), with two-thirds of the weeds occurring in the alpine and sub-alpine areas (DPIE 2021). The number of weed species has been increasing in numbers in the park since the 1950s and reflects a strong association with anthropogenic disturbance (Bear et al. 2006). Surveys conducted along roadside native vegetation have shown a steady increase in the number of new weed species entering KNP since 2006, with many weeds reaching higher elevations than previously recorded (Bear et al. 2006; McDougall et al. 2011; Iseli et al. 2023).

Weed species in KNP cover a broad spectrum of invasiveness, from those that can transform the function of the ecosystems they occur in (transforming weeds), to species that occur sporadically and have less noticeable effects on the ecosystems they occupy. Overall, their increasing occurrence presents a risk to the natural values of the park. The impacts caused by weed infestation and establishment varies across KNP, depending on the complex interaction of elevation, land systems and land-use history.

Methods and results

Weeds were detected at 79 (83% of sites) of the park-wide surveillance monitoring sites (Figure 56). Across these sites 55 weed species were identified. The extent of weeds in KNP is highlighted by a comparison with the RHG Scorecard, where weeds were detected at only 10% of the park-wide monitoring sites, with only 5 weed species identified.

In the park-wide surveillance monitoring sites, more weed species were recorded in the wet sclerophyll forest (grassy sub-formation) compared to other formations, with 34 weed species recorded in 78% of the sites and an average of 3 species per site (range: 0–12). The alpine complex vegetation formation recorded the least number of weed species with only 11 species detected and an average of 3 species per site (range: 0–7), however, they were found at every site sampled in this vegetation formation (Figure 56). The average number of weed species per site for dry sclerophyll forest (shrub/grass sub-formation) was 5 species per site (range: 0–9), for dry sclerophyll forest (shrubby sub-formation) was 3 weed species per site (range: 0–9) and for grassy woodlands was 5 weed species per site (range: 0–12). Three species of high ecological significance were detected in the park-wide surveillance monitoring sites: blackberry was recorded at 9 sites; sweet vernal grass was recorded at 23 sites; and ox-eye daisy was recorded at one site.

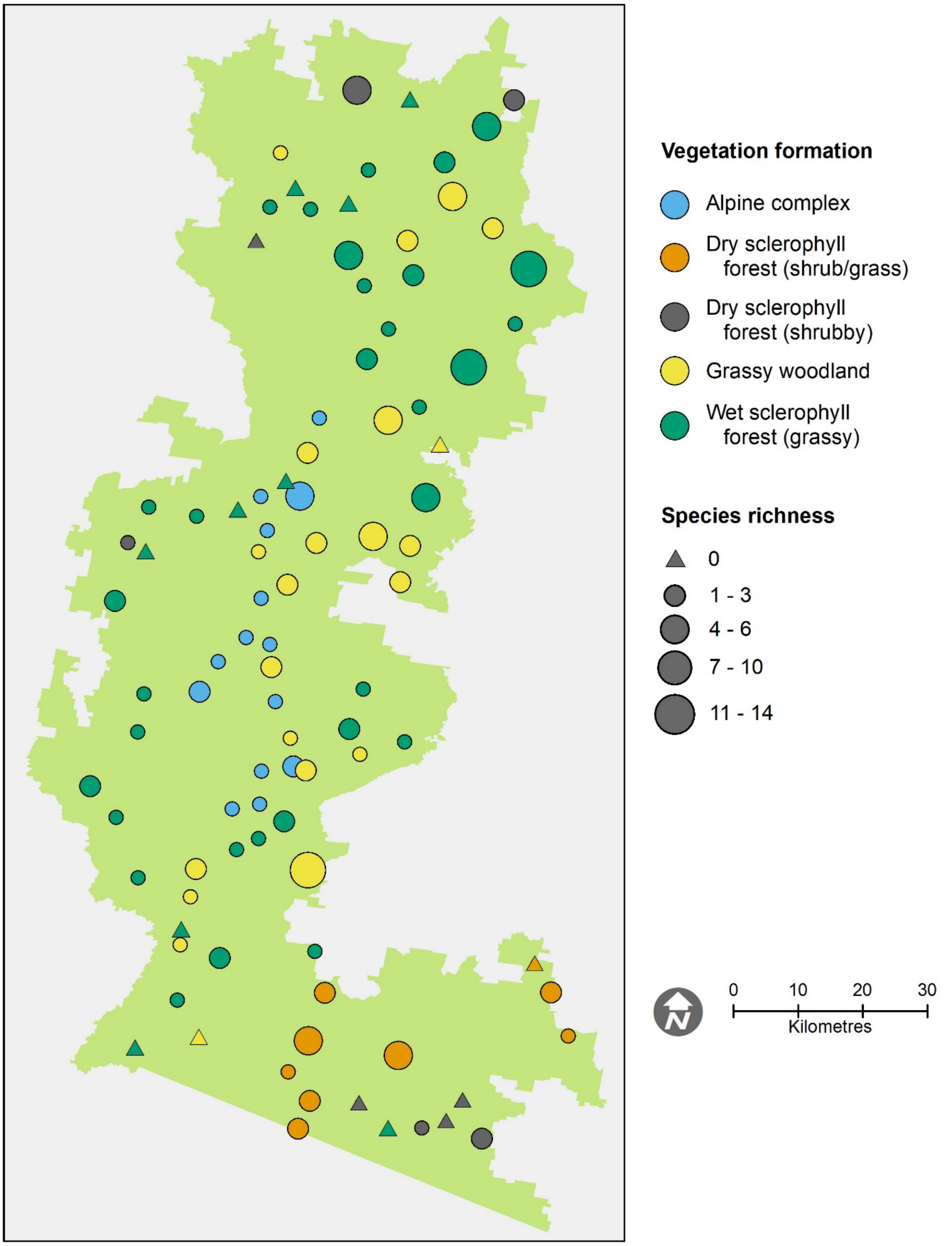


Figure 50 Number of weed species for each vegetation formation at Kosciusko National Park park-wide surveillance monitoring sites

Symbol sizes are graduated by the number of exotic plant species recorded at each site, with the larger symbols representing more-impacted sites within the park.

Management summary

Individual weed species that are currently targeted as part of control measures in KNP include ox-eye daisy (*Leucanthemum vulgare*), orange hawkweed (*Pilosella aurantiaca*), mouse-ear hawkweed (*Pilosella officinarum*), scotch broom (*Cytisus scoparius*), willow (*Salix* spp.), sweet vernal grass (*Anthoxanthum odoratum*), serrated tussock (*Nassella trichotoma*), and blackberry complex (*Rubus fruticosus* sp. agg.) (Table 12). This list is being reviewed.

The hawkweed species have targeted eradication programs which involve an intense level of surveillance, detection and management including aerial surveys and detection dogs. Other weed species are managed as part of containment programs or controlled in areas of high ecological or recreational significance. Some of these species are widespread in lower elevation areas and may only be controlled where they are a new occurrence or pose an immediate threat to a conservation asset in higher alpine and sub-alpine areas, for example sweet vernal grass is only treated in the alpine zone. These strategies are being reviewed.

In the 2022–23 financial year, NPWS invested 24,871 hours (staff and volunteer) in weed control programs that treated 15,850 ha of weeds at a cost of $1,375,641 (Table 12).

Table 12 Weed control programs in Kosciuszko National Park, 2022–23 financial year

Indicator	Expenditure ($)	Management activity	Input	Output (area treated)
All weed species	$1,375,641#	All treatment	24,871 hrs#	15,850 ha#
Blackberry complex		Foliar spraying#		1,239 ha+
Mouse-ear hawkweed	$187	Foliar spraying	4.25 hrs	7.9 m^2
	$268,015^	Surveillance and detection	7,890^308	308 ha
Orange hawkweed	$43,175	Foliar spraying	448 hrs	8,915 m^2
	$478,814^	Surveillance and detection	8,996.1^	29,000 ha
Ox-eye daisy	$107,029*	Foliar spraying	2,612 hrs*	3,871 ha
Perennial exotic grasses	$15,270*	Foliar spraying	273 hrs*	0.004 ha
Scotch broom	$12,362*	Foliar spraying/physical removal, cut and paint	126 hrs*	0.059 ha
Willow# (*Salix* spp.)		Foliar spraying/physical removal, cut and paint#		0.0094 ha

Expenditure and input metrics cannot be determined for individual species control programs due to the aggregated nature of the data.

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

^ These figures represent the other total costs for the respective Hawkweed program – detection and monitoring, as well as some additional components related to treatment effort.

* This figure does not represent the total NPWS investment into these control programs. Some expenditure, and staff hours for this action are included in the expenditure and staff hour values for the 'All weed species' line item.

Discussion

The current NPWS approach to weed management is guided by NPWS branch-level pest management strategies, weed control priorities plans, and weed priorities from the relevant Local Land Services regional strategic weed management strategies that cover KNP (Local Land Services 2023). Except for a few priority species, NPWS does not have park-wide monitoring established for weeds. Monitoring has been 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.

In KNP, the hawkweed species are an eradication priority species with a priority focus on the alpine and sub-alpine areas of the park. Ox-eye daisy, scotch broom, willow, blackberry and perennial exotic grasses will be contained where they have been identified. In 2023–24, mapping of initial priority species will occur. Most of these initial priority species will be mapped using ground surveys. Aerial surveys will also be used to map blackberry, orange hawkweed, ox-eye daisy, scotch broom and willow. Detection dogs will also be deployed to detect hawkweed species. Aerial surveys for the 2 hawkweed species is completed for up to 20,000 ha annually.

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.

Mouse-ear hawkweed

Conservation context

Mouse-ear hawkweed is a perennial herb native to Europe and Asia. It is considered a serious weed elsewhere, particularly in Canada, the USA and New Zealand. The species is allelopathic, preventing the growth of surrounding plants due to secretion of toxic chemicals into the soil. Seeds are wind dispersed (Hamilton et al. 2015), but dispersal of seed can be aided by animals, vehicles and humans (Rinella and Sheley 2002). In Australia, it occurs in restricted locations in the alpine areas of New South Wales and Victoria but has the potential to spread to much of south-eastern Australia.

It was identified in KNP near the Blue Lake RAMSAR site in 2014 by a bushwalker and was subjected to immediate control and eradication. It is likely the incursion was present for several years prior to detection. Surveillance and monitoring occur annually, as soil seed bank viability is up to 5 years. No seeding events have been observed since 2022.

Methods and results

The delimitation area for mouse-ear hawkweed is defined by spatial models that predict the likelihood of species presence (Figure 57). Delimitation boundaries are updated annually to reflect improved knowledge on factors correlated with or influencing its distribution, and any new extra-limital occurrences.

Within the delimitation area, ground-based surveys are conducted using human observers and detector dogs to identify new occurrences of mouse-ear hawkweed. A 50 × 50 m grid is established around newly detected plants and these grids are searched each year. Areas within the known infestation area (Figure 57, blue polygons) are also re-surveyed every year but not included in the cumulative totals.

The current metric to measure efficacy of the program is the number of plants recorded each year divided by total area searched and adjusted to 100 hectares for comparison between years. The area searched is a subset of the delimitation area. The measure of success of the eradication program is a continued decline in the extent of hawkweed occurrence taking into account the total area searched (Figure 58). Since 2015, the number of plants found has declined. In 2021–22, this number was 133, and in 2022–23 it was just 4 plants found per 100 hectares searched.

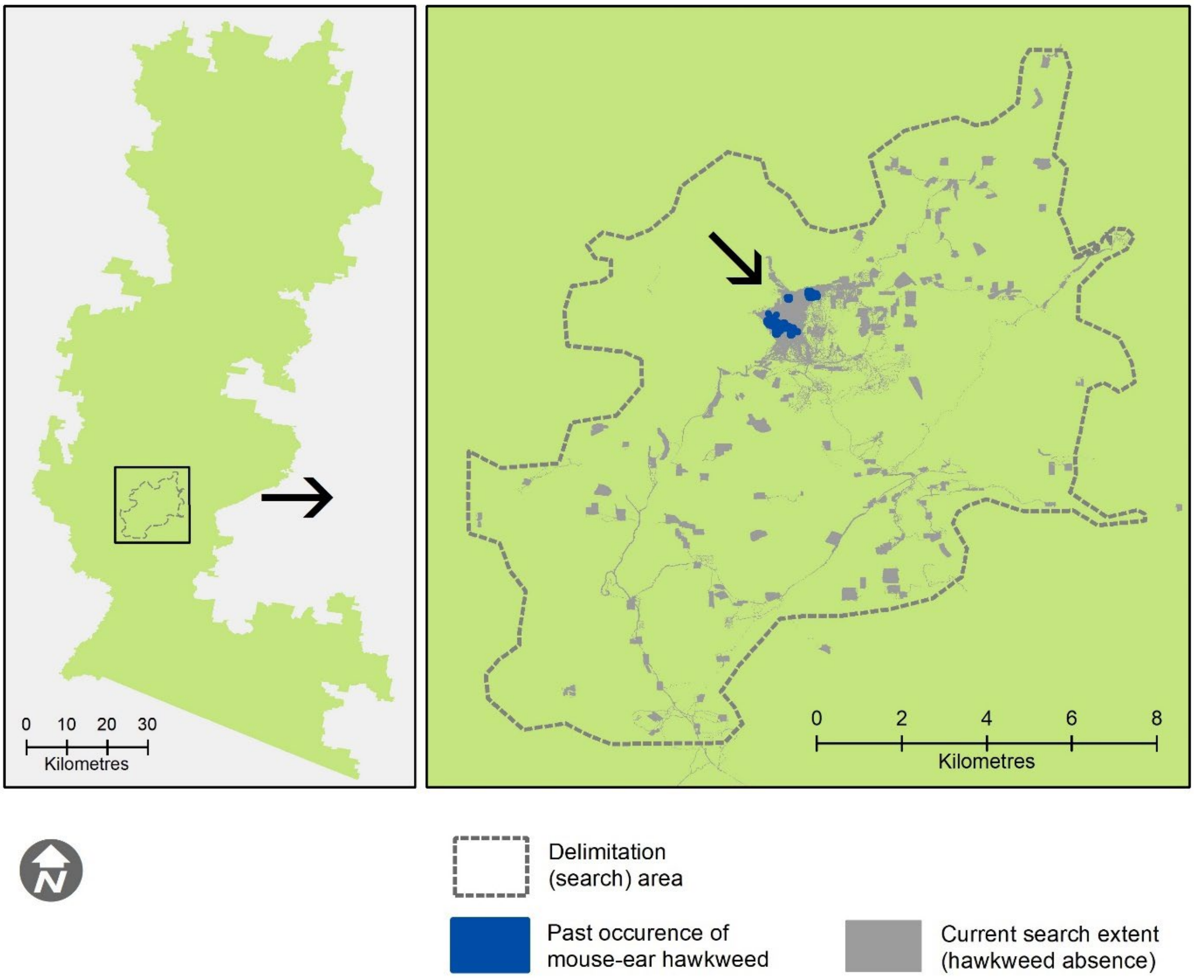


Figure 51 Map showing the known extent of mouse-ear hawkweed in Kosciuszko National Park (left) and the surveillance and delimitation area (right)

Dashed grey polygon is the mouse-ear hawkweed delimitation area. Solid grey polygons are previously surveyed areas confirmed as absent of mouse-ear hawkweed. Small blue polygons (arrow) are 50 × 50 m grids where mouse-ear hawkweed plants were detected and controlled.

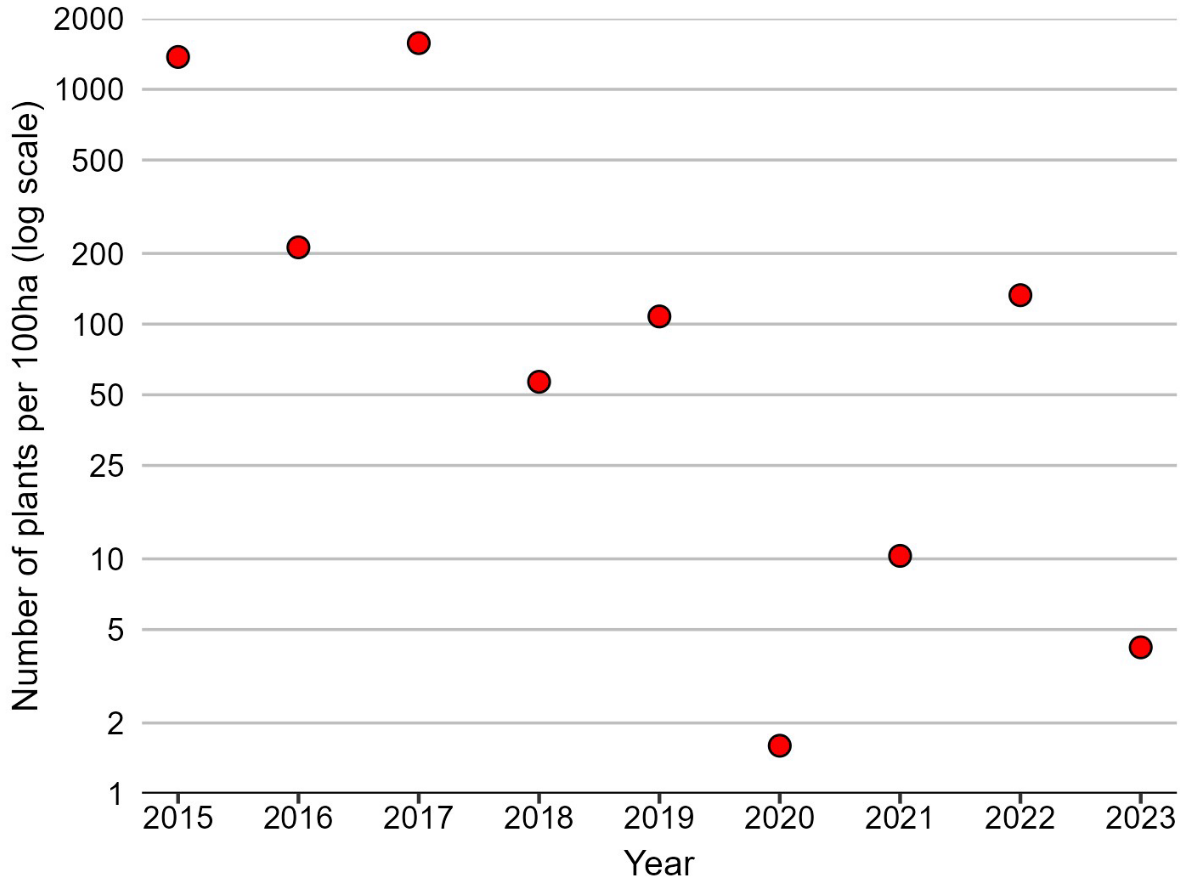


Figure 52 The number of mouse-ear hawkweed plants detected in the delimitation area per 100 hectares searched in Kosciuszko National Park since 2015. Y-axis scale is logarithmic to enable comparisons due to plant numbers varying by orders of magnitude.

Management summary

Monitoring and control for mouse-ear hawkweed has occurred since its detection in 2014. Since then, efforts to control and eradicate the species have continued with increasing success (Figure 58). Using adaptive spatial modelling to characterise the probable extent of mouse-ear hawkweed has further improved the efficacy of the search effort.

Discussion

Mouse-ear hawkweed has the potential to invade significant areas across south-east Australia if control programs are not continued. If allowed to spread, this species is likely to seriously affect biological values and ecological integrity of native plant communities. Its distribution within alpine areas of New South Wales and Victoria remains localised and efforts to eradicate the species have resulted in a decline in the area of infestation since 2015. Eradication programs are considered successful when the target species no longer persists in the landscape either as above-ground vegetation or as seed (Hamilton et al. 2015).

Park-wide threats: climate change

Seasonal snow covers up to 2,500 km^2 of the park and represents the most extensive snow-covered area in Australia. The presence of snow impacts the life cycle of many flora and fauna species in KNP and the weather systems vary across the park depending on the range of elevation, topography and aspect (DPIE 2021).

Temperature and rainfall data included in this report have been sourced from 3 weather stations in KNP (Thredbo AWS 71032, Khancoban AWS 72162 and Cabramurra SMHEA AWS 72161), which covers the geographic range of the park (BOM 2024). In the north of the park at an elevation of 1,482 m above sea level, the weather station at Cabramurra has recorded a mean annual maximum temperature of 12.5°C and a mean annual minimum temperature of 5.1°C. The mean annual rainfall in this region is 1,225.6 mm. In the middle of the park at an elevation of 339 m above sea level, the weather station at Khancoban has recorded a mean annual maximum temperature of 20.5°C and a mean annual minimum temperature of 7.0°C. The mean annual rainfall in this region is 961.7 mm. In the south at an elevation of 1,957 m above sea level, the Thredbo weather station has recorded a mean annual maximum temperature of 8.3°C and a mean annual minimum temperature of 0.8°C. The mean annual rainfall in this region is 1,399.5 mm. During the park-wide monitoring survey, from November 2022 to January 2023, above-average rainfall was experienced across the range of the park (Figure 59 and Figure 60).

The NSW Government Interactive Climate Change Projections Map provides information on the south-east and tablelands region of New South Wales that will be affected by climate change (AdaptNSW 2024). Based on this information, KNP is projected to experience an increase in the number of hot days and a decrease in the number of cold nights. Rainfall is projected to increase in summer and autumn and decline in winter and spring. Average and severe fire weather is projected to increase in spring and summer (AdaptNSW 2024).

The effect of anthropogenic climate on Australian terrestrial flora and fauna is becoming well documented (Hoffman et al. 2019). Temperature data recorded from 1978 to 2002 revealed that trends in warming were greater at higher elevations (Hennessy et al. 2003) and that snow depth and duration has declined since records began in the 1950s, with the date of snow melt increasing by 2.75 days per decade (Green 2010). Alpine species are unable to retreat uphill if snow cover (i.e. their habitat) is affected by climate change (Brereton et al. 1995). With increases in temperature and changes in summer and winter rainfall it is predicted that species with narrow habitat requirements, like the mountain pygmy-possum, would not persist in the wild (Brereton et al. 1995). However, alpine systems are complex, and no single species can be used as an indicator of the response of alpine taxa to climate change (Green 2010). For example, changes in the occurrence and distributions of dominant plant communities and the decline of more-sensitive plant communities, and the distribution and abundance of some fauna species (mountain pygmy-possum and broad-toothed rat) may decline, whereas the diversity and abundance of others (birds) may increase at higher altitudes due to warming temperatures (Pickering et al. 2004).

Climate change may also impact native species and ecosystems by creating favourable conditions for the spread of weed species and pathogens. Loss of snow cover as a result of climate change (Henessey et al. 2003) may increase the risk of weed invasion into sensitive plant communities and habitats that occur only above the snowline (McDougall et al. 2005). Increases in mean temperatures over the coming decade may also increase suitable habitat for phytophthora across KNP (McDougall and Wright 2023), which in turn would impact new species that are not currently threatened by this pathogen. More severe and frequent fires, as an indirect result of prolonged changes in rainfall and temperature patterns, will impact fire-sensitive communities and species (Brereton et al. 1995; Pickering et al. 2004; Gallagher et al. 2021). Directly attributing climate change impacts to changes in the distribution and abundance of native taxa requires tailored long-term monitoring programs.

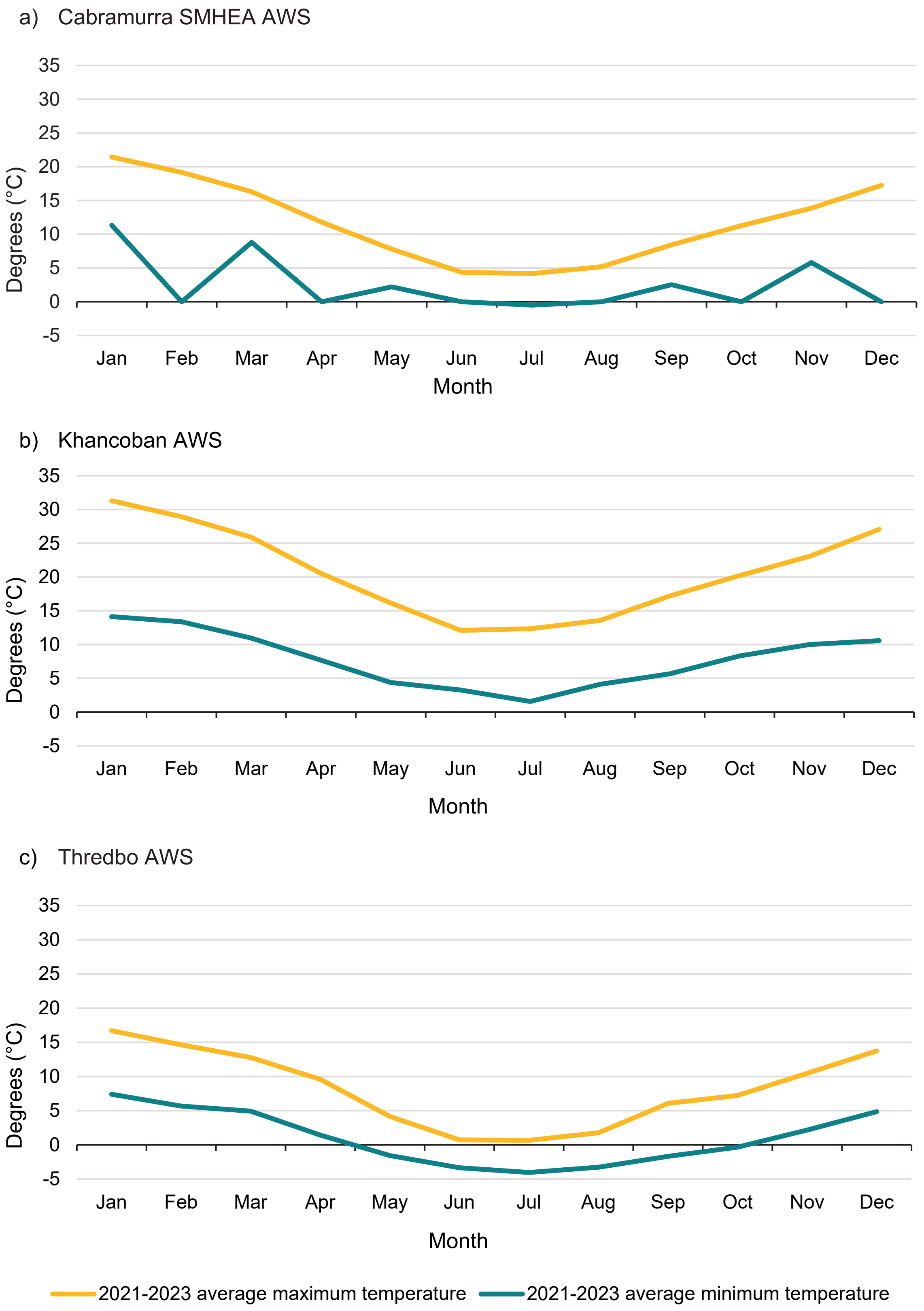


Figure 53 **Monthly average maximum and minimum temperature for the weather stations in Kosciuszko National Park: a) Cabramurra SMHEA AWS (072161), b) Khancoban AWS (072162) and c) Thredbo AWS (071032)**

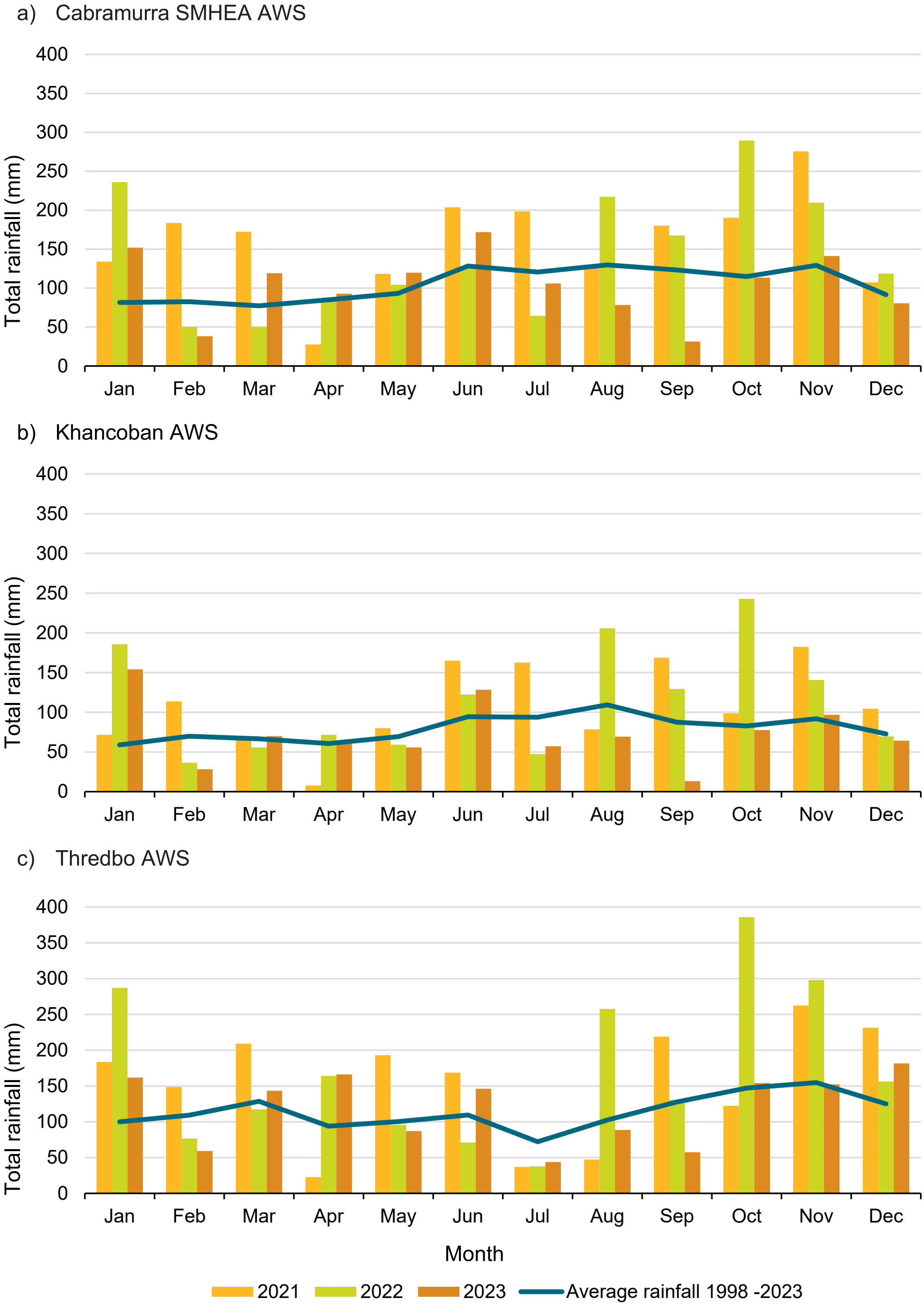


Figure 60 **Monthly rainfall from 2021 to 2023 and average rainfall from 1998 to 2023 for the weather stations a) Cabramurra SMHEA AWS (072161), b) Khancoban AWS (072162) and c) Thredbo AWS (071032) in Kosciuszko National Park**

Park-wide fire metrics

Conservation context

Fire is one of many natural ecological processes shaping Australian ecosystems (Bradstock et al. 2012). A key threatening process in KNP is inappropriate fire regimes, where the combined effects of fire frequency, severity, seasonality, and the spatial distribution of fires, may impact key ecological assets and processes, causing declines in biodiversity. Inappropriate fire regimes may also advantage feral animal and weed species by providing an opportunity for their populations to increase in the park which would also negatively impact biodiversity. Future impacts from a changing climate may further compound these impacts, particularly for fire-sensitive plant communities and species across KNP.

The incidence of fire in KNP since the mid-19th century has contributed to changes in native vegetation, with reduction in old-growth vegetation and changes in vegetation structure and composition (Doherty et al. 2021). Recovery of biodiversity after fire depends on a multitude of factors including the frequency and intensity of past fire regimes, the severity of the fire event, and the environmental conditions proceeding the fire event. Vegetation communities in the alpine complex formation have recovered post-fire although the recovery may not be without loss of keystone species at the local scale (Walsh and McDougall 2004), or without the use of rehabilitation measures, such as the use of temporary soft barriers in wetland communities to reduce erosion (Hope et al. 2012). Excluding fire from these areas in the future will be an important management consideration to allow for their complete recovery.

Some species such as alpine ash (*Eucalyptus delegatensis*) are killed by fire. This species is an obligate seeder with a canopy-stored seed bank and requires fire-free intervals of at least 15 to 20 years to reach reproductive maturity (Noble and Slatyer 1980). Its persistence is threatened by high-severity fires, which kill individuals as well as their seed banks, and fire intervals of less than 10 years which threaten its capacity to reach reproductive maturity (Gill 1997). White cypress pine (*Callitris glaucophylla*), which has a disjunct distribution in the lower Snowy River area of the park, is killed by fire and regenerates from canopy-stored seed (OEH 2014). Other species such as snow gum (*Eucalyptus pauciflora*) can resprout from lignotubers and epicormic buds following fire. This species also has a canopy-held seed bank (Bryant 1971) and can take several decades before the canopy is restored, especially at higher elevations where growth rates are slow (Morgan et al. 2024).

Our understanding of the risk to fauna species from fire in general, and specifically from inappropriate fire regimes, remains relatively limited (NSW NPWS 2003c). The fire requirements for some threatened or vulnerable species are known, however research is required to understand requirements for fauna and different habitats generally. More recent research has focused on the importance of post-fire refugial areas for ecological function in fire-impacted landscapes (Robinson et al. 2013; Harris et al. 2023), where areas less impacted or not impacted by fire events provide interim habitat or viable populations for dispersal. Inappropriate fire frequency that alters vegetation composition and structure may lead to a reduction in food availability and affect the persistence of some species in the park. For example, yellow-bellied gliders rely on old-growth hollow-bearing eucalyptus trees to persist in an area, which may become limited in fire-affected areas.

The impact of landscape-scale fires on catchment values can be significant. The loss of ground and canopy vegetation cover increases erosion, impacting soils, which in turn can affect vegetation recovery and release nutrient-laden sediments into waterways. Altered hydrological processes and changing water yields can then lead to a decline in water quality (Williams and Bradstock 2008).

Methods and results

Spatial data and figures for total areas burnt by prescribed burns, bushfires, as well as canopy burnt have been provided by the Bushfire Risk and Evaluation Unit (NSW National Parks and Wildlife Service).

The total area burnt for both prescribed burns and bushfire in KNP was reported for the past 30 years (from 1993). This period is dominated by 2 extreme bushfire events: the first in 2002–03 (477,507 ha), and the second in 2019–20 (235,259 ha) (Figure 61). These 2 fires comprised 93.5% of all bushfire-affected areas in the past 30 years. The next most extensive bushfire was 2006–07 where just over 28,000 ha of KNP burnt, which was just 3.7% of the total area affected by bushfires in the park.

Over the last 20 years, the average area burnt per annum is 2.74% of KNP, with most of the area being burnt by unplanned bushfires (1.98% of KNP) and only a small proportion in planned prescribed burns (0.74% of KNP) (Table 13). The 20-year average of the number of bushfires occurring in the park was 5.4, with the majority (63%) of these being less than 10 ha in size. Based on the fire management zoning system, approximately 93% of the park is classed as land management zone (LMZ). In a LMZ, decisions to carry out hazard-reduction burns are based on the extent of biodiversity and presence of cultural heritage. During the 2022–23 reporting period, 3,065 ha of the park was burnt with prescribed burning, with most of these occurring in areas zoned LMZ (Table 13).

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 KNP:

- dry sclerophyll forest (shrubby)
- dry sclerophyll forest (shrub/grass)
- grassy woodland
- wet sclerophyll forest (grassy)
- alpine complex.

The remaining vegetation formations, comprising 3% of the park, include forested wetlands, freshwater wetlands, grasslands, heathlands, rainforest and wet sclerophyll forest (shrubby). Descriptions of the 5 major vegetation formations can be found in Table 6 (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.

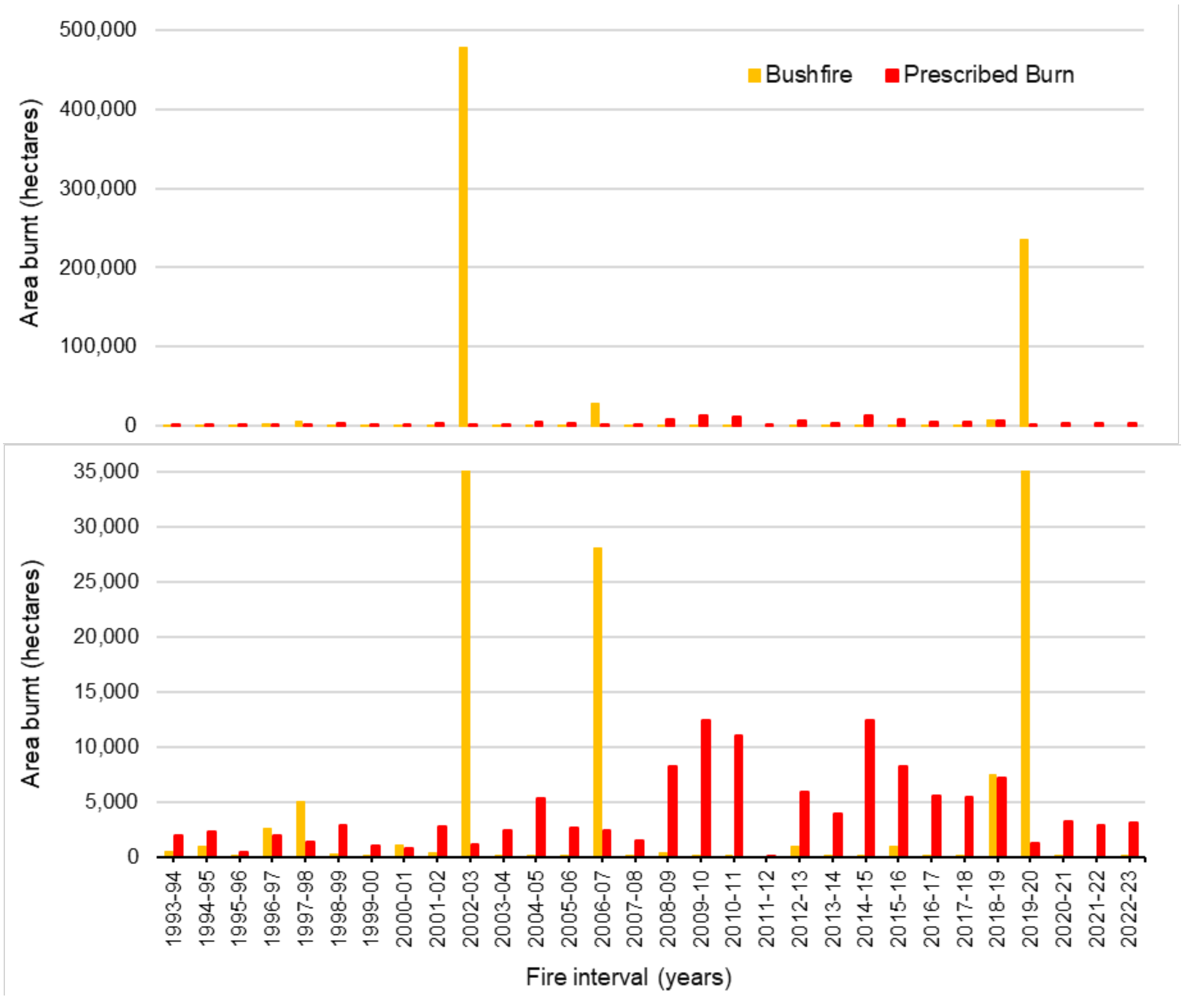


Figure 61 Area burnt by prescribed fires and bushfires in Kosciuszko National Park between 1993–94 and 2022–23

Top and bottom graphs depict the same data but bottom graph has the Y-axis truncated to better display area burnt outside of the 2002–03 and 2019–20 periods. Top graph displays the actual value of the area burnt for 2002–03 and 2019–20 periods.

Table 13 Area burnt in Kosciuszko National Park

	2022–23 financial year		20-year average	
Metric	**Area (ha)**	**% of reserve**	**Area (ha)**	**% of reserve**
Total area burnt	3,065	0.4	18,933	2.74
Total area with canopy burnt	26	0.0	7,869	1.14
Total area unburnt	686,663	99.6	670,795	97.27
Prescribed burn area	3,065	0.4	5,255	0.76
Prescribed burn – canopy burnt	26	0.0	n/a #	n/a #
Prescribed burn by zone type				
Area of SFAZ	37,956	5.5	n/a #	n/a #
Prescribed burn – actual area burnt – SFAZ	949	0.1	n/a #	n/a #
Area of LMZ	637,824	92.5	n/a #	n/a #
Prescribed burn – actual area burnt – LMZ	2,116	0.3	n/a	n/a
Bushfire area burnt	0.13	<0.1	13,678	1.98
No. of bushfires	2	n/a#	5.4	n/a*
% of bushfires <10 ha	–	100%	–	63%
% of bushfires contained in the park	0.13	100%	n/a#	n/a#
Fire patchiness	**10-yr**	**20-yr**	**30-yr**	
Average distance (m) between burnt and long-unburnt patches	63,246	57,688	33,143	
Heterogeneity index (burnt/unburnt)		Being developed		
Heterogeneity index (canopy burnt)		Being developed		

Data unavailable. LMZ = land management zone, SFAZ = strategic fire advantage zone

Dry sclerophyll forest (shrubby)

Dry sclerophyll forest (shrubby sub-formation) vegetation formation covers 14.8% (99,509 ha) of KNP. The desired fire interval for this vegetation formation is 9 to 30 years, or 15 to 30 years when the previous fire was of high severity (DCCEEW unpublished data 2024). These desired fire intervals do not, however, fully take into account fauna requirements.

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). 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.

Key findings

- Only 12% of the dry sclerophyll forest (shrubby) vegetation formation has remained unburnt for more than 30 years (Figure 63; Table 14). However, 60% of the formation has not experienced a canopy fire in the last 30 years.
- About 26% of the dry sclerophyll forest (shrubby) vegetation formation has been burnt more frequently than the minimum desired fire interval of 9 years, including 8% of the canopy, and indicates fire should be avoided in these areas (Figure 62 and Figure 63; Table 14).
- There have been 3 large fire events in the last 30 years in the dry sclerophyll forest (shrubby) vegetation, with 87% of it burnt at least once and over 35% burnt at least twice. Only a small proportion (1%) has been burnt more than 3 times (Figure 64).
- Two periods of high fire severity impacted the canopy of this vegetation formation: 32% of the canopy burnt in the period between 1998 and 2003 and 7% of the canopy burnt in the period 2018 to 2023 (Figure 62 and Figure 64; Table 14).

Table 14 Fire history for dry sclerophyll forest (shrubby) in Kosciuszko National Park

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)	16,760	16.8	7,232	7.27
6 to 10 years	(2013–14 to 2017–18)	9,375	9.4	256	0.26
11 to 15 years	(2008–09 to 2012–13)	14,233	14.3	77	0.08
16 to 20 years	(2003–04 to 2007–08)	2,250	2.3	282	0.28
21 to 25 years	(1998–99 to 2002–03)	44,592	44.8	32,165	32.32
26 to 30 years	(1993–94 to 1997–98)	169	0.2	114	0.11
31 to 40 years	(1983–84 to 1992–93)	2,866	2.9	n/a*	n/a*
41 to 50 years	(1973–74 to 1982–83)	1,126	1.1	n/a	n/a
50+ years	(pre-1972–73)	n/a	n/a	n/a	n/a
30-year fire history*					
Area unburnt		12,130	12.19	59,391	59.68
Area burnt once		51,669	51.92	37,371	37.56
Area burnt twice		30,286	30.44	2,712	2.73
Area burnt 3 times		4,573	4.60	30	0.03
Area burnt >3 times		851	0.86	5	0.01

Note: 99,509 ha in KNP. Desired fire interval 9 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. Data is only available to 1973.

* Current data is only available only from 1990–91; in subsequent years reporting of canopy fires will be extended to better represent the desired fire-interval range limits.

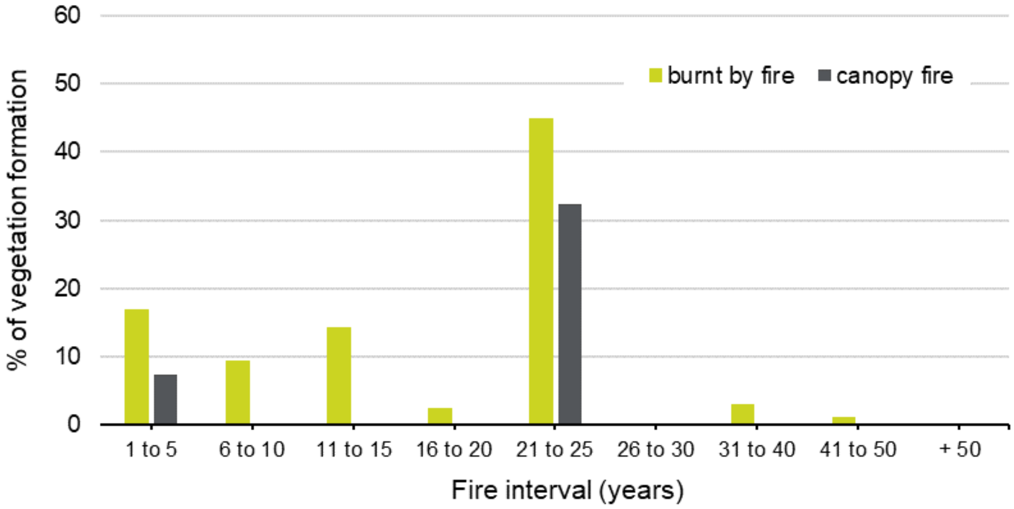


Figure 62 Percentage of dry sclerophyll forest (shrubby) burnt within each time interval for all fire and canopy fire (desired fire interval 9 to 30 years)

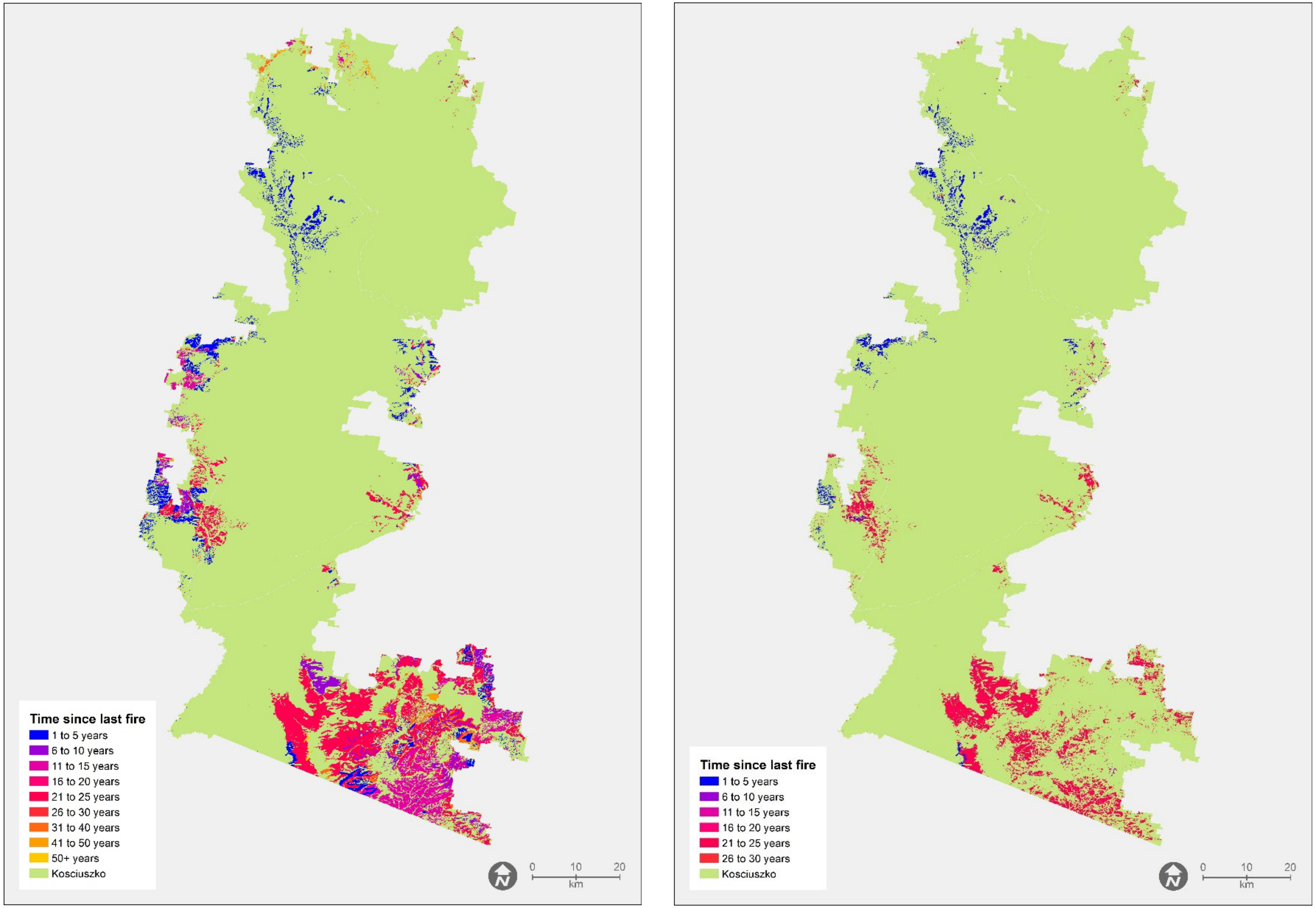
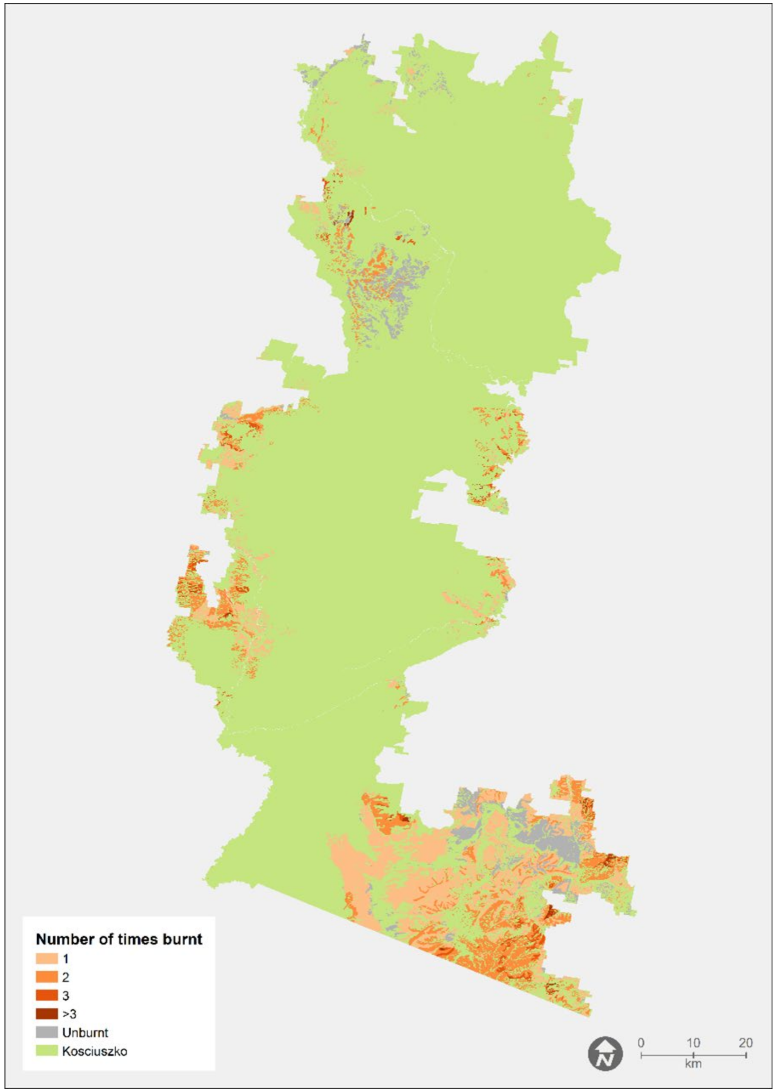


Figure 54 Fire history in dry sclerophyll forest (shrubby): all fire (left), canopy fire (right)



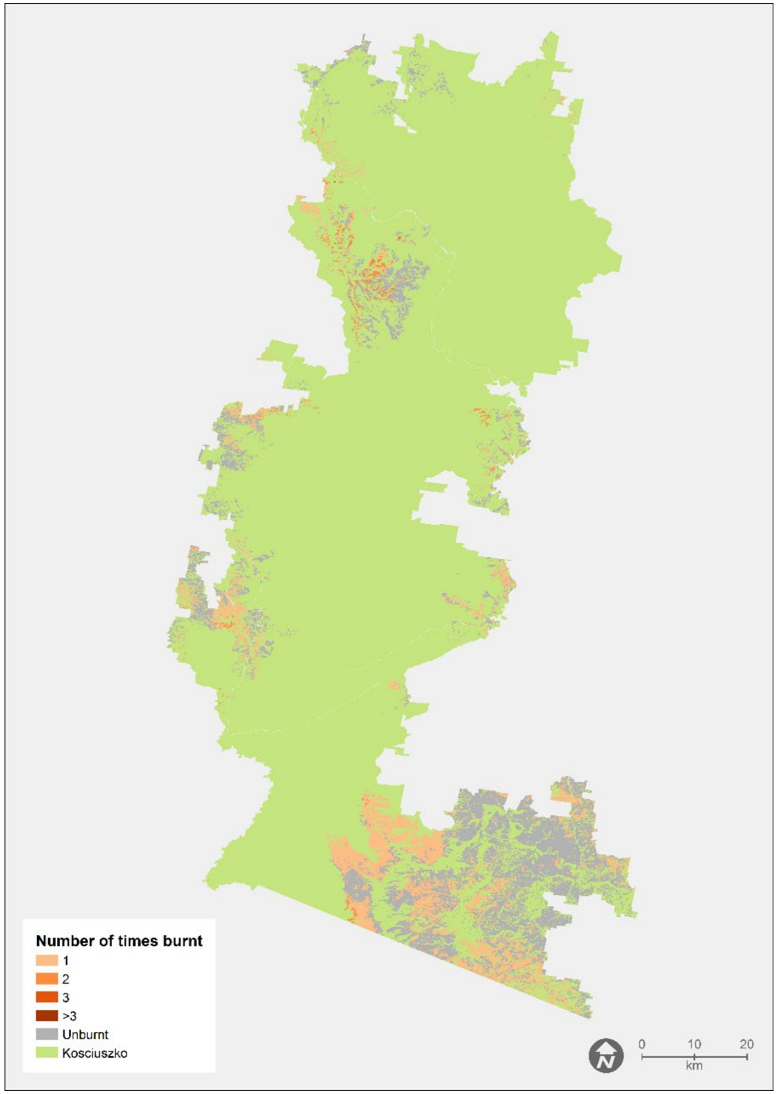


Figure 55 Fire frequency in dry sclerophyll forests (shrubby) over the last 30 years: all fire (left), canopy fire (right)

Dry sclerophyll forest (shrub/grass)

Dry sclerophyll forest (shrub/grass sub-formation) vegetation formation covers 2.2% (14,600 ha) of KNP. The desired fire interval for this vegetation formation is 9 to 50 years, or 15 to 50 years when the previous fire was of high severity (DCCEEW unpublished data 2024). These desired fire intervals do not, however, fully take into account fauna requirements.

Key findings

- 35% of the dry sclerophyll forest (shrub/grass) vegetation formation has not burnt for 30 years – 78% has not had a canopy fire in 30 years.
- About 9% of the dry sclerophyll forest (shrub/grass) vegetation formation has been burnt more frequently than the desired fire interval of 9 years, and much of this included the canopy being burnt (Figure 65 and Figure 66; Table 15).
- One significant fire event has occurred in this vegetation formation in the last 50 years during the 1998 to 2003 period, which burnt under half (49.5%) of the dry sclerophyll forest (shrub/grass) vegetation including 18% of the canopy (Figure 65 and Figure 67; Table 15).

Table 15 Fire history for dry sclerophyll forest (shrub/grass) in Kosciuszko National Park

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)	961	6.6	669	4.6
6 to 10 years	(2013–14 to 2017–18)	406	2.8	0	0
11 to 15 years	(2008–09 to 2012–13)	638	4.4	5	0
16 to 20 years	(2003–04 to 2007–08)	198	1.4	0	0
21 to 25 years	(1998–99 to 2002–03)	7,231	49.5	2,583	17.7
26 to 30 years	(1993–94 to 1997–98)	0	0	0	0
31 to 40 years	(1983–84 to 1992–93)	1,938	13.3	n/a*	n/a*
41 to 50 years	(1973–74 to 1982–83)	88	0.6	n/a	n/a
50+ years	(pre-1972–73)	n/a	n/a	n/a	n/a
30-year fire history*					
Area unburnt		5,165	35.38	11,342	77.68
Area burnt once		8,068	55.26	3,006	20.59
Area burnt twice		1,066	7.30	159	1.09
Area burnt 3 times		280	1.92	93	0.64
Area burnt >3 times		21	0.14	0	0

Note: 14,600 ha in KNP. Desired fire interval 9 to 50 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. Data is available only to 1973.

*Current data is available only from 1990–91; in subsequent years reporting of canopy fires will be extended to better represent the desired fire-interval range limits.

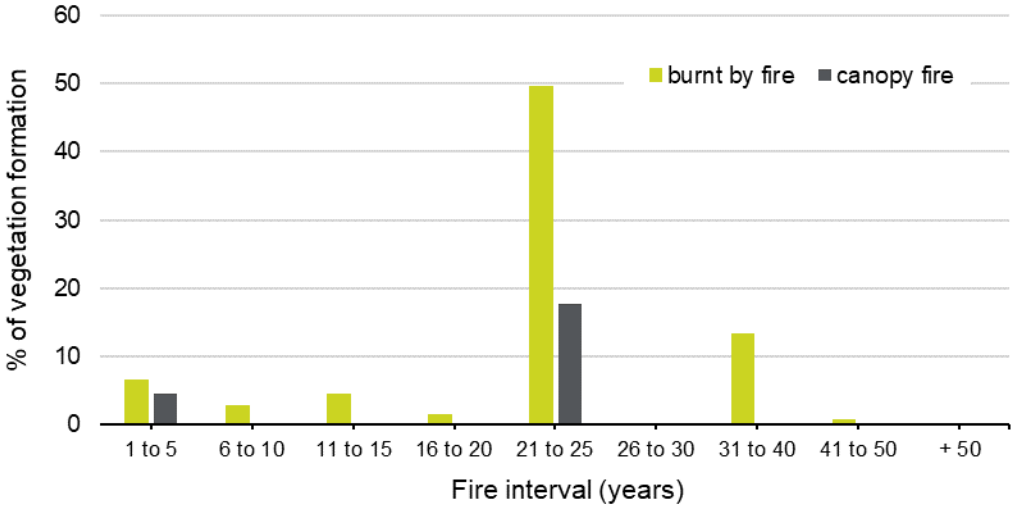


Figure 56 Percentage of dry sclerophyll forest (shrub/grass) burnt within each time interval for all fire and canopy fire (desired fire interval 9 to 50 years)

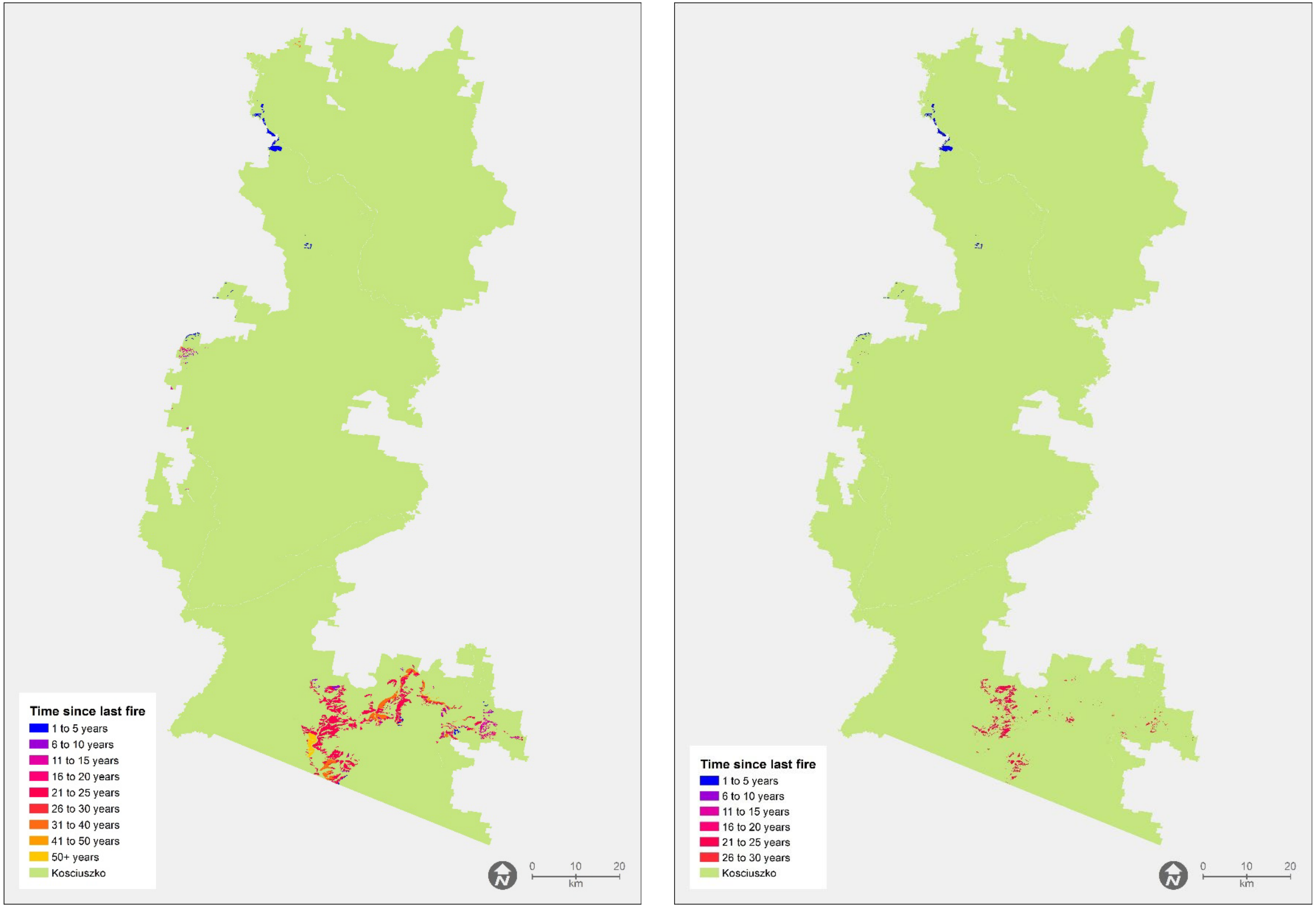
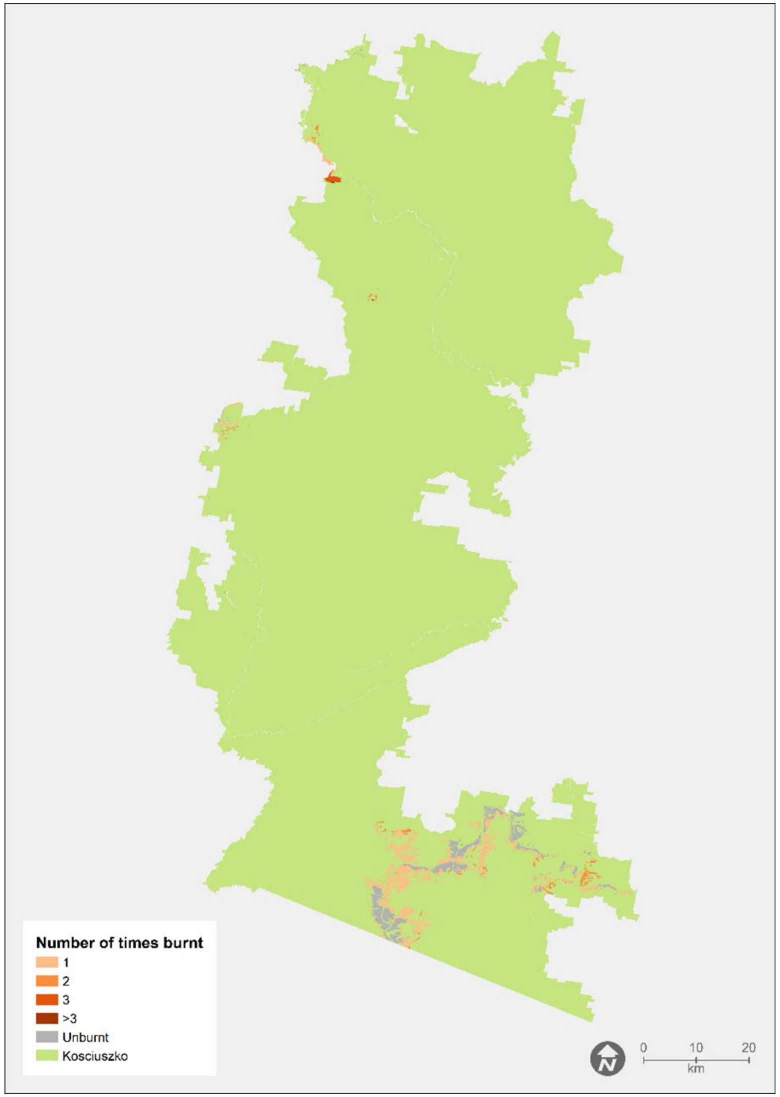


Figure 57 Fire history in dry sclerophyll forests (shrub/grass): all fire (left), canopy fire (right)



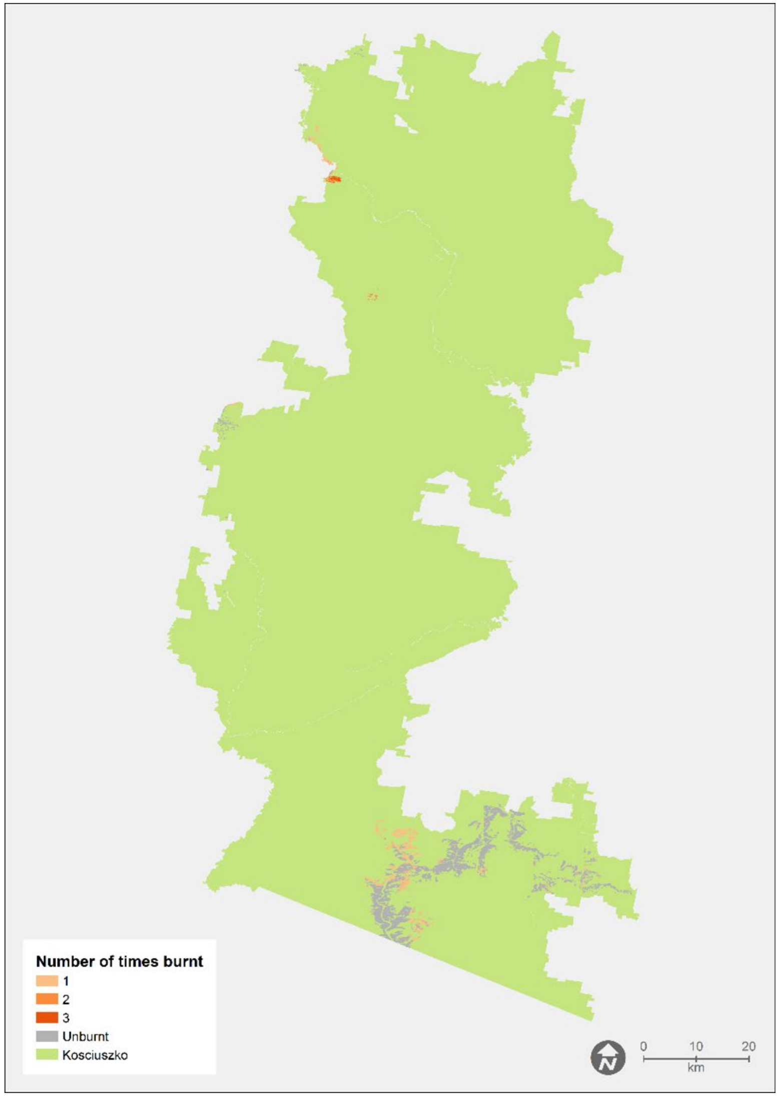


Figure 58 Fire frequency in dry sclerophyll forests (shrub/grass) over the last 30 years: all fire (left), canopy fire (right)

Grassy woodland

Grassy woodland vegetation formation covers 23.2% (156,023 ha) of KNP. The desired fire interval for this vegetation formation is 13 to 40 years, or 15 to 40 years when the previous fire was of high severity (DCCEEW unpublished data 2024). These desired fire intervals do not, however, fully take into account fauna requirements.

Sub-alpine grassy woodlands make up 79% of the grassy woodlands in KNP, and are dominated by one species, the snow gum. Recovery of snow gum after fire is from lignotubers, and the redevelopment of a mature open canopy may take decades. Climate change is creating more extreme conditions resulting in longer fire seasons associated with more extensive, intense and frequent fires (Abatzoglou et al. 2019; Jones et al. 2022) which may interact with other threats impacting the persistence of this slow-growing species.

Key findings

- About 9% of the grassy woodland vegetation has not burnt for at least 30 years, with almost half (49%) experiencing one burn in the last 30 years (Figure 70), 34% of the formation has not had a canopy burn in 30 years.
- About 46% of the grassy woodland vegetation formation has been burnt more frequently than the desired fire interval of 13 years, including 31% of the canopy being burnt, and indicates fire should be avoided in these areas (Figure 68 and Figure 69; Table 16).
- Two significant large fire events have occurred in the last 50 years: 43% of this community burnt in the period 2018 to 2023, and 40% of this community burnt between 1998 and 2003. The fires in both periods were of high severity, with about 32% of the canopy burning each time (Figure 68 and Figure 70; Table 16).

Table 16 **Fire history for grassy woodland in Kosciuszko National Park**

Fire history		Area (ha) burnt	% of formation	Area (ha) burnt by canopy fire	% of formation
Time since fire					
1 to 5 years	(2018–19 to 2022–23)	66,533	42.6	48,759	31.25
6 to 10 years	(2013–14 to 2017–18)	3,028	1.9	261	0.17
11 to 15 years	(2008–09 to 2012–13)	3,695	2.4	82	0.05
16 to 20 years	(2003–04 to 2007–08)	4,940	3.2	3,034	1.94
21 to 25 years	(1998–99 to 2002–03)	63,195	40.5	50,624	32.45
26 to 30 years	(1993–94 to 1997–98)	264	0.2	158	0.10
31 to 40 years	(1983–84 to 1992–93)	2,137	1.4	n/a*	n/a*
41 to 50 years	(1973–74 to 1982–83)	4,394	2.8	n/a	n/a
50+ years	(pre-1972–73)	n/a	n/a	n/a	n/a
30-year fire history*					
Area unburnt		14,368	9.21	53,104	34.04
Area burnt once		76,231	48.86	67,770	43.44
Area burnt twice		57,406	36.79	34,135	21.88
Area burnt 3 times		7,043	4.51	948	0.61
Area burnt >3 times		975	0.62	66	0.04

Note: 156,023 ha in KNP. Desired fire interval 13 to 40 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. Data is available only to 1973.

*Current data available only from 1990–91; in subsequent years reporting of canopy fires will be extended to better represent the desired fire-interval range limits

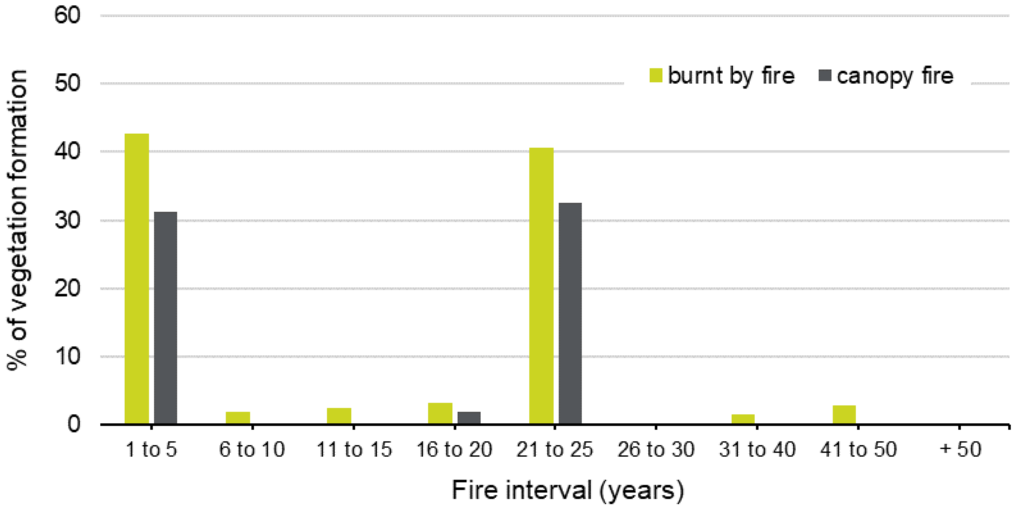


Figure 59 **Percentage of grassy woodland burnt within each time interval for all fire and canopy fire (desired fire interval 13 to 40 years)**

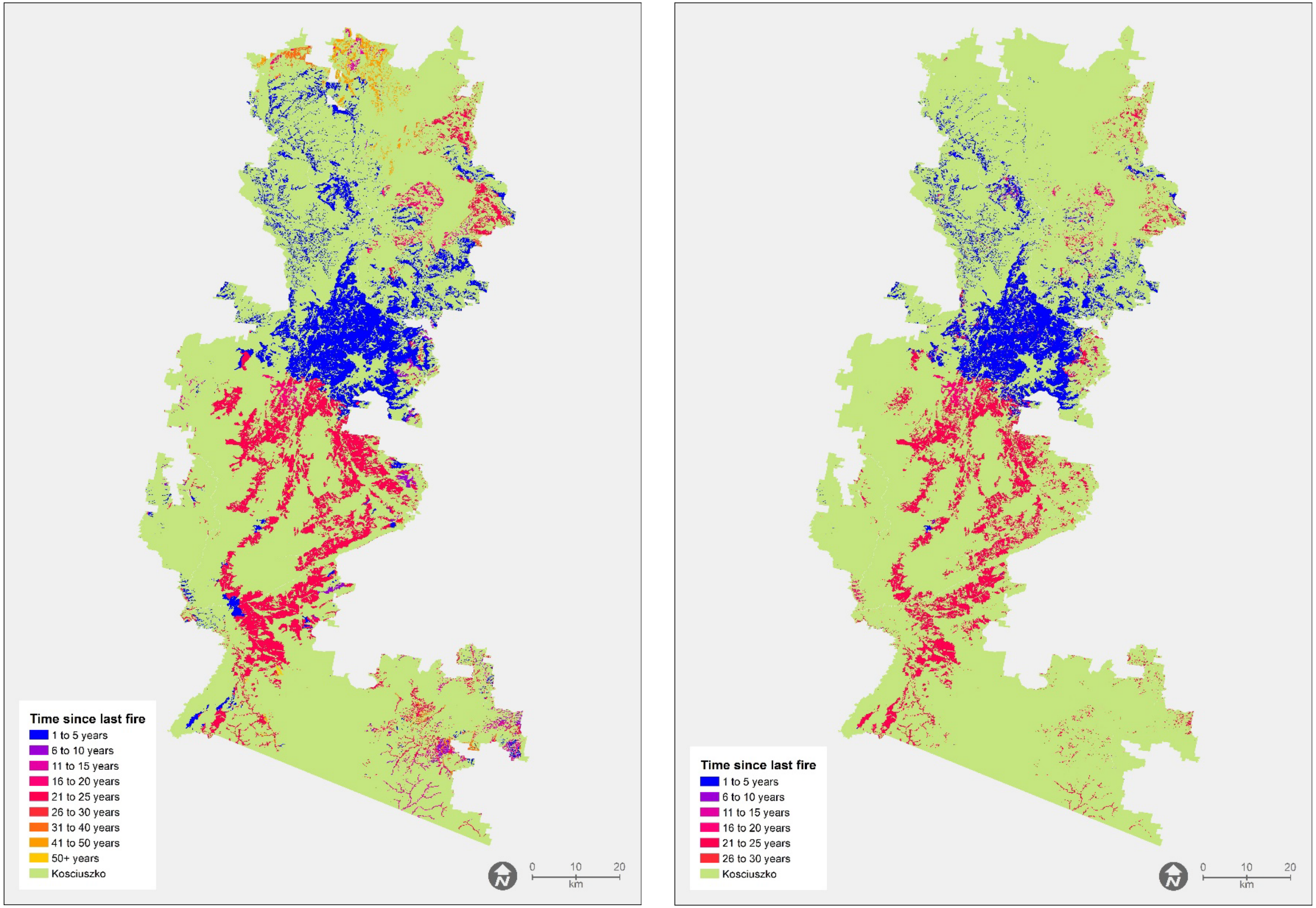


Figure 60 Fire history in grassy woodlands: all fire (left), canopy fire (right)

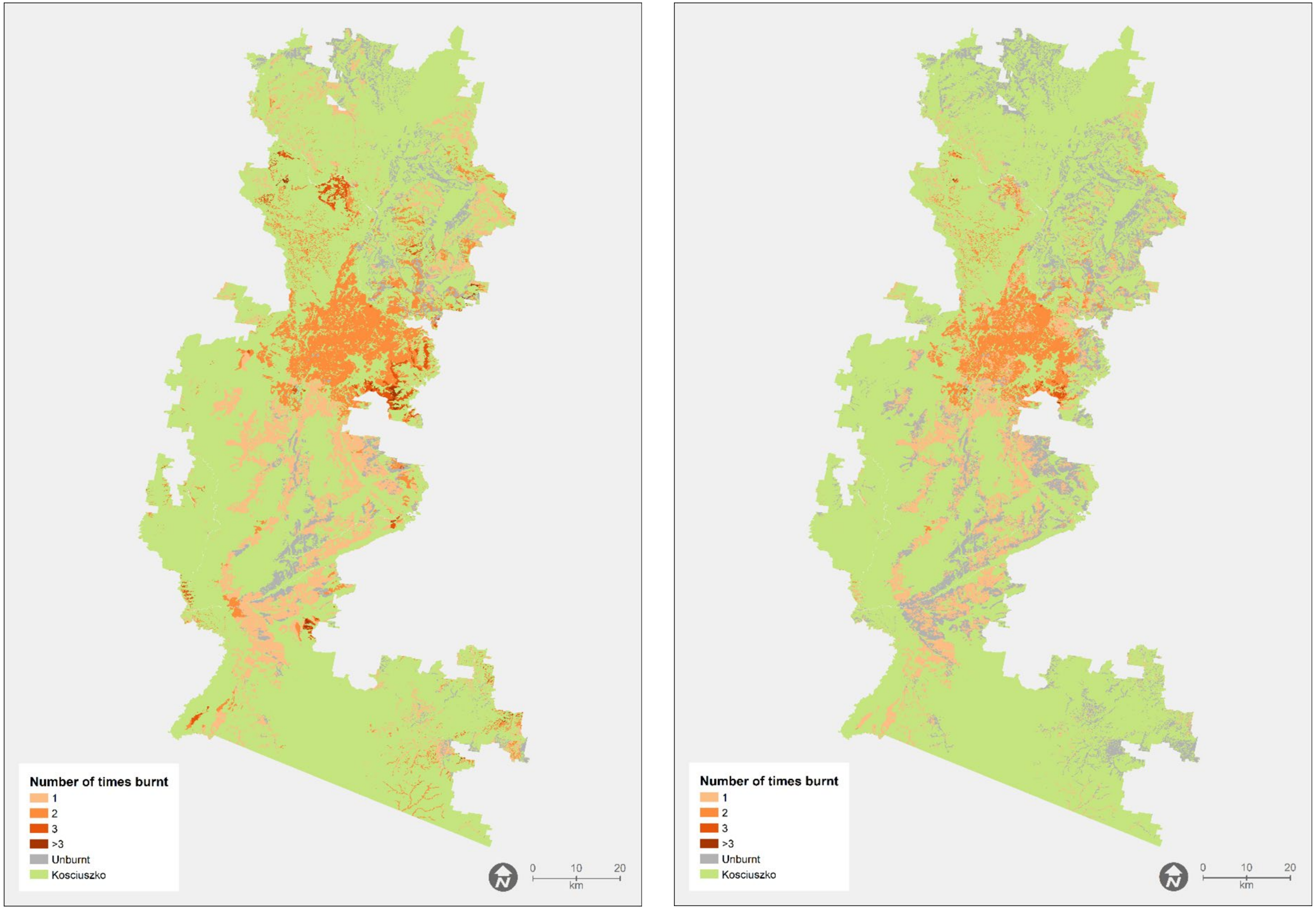


Figure 70 Fire frequency in grassy woodlands over the last 30 years: all fire (left), canopy fire (right)

Wet sclerophyll forest (grassy)

Wet sclerophyll forest (grassy sub-formation) vegetation formation covers 47.3% (319,904 ha) of KNP. The desired fire interval for this vegetation formation is 15 to 50 years regardless of whether the previous fire was of high severity (DCCEEW unpublished data 2024). These desired fire intervals do not, however, fully take into account fauna requirements.

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). The wet sclerophyll forests of KNP includes tall forests dominated by mountain gum and brown barrel, species which are known to recover after fire from epicormic growth. Other canopy species include the alpine ash, an obligate seeder which only germinates from seed after fire. This species requires long intervals between fire events for seed to reach maturity and the canopy may take up to 40 years to reform. It is common for the understorey vegetation formation to become thick and shrub-filled for the first 5 to 10 years following a fire, often comprised of Acacia species. The understorey will naturally thin over time when individual plants are outcompeted and shaded by the reforming canopy.

Key findings

- Only 12% of the wet sclerophyll forest (grassy) vegetation formation has not burnt for 30 years, 54% has not had a canopy fire for 30 years.
- About 51% of the wet sclerophyll forest (grassy) vegetation formation has been burnt within 15 years, more frequently than the desired fire interval, including 23% of the canopy being burnt, and indicates fire should be avoided in these areas (Figure 71 and Figure 72; Table 17).
- About 49% of the wet sclerophyll forest (grassy) vegetation has been burnt once, and a further 39% burnt twice or more, in the last 30 years (Figure 73).
- Two significant large fire events have occurred in the last 50 years: 1998–2003 and 2018–23. The fires in both periods were of high severity, with about 22% of the canopy burning each time (Figure 73; Table 17).

Table 17 Fire history for wet sclerophyll forest (grassy) in Kosciuszko National Park

Fire history		Area (ha) burnt	% of formation	Area (ha) burnt by canopy fire	% of formation
Time since fire					
1 to 5 years	(2018–19 to 2022–23)	142,441	44.6	71,746	22.49
6 to 10 years	(2013–14 to 2017–18)	10,482	3.3	554	0.17
11 to 15 years	(2008–09 to 2012–13)	8,892	2.8	75	0.02
16 to 20 years	(2003–04 to 2007–08)	8,001	2.5	5,201	1.63
21 to 25 years	(1998–99 to 2002–03)	111,123	34.8	70,257	22.02
26 to 30 years	(1993–94 to 1997–98)	370	0.1	182	0.06
31 to 40 years	(1983–84 to 1992–93)	5,550	1.7	n/a*	n/a*
41 to 50 years	(1973–74 to 1982–83)	16,806	5.3	n/a	n/a
50+ years	(pre-1972–73)	n/a	n/a	n/a	n/a
30-year Fire History*					
Area unburnt		37,725	11.82	171,021	53.61
Area burnt once		155,847	48.85	127,173	39.86
Area burnt twice		108,274	33.94	20,526	6.43
Area burnt 3 times		15,777	4.95	300	0.09
Area burnt > 3 times		1,411	0.44	14	0.00

Note: 319,034 ha in KNP. Desired fire interval 15 to 50 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. Data is available only to 1973.

*Current data available only from 1990–91; in subsequent years reporting of canopy fires will be extended to better represent the desired fire-interval range limits

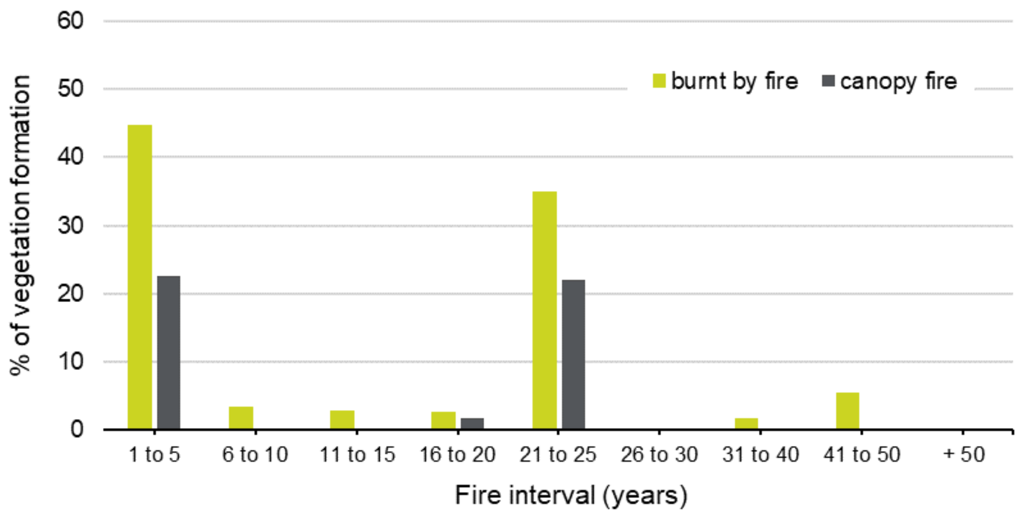


Figure 71 Percentage of wet sclerophyll forest (grassy) burnt within each time interval for all fire and canopy fire (desired fire interval 15 to 50 years)

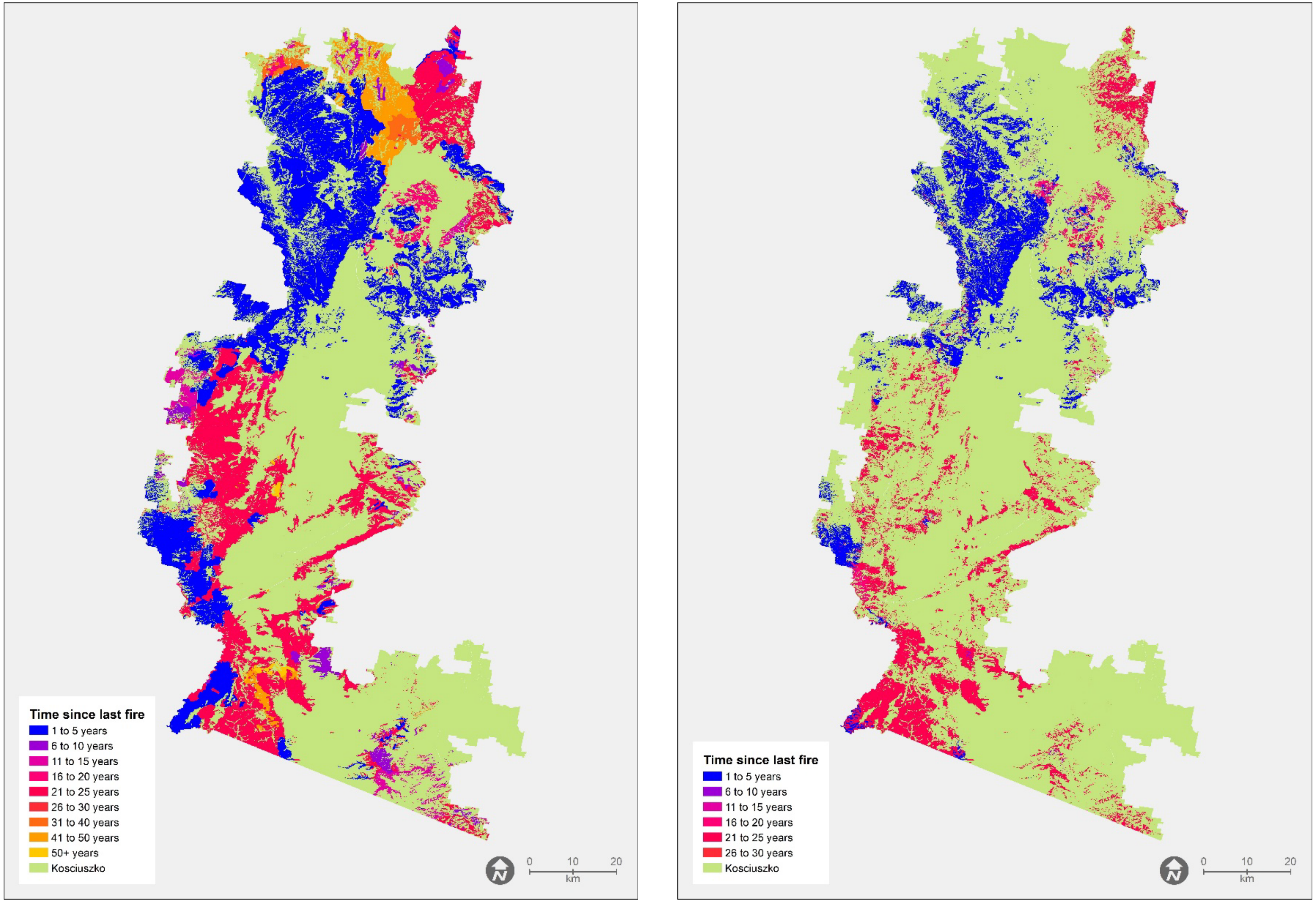


Figure 72 Fire history in wet sclerophyll forest (grassy): all fire (left), canopy fire (right)

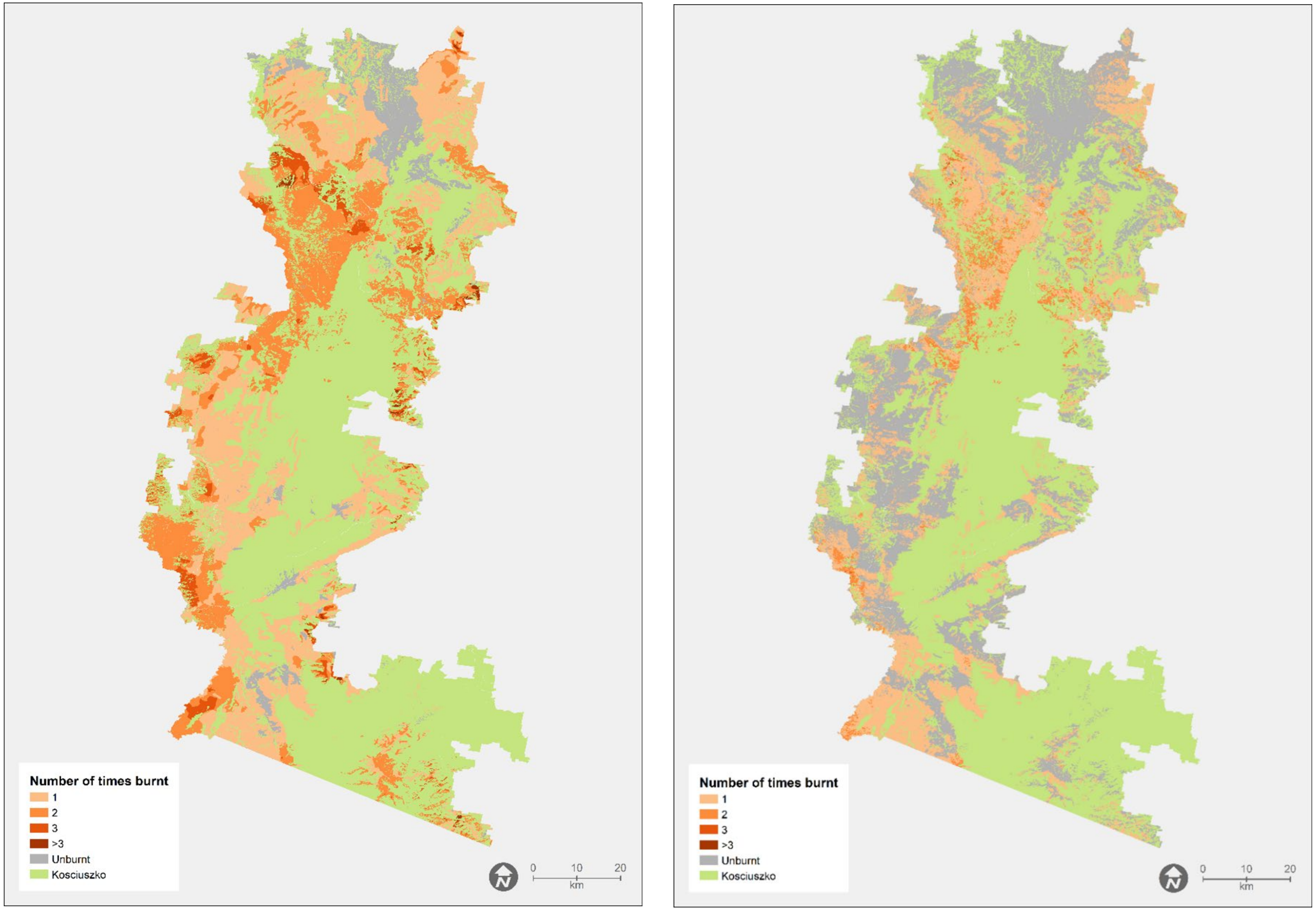


Figure 61 Fire frequency in wet sclerophyll forest (grassy) over the last 30 years: all fire (left), canopy fire (right)

Alpine complex

The Alpine complex covers 12.4% (83,839 ha) of KNP and is considered a fire-sensitive community (Kenny et al. 2003) which should not burn.

There are 56 species (both flora and fauna) listed in the Biodiversity Conservation Act found in this formation. Inappropriate fire frequency and intensity that destroys plants and depletes seed banks may lead to a decline or extinction of flora species in this vegetation formation. Conversely, inappropriate fire regimes that alter vegetation composition, structure and function of fauna habitat may lead to a reduction in suitable habitat and food availability and affect the persistence of these species in this vegetation formation in KNP.

Key findings

- Around 75% of the alpine complex vegetation formation has burnt in the last 30 years (Figure 74; Table 18).
- In the last 5 years (2018–2023), almost 26% of the alpine complex vegetation was burnt (Figure 74 and Figure 75; Table 18).
- Two significant large fire events have occurred in this vegetation formation in the last 50 years: 1998–2003 and 2018–23. Almost 42% of alpine complex vegetation was burnt in the 1998 to 2003 period (Figure 74; Table 18). Over half (52%) of the area covered by alpine complex in KNP has experienced at least one fire event.

Table 18 Fire history for the Alpine complex vegetation in Kosciuszko National Park

Fire history		Area (ha) burnt	% of formation
Time since fire			
1 to 5 years	(2018–19 to 2022–23)	21,750	25.9
6 to 10 years	(2013–14 to 2017–18)	153	0.2
11 to 15 years	(2008–09 to 2012–13)	307	0.4
16 to 20 years	(2003–04 to 2007–08)	5,735	6.8
21 to 25 years	(1998–99 to 2002–03)	34,981	41.7
26 to 30 years	(1993–94 to 1997–98)	4	0
31 to 40 years	(1983–84 to 1992–93)	265	0.3
41 to 50 years	(1973–74 to 1982–83)	379	0.5
50+ years	(pre-1972–73)	n/a	n/a
30-year fire history*			
Area unburnt		20,908	24.94
Area burnt once		43,143	51.46
Area burnt twice		18,263	21.78
Area burnt 3 times		1,450	1.73
Area burnt >3 times		75	0.09

Note: 83,839 ha in KNP. Fire sensitive vegetation. Canopy fire data does not apply to this vegetation type.

*Current data is available only from 1990–91; in subsequent years reporting of canopy fires will be extended to better represent the desired fire-interval range limits.

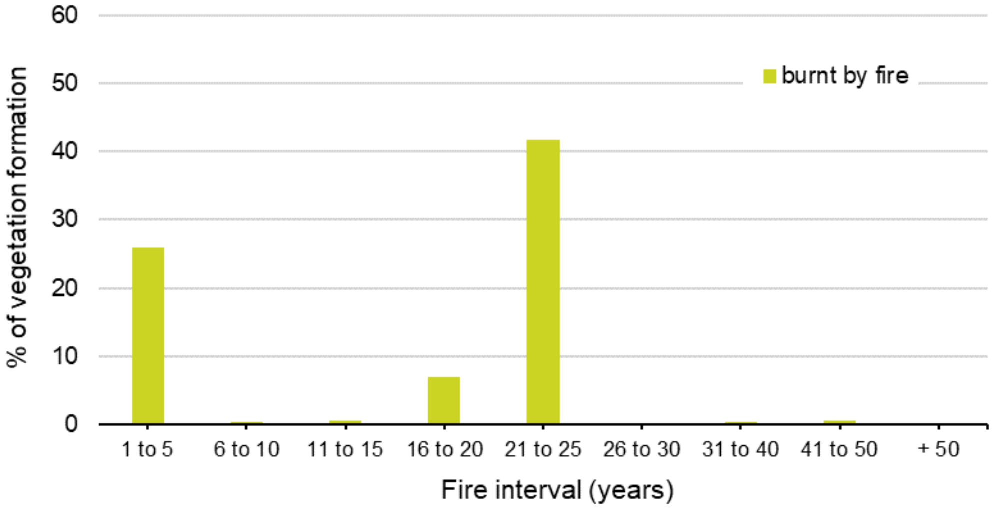


Figure 62 Percentage of alpine complex burnt within each time interval for all fires (fire-sensitive vegetation)

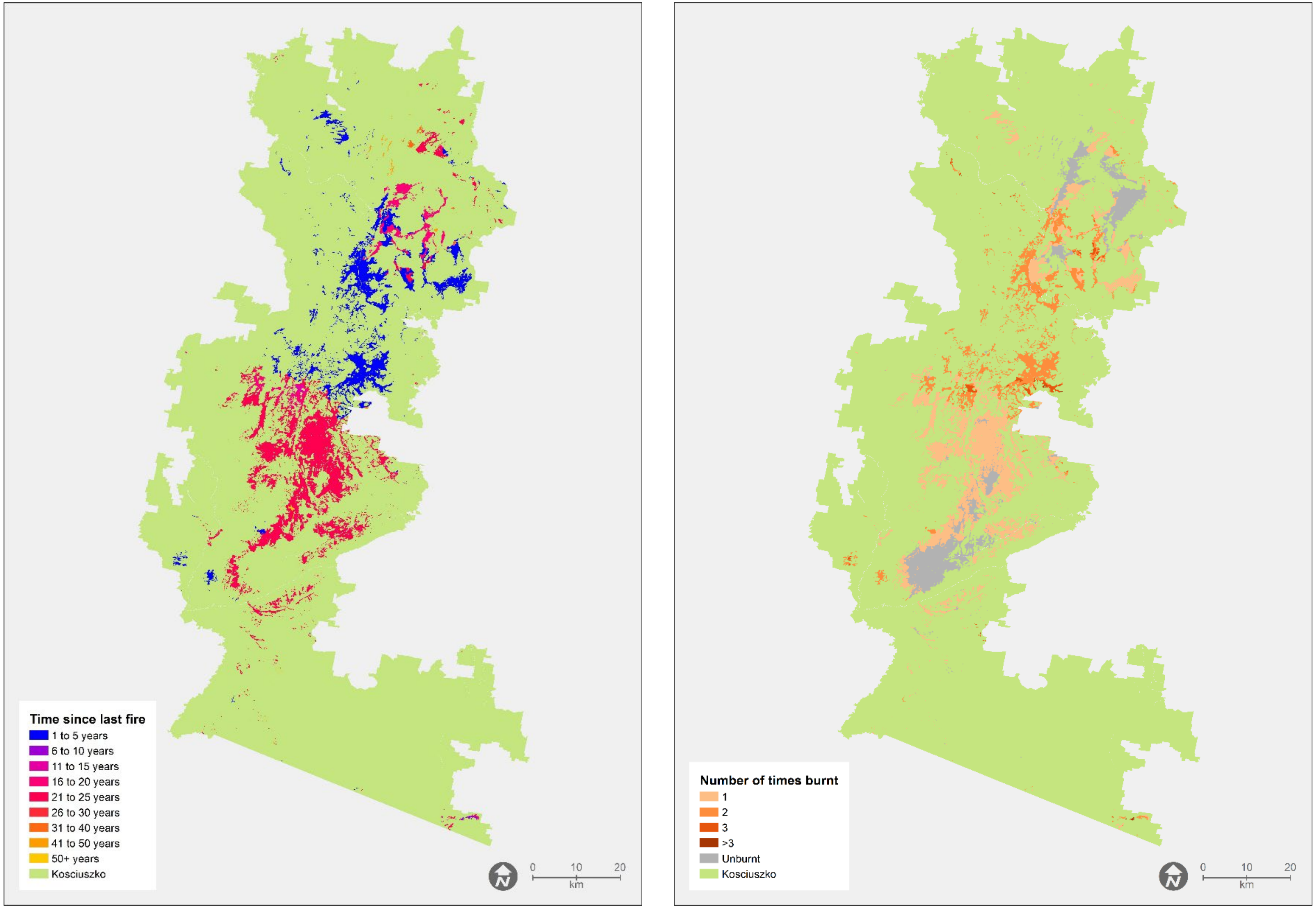


Figure 63 Fire history in alpine complex: time since last fire (left), and fire frequency (right)

Discussion

The aim for fire management in KNP is to prevent extensive and severe bushfires, 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 an appropriate combination of prescribed burning and fire suppression, particularly in the face a changing climate (Driscoll et al. 2024).

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Appendix 1

Lists of mammal species for Kosciuszko National Park

All mammal species recorded in KNP in the last 5 years are from records in the Atlas of Living Australia (ALA), and BioNet databases (30 June 2018 – 30 June 2023), as well as the 2022–23 Scorecards program (Table 19). A list of additional mammal species not recorded in the last 5 years in KNP is provided in Table 20.

Table 19 Mammals recorded in Kosciuszko National Park in the last 5 years (ALA and BioNet databases and the Scorecards program)

Mammal guild	Common name	Scientific name	Record source[1]	
			ALA/BioNet	Scorecard[2]
Small ground-dwelling				
	Agile antechinus	*Antechinus agilis*	✓	✓
	Broad-toothed rat	*Mastacomys fuscus*	✓	✓
	Bush rat	*Rattus fuscipes*	✓	✓
	Common dunnart	*Sminthopsis murina*	✓	✓
	Dusky antechinus	*Antechinus swainsonii*	✓	✓
	Mountain pygmy-possum	*Burramys parvus*	✓	×
	Smoky mouse	*Pseudomys fumeus*	✓	✓
	Swamp rat	*Rattus lutreolus*	✓	✓
Medium ground-dwelling				
	Long-nosed bandicoot	*Perameles nasuta*	✓	✓
	Short-beaked echidna	*Tachyglossus aculeatus*	✓	✓
	Spotted-tailed quoll	*Dasyurus maculatus*	✓	✓
Large (>15 kg)				
	Bare-nosed wombat	*Vombatus ursinus*	✓	✓
	Common wallaroo	*Osphranter robustus*	✓	✓
	Dingo	*Canis familiaris*	✓	✓
	Eastern grey kangaroo	*Macropus giganteus*	✓	✓
	Red-necked wallaby	*Notamacropus rufogriseus*	✓	✓
	Swamp wallaby	*Wallabia bicolor*	✓	✓
Semi-aquatic				
	Platypus	*Ornithorhynchus anatinus*	✓	×
	Water-rat	*Hydromys chrysogaster*	✓	✓
Arboreal				
	Common brushtail possum	*Trichosurus vulpecula*	✓	✓
	Common ringtail possum	*Pseudocheirus peregrinus*	✓	✓
	Eastern pygmy-possum	*Cercartetus nanus*	✓	✓
	Feathertail glider	*Acrobates pygmaeus*	✓	×

Mammal guild	Common name	Scientific name	Record source[1]	
			ALA/BioNet	Scorecard[2]
	Greater glider	*Petauroides volans*	✓	×
	Koala*	*Phascolarctos cinereus*	✓	✓
	Mountain brushtail possum	*Trichosurus cunninghami*	✓	✓
	Sugar glider	*Petaurus breviceps*	✓	×
	Squirrel glider	*Petaurus norfolcensis*	✓	×
	Yellow-bellied glider	*Petaurus australis*	✓	×
Bats – mega				
	Grey-headed flying-fox	*Pteropus poliocephalus*	✓	×
Bats – micro				
	Chocolate wattled bat	*Chalinolobus morio*	✓	✓
	Eastern false pipistrelle	*Falsistrellus tasmaniensis*	✓	✓
	Eastern freetail 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 bentwing bat	*Miniopterus orianae oceanensis*	✓	✓
	Large forest bat	*Vespadelus darlingtoni*	✓	✓
	Lesser long-eared bat	*Nyctophilus geoffroyi*	✓	✓
	Little forest bat	*Vespadelus vulturnus*	✓	✓
	Southern forest bat	*Vespadelus regulus*	✓	✓
	Southern myotis	*Myotis macropus*	✓	✓
	White-striped freetail bat	*Austronomus australis*	✓	✓
	Yellow-bellied sheathtail bat	*Saccolaimus flaviventris*	×	✓

*Records from ANU survey. Koalas detected at 6 sites.

[1] ✓ = recorded × = not recorded within each database.

[2] Scorecard records include detections from camera-based surveys, acoustic surveys and incidental sightings.

Table 20 Mammal not recorded in Kosciuszko National Park in the last 5 years (ALA and BioNet databases)

Mammal guild	Common name	Scientific name
Small ground-dwelling		
	Hastings River mouse*+	*Pseudomys oralis*
	New Holland mouse*+	*Pseudomys novaehollandiae*
	Long-tailed mouse*+	*Pseudomys higginsi*
	Yellow-footed antechinus	*Antechinus flavipes*
Medium ground-dwelling		
	Brush-tailed rock-wallaby*	*Petrogale penicillata*
	Eastern quoll*	*Dasyurus viverrinus*
	Long-footed potoroo*+	*Potorous longipes*
	Southern brown bandicoot*+	*Isoodon obesulus*
Arboreal		
	Brush-tailed phascogale+	*Phascogale tapoatafa*
	White-footed rabbit rat **+	*Conilurus albipes*
Bats		
	Eastern broad-nosed bat	*Scotorepens orion*
	South-eastern freetail bat	*Ozimops planiceps*

*Locally extinct

**Extinct

+ historic records and distribution from *The Action Plan for Australian Mammals 2012* (Burbidge et al. 2014)

Appendix 2

Lists of bird species for Kosciuszko National Park

All bird species recorded in KNP in the last 5 years are from records in the Atlas of Living Australia (ALA), BioNet and eBird databases, as well as records collected from cameras, acoustic devices and diurnal bird surveys during the 2022–23 Scorecards program (Table 21). A list of additional bird species not recorded in the last 5 years in KNP is also provided for those species expected (Table 22) and not expected to occur in the park (Table 23) based on records in the Atlas of Living Australia (ALA), BioNet and eBird databases.

Table 20 Birds recorded in **Kosciuszko National Park** in the last 5 years (ALA, BioNet and eBird databases and the Scorecards program)

		Record source[1]	
Common name	Scientific name	ALA/BioNet/eBird	Scorecard
Australasian darter	*Anhinga novaehollandiae*	✓	×
Australasian grebe	*Tachybaptus novaehollandiae*	✓	×
Australasian swamphen	*Porphyrio melanotus*	✓	×
Australian hobby	*Falco longipennis*	✓	✓
Australian king-parrot	*Alisterus scapularis*	✓	✓
Australian magpie	*Gymnorhina tibicen*	✓	✓
Australian masked owl	*Tyto novaehollandiae*	✓	×
Australian owlet-nightjar	*Aegotheles cristatus*	✓	✓
Australian pelican	*Pelecanus conspicillatus*	✓	×
Australian pipit	*Anthus novaeseelandiae*	✓	✓
Australian raven	*Corvus coronoides*	✓	✓
Australian reed-warbler	*Acrocephalus australis*	✓	×
Australian rufous fantail	*Rhipidura rufifrons*	✓	✓
Australian wood duck	*Chenonetta jubata*	✓	✓
Azure kingfisher	*Ceyx azureus*	✓	×
Barking owl	*Ninox connivens*	✓	×
Bassian thrush	*Zoothera lunulata*	✓	✓
Black kite	*Milvus migrans*	✓	×
Black swan	*Cygnus atratus*	✓	✓
Black-eared cuckoo	*Chalcites osculans*	✓	×
Black-faced cuckoo-shrike	*Coracina novaehollandiae*	✓	✓
Black-faced monarch	*Monarcha melanopsis*	✓	×
Black-fronted dotterel	*Charadrius melanops*	✓	×
Australian white ibis	*Threskiornis molucca*	✓	×
Black-shouldered kite	*Elanus axillaris*	✓	×
Brown cuckoo-dove	*Macropygia phasianella*	✓	×
Brown falcon	*Falco berigora*	✓	✓
Brown goshawk	*Accipiter fasciatus*	✓	✓
Brown quail	*Synoicus ypsilophorus*	✓	✓

Common name	Scientific name	Record source[1]	
		ALA/BioNet/eBird	Scorecard
Brown songlark	*Cincloramphus cruralis*	✓	×
Brown thornbill	*Acanthiza pusilla*	✓	✓
Brown treecreeper	*Climacteris picumnus*	✓	✓
Brown-headed honeyeater	*Melithreptus brevirostris*	✓	×
Brush bronzewing	*Phaps elegans*	✓	×
Brush cuckoo	*Cacomantis variolosus*	✓	✓
Budgerigar	*Melopsittacus undulatus*	✓	×
Buff-banded rail	*Hypotaenidia philippensis*	✓	×
Buff-rumped thornbill	*Acanthiza reguloides*	✓	✓
Cattle egret	*Bubulcus ibis*	✓	×
Chestnut teal	*Anas castanea*	✓	×
Chestnut-rumped heathwren	*Hylacola pyrrhopygia*	✓	✓
Collared sparrowhawk	*Accipiter cirrocephalus*	✓	✓
Common bronzewing	*Phaps chalcoptera*	✓	✓
Common cicadabird	*Edolisoma tenuirostre*	✓	×
Crescent honeyeater	*Phylidonyris pyrrhopterus*	✓	✓
Crested pigeon	*Ocyphaps lophotes*	✓	✓
Crimson rosella	*Platycercus elegans*	✓	✓
Diamond firetail	*Stagonopleura guttata*	✓	✓
Dollarbird	*Eurystomus orientalis*	✓	×
Dusky moorhen	*Gallinula tenebrosa*	✓	✓
Dusky woodswallow	*Artamus cyanopterus*	✓	✓
Eastern barn owl	*Tyto javanica*	✓	×
Eastern rosella	*Platycercus eximius*	✓	✓
Eastern shrike-tit	*Falcunculus frontatus*	✓	×
Eastern spinebill	*Acanthorhynchus tenuirostris*	✓	✓
Eastern whipbird	*Psophodes olivaceus*	✓	✓
Eastern yellow robin	*Eopsaltria australis*	✓	✓
Emu	*Dromaius novaehollandiae*	✓	✓
Eurasian coot	*Fulica atra*	✓	×
Fairy martin	*Petrochelidon ariel*	✓	×
Fan-tailed cuckoo	*Cacomantis flabelliformis*	✓	✓
Flame robin	*Petroica phoenicea*	✓	✓
Fuscous honeyeater	*Ptilotula fusca*	✓	×
Galah	*Eolophus roseicapilla*	✓	✓
Gang-gang cockatoo	*Callocephalon fimbriatum*	✓	✓
Glossy black-cockatoo	*Calyptorhynchus lathami*	✓	✓
Golden whistler	*Pachycephala pectoralis*	✓	✓
Golden-headed cisticola	*Cisticola exilis*	✓	×
Great cormorant	*Phalacrocorax carbo*	✓	×
Grey butcherbird	*Cracticus torquatus*	✓	✓
Grey currawong	*Strepera versicolor*	✓	✓
Grey fantail	*Rhipidura albiscapa*	✓	✓

Common name	Scientific name	Record source[1]	
		ALA/BioNet/eBird	Scorecard
Grey goshawk	*Accipiter novaehollandiae*	✓	×
Grey shrike-thrush	*Colluricincla harmonica*	✓	✓
Grey teal	*Anas gracilis*	✓	×
Hardhead	*Aythya australis*	✓	×
Hoary-headed grebe	*Poliocephalus poliocephalus*	✓	×
Hooded robin	*Melanodryas cucullata*	✓	×
Horsfield's bronze-cuckoo	*Chrysococcyx basalis*	✓	×
Jacky winter	*Microeca fascinans*	✓	✓
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 crow	*Corvus bennetti*	✓	×
Little eagle	*Hieraaetus morphnoides*	✓	×
Little friarbird	*Philemon citreogularis*	✓	✓
Little grassbird	*Poodytes gramineus*	✓	✓
Little lorikeet	*Parvipsitta pusilla*	✓	×
Little pied cormorant	*Microcarbo melanoleucos*	✓	×
Little raven	*Corvus mellori*	✓	✓
Magpie-lark	*Grallina cyanoleuca*	✓	✓
Masked lapwing	*Vanellus miles*	✓	✓
Masked woodswallow	*Artamus personatus*	✓	×
Mistletoebird	*Dicaeum hirundinaceum*	✓	×
Nankeen kestrel	*Falco cenchroides*	✓	✓
Nankeen night heron	*Nycticorax caledonicus*	✓	×
New holland honeyeater	*Phylidonyris novaehollandiae*	✓	✓
Noisy friarbird	*Philemon corniculatus*	✓	✓
Noisy miner	*Manorina melanocephala*	✓	✓
Olive whistler	*Pachycephala olivacea*	✓	✓
Olive-backed oriole	*Oriolus sagittatus*	✓	✓
Pacific black duck	*Anas superciliosa*	✓	✓
Painted button-quail	*Turnix varius*	✓	✓
Painted honeyeater	*Grantiella picta*	✓	×
Pallid cuckoo	*Cacomantis pallidus*	✓	×
Peaceful dove	*Geopelia placida*	✓	×
Peregrine falcon	*Falco peregrinus*	✓	✓
Pied butcherbird	*Cracticus nigrogularis*	✓	✓
Pied cormorant	*Phalacrocorax varius*	✓	×
Pied currawong	*Strepera graculina*	✓	✓
Pilotbird	*Pycnoptilus floccosus*	✓	✓

		Record source[1]	
Common name	**Scientific name**	**ALA/BioNet/eBird**	**Scorecard**
Pink robin	*Petroica rodinogaster*	✓	✓
Powerful owl	*Ninox strenua*	✓	✓
Rainbow bee-eater	*Merops ornatus*	✓	✓
Rainbow lorikeet	*Trichoglossus haematodus*	✓	×
Red wattlebird	*Anthochaera carunculata*	✓	✓
Red-browed finch	*Neochmia temporalis*	✓	✓
Red-browed treecreeper	*Climacteris erythrops*	✓	✓
Red-capped robin	*Petroica goodenovii*	✓	✓
Red-chested button-quail	*Turnix pyrrhothorax*	✓	×
Red-rumped parrot	*Psephotus haematonotus*	✓	✓
Regent honeyeater	*Anthochaera phrygia*	✓	×
Restless flycatcher	*Myiagra inquieta*	✓	×
Rose robin	*Petroica rosea*	✓	✓
Rufous songlark	*Cincloramphus mathewsi*	✓	×
Rufous whistler	*Pachycephala rufiventris*	✓	✓
Sacred kingfisher	*Todiramphus sanctus*	✓	✓
Satin bowerbird	*Ptilonorhynchus violaceus*	✓	✓
Satin flycatcher	*Myiagra cyanoleuca*	✓	✓
Scarlet honeyeater	*Myzomela sanguinolenta*	✓	×
Scarlet robin	*Petroica boodang*	✓	✓
Shining bronze-cuckoo	*Chrysococcyx lucidus*	✓	✓
Silver gull	*Chroicocephalus novaehollandiae*	✓	×
Silvereye	*Zosterops lateralis*	✓	✓
Singing honeyeater	*Gavicalis virescens*	✓	×
Sooty owl	*Tyto tenebricosa*	✓	×
Southern boobook	*Ninox boobook*	✓	✓
Speckled warbler	*Pyrrholaemus sagittatus*	✓	×
Spotted nightjar	*Eurostopodus argus*	✓	×
Spotted pardalote	*Pardalotus punctatus*	✓	✓
Spotted quail-thrush	*Cinclosoma punctatum*	✓	✓
Straw-necked ibis	*Threskiornis spinicollis*	✓	×
Striated pardalote	*Pardalotus striatus*	✓	✓
Striated thornbill	*Acanthiza lineata*	✓	✓
Stubble quail	*Coturnix pectoralis*	✓	×
Sulphur-crested cockatoo	*Cacatua galerita*	✓	✓
Superb fairy-wren	*Malurus cyaneus*	✓	✓
Superb lyrebird	*Menura novaehollandiae*	✓	✓
Swamp harrier	*Circus approximans*	✓	✓
Swift parrot	*Lathamus discolor*	✓	×
Tawny frogmouth	*Podargus strigoides*	✓	✓
Tree martin	*Petrochelidon nigricans*	✓	×
Turquoise parrot	*Neophema pulchella*	✓	✓
Varied sittella	*Daphoenositta chrysoptera*	✓	✓

Common name	Scientific name	Record source[1]	
		ALA/BioNet/eBird	Scorecard
Variegated fairy-wren	*Malurus lamberti*	✓	✓
Wedge-tailed eagle	*Aquila audax*	✓	✓
Weebill	*Smicrornis brevirostris*	✓	✓
Welcome swallow	*Hirundo neoxena*	✓	×
Western gerygone	*Gerygone fusca*	✓	×
Whistling kite	*Haliastur sphenurus*	✓	×
White-bellied cuckoo-shrike	*Coracina papuensis*	✓	×
White-bellied sea-eagle	*Icthyophaga leucogaster*	✓	×
White-browed scrubwren	*Sericornis frontalis*	✓	✓
White-browed woodswallow	*Artamus superciliosus*	✓	×
White-eared honeyeater	*Nesoptilotis leucotis*	✓	✓
White-faced heron	*Egretta novaehollandiae*	✓	✓
White-fronted chat	*Epthianura albifrons*	✓	×
White-naped honeyeater	*Melithreptus lunatus*	✓	✓
White-plumed honeyeater	*Ptilotula penicillata*	✓	✓
White-throated gerygone	*Gerygone olivacea*	✓	✓
White-throated honeyeater	*Melithreptus albogularis*	✓	×
White-throated needletail	*Hirundapus caudacutus*	✓	✓
White-throated nightjar	*Eurostopodus mystacalis*	✓	×
White-throated treecreeper	*Cormobates leucophaea*	✓	✓
White-winged chough	*Corcorax melanorhamphos*	✓	✓
White-winged triller	*Lalage tricolor*	✓	×
Willie wagtail	*Rhipidura leucophrys*	✓	✓
Wonga pigeon	*Leucosarcia melanoleuca*	✓	✓
Yellow thornbill	*Acanthiza nana*	✓	×
Yellow-faced honeyeater	*Caligavis chrysops*	✓	✓
Yellow-rumped thornbill	*Acanthiza chrysorrhoa*	✓	✓
Yellow-tailed black-cockatoo	*Zanda funerea*	✓	✓
Yellow-tufted honeyeater	*Lichenostomus melanops*	✓	✓

[1] ✓ = recorded

× = not recorded from ALA, BioNet, eBird or Scorecard

Table 21 Bird species not recorded in the last 5 years in Kosciuszko National Park but still expected to occur in the park (ALA, BioNet and eBird databases)

Common name	Scientific name
Australasian shoveler	*Anas rhynchotis*
Australian ibis	*Threskiornis molucca*
Australian painted snipe	*Rostratula australis*
Australian shelduck	*Tadorna tadornoides*
Banded lapwing	*Vanellus tricolor*
Barn owl	*Tyto alba*
Black falcon	*Falco subniger*
Blue-winged parrot	*Neophema chrysostoma*
Fork-tailed swift	*Apus pacificus*
Great crested grebe	*Podiceps cristatus*
Great egret	*Ardea alba*
Musk duck	*Biziura lobata*
Purple swamphen	*Porphyrio porphyrio*
Singing bushlark	*Mirafra javanica*
Southern whiteface	*Aphelocephala leucopsis*
Square-tailed kite	*Lophoictinia isura*
Yellow-billed spoonbill	*Platalea flavipes*

Table 22 Bird species historically recorded in Kosciuszko National Park (ALA, BioNet and eBird databases) and are not expected to occur in the park

Common name	Scientific name
Australasian bittern	*Botaurus poiciloptilus*
Australian bustard	*Ardeotis australis*
Australian ringneck	*Barnardius zonarius*
Australian spotted crake	*Porzana fluminea*
Banded stilt	*Cladorhynchus leucocephalus*
Bell miner	*Manorina melanophrys*
Black-faced woodswallow	*Artamus cinereus*
Black-necked ibis	*Threskiornis moluccus*
Bush stone-curlew	*Burhinus grallarius*
Channel-billed cuckoo	*Scythrops novaehollandiae*
Common sandpiper	*Actitis hypoleucos*
Crested bellbird	*Oreoica gutturalis*
Diamond dove	*Geopelia cuneata*
Double-barred finch	*Stizoptera bichenovii*
Freckled duck	*Stictonetta naevosa*
Gilbert's whistler	*Pachycephala inornata*
Glossy ibis	*Plegadis falcinellus*
Grey falcon	*Falco hypoleucos*
Letter-winged kite	*Elanus scriptus*
Little egret	*Egretta garzetta*

Common name	Scientific name
Musk lorikeet	*Glossopsitta concinna*
Orange-bellied parrot	*Neophema chrysogaster*
Pacific koel	*Eudynamys orientalis*
Pale-yellow robin	*Tregellasia capito*
Pied stilt	*Himantopus leucocephalus*
Pink-eared duck	*Malacorhynchus membranaceus*
Plumed egret	*Ardea plumifera*
Plumed whistling-duck	*Dendrocygna eytoni*
Red-kneed dotterel	*Erythrogonys cinctus*
Royal spoonbill	*Platalea regia*
Sharp-tailed sandpiper	*Calidris acuminata*
Shining flycatcher	*Myiagra alecto*
Short-tailed shearwater	*Ardenna tenuirostris*
Slender-billed cicadabird	*Edolisoma tenuirostre*
Spotless crake	*Zapornia tabuensis*
Spotted harrier	*Circus assimilis*
Superb parrot	*Polytelis swainsonii*
Whiskered tern	*Chlidonias hybrida*
White-backed swallow	*Cheramoeca leucosterna*