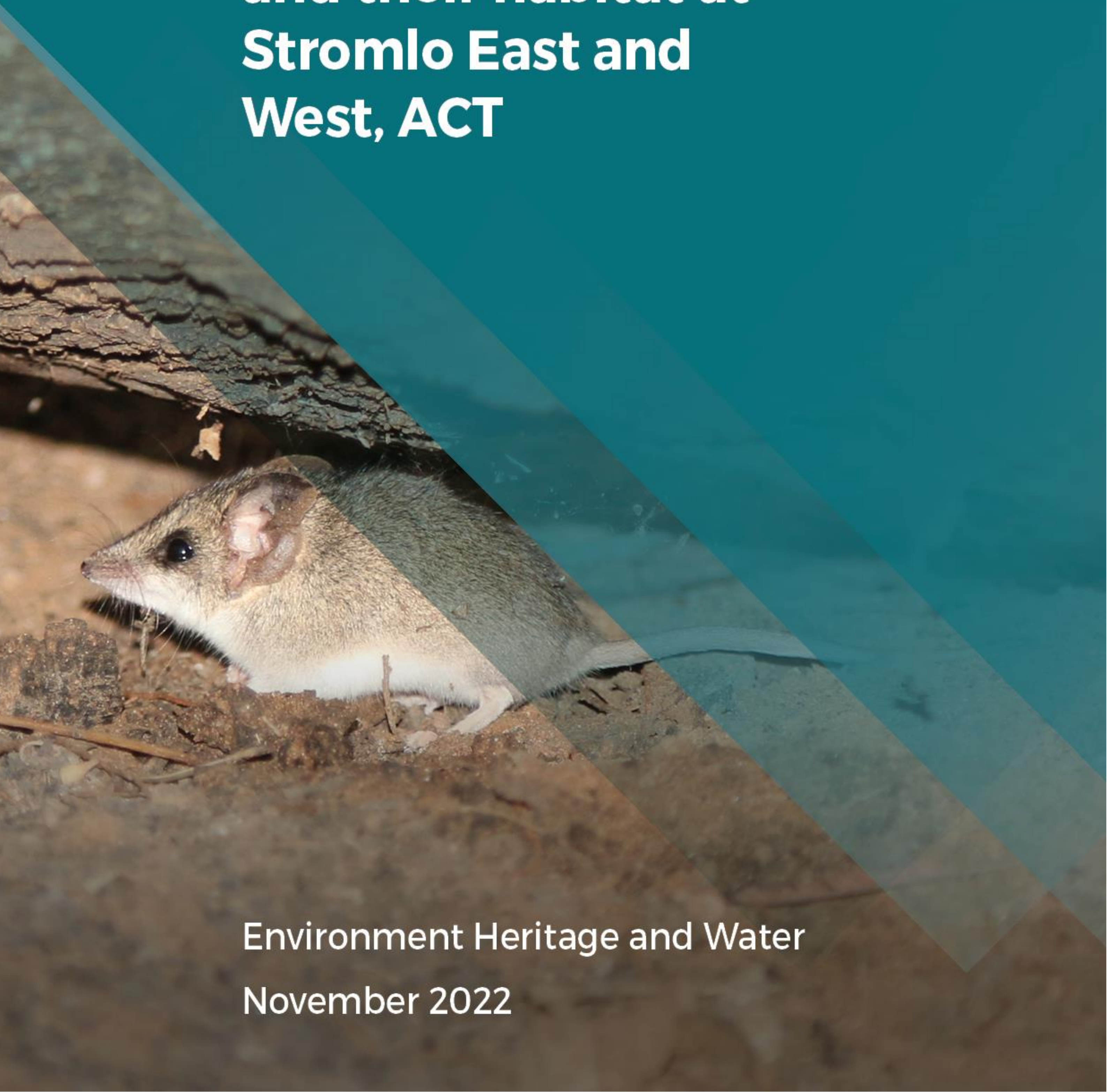
A preliminary survey of small native mammals and their habitat at Stromlo East and West, ACT



Environment Heritage and Water

November 2022

Yuma
Dhawura Nguna Dhawura Ngunnawal
Ngunnawalwari dhawurawari
Nginggada Dindi yindumaralidjinyin
Dhawura Ngunnawal yindumaralidjinyin

Hello
This is Ngunnawal Country
We always respect Elders, male and female
We always respect Ngunnawal Country

We acknowledge the Traditional Custodians of the ACT, the Ngunnawal people. We recognise the special relationship and connection that Ngunnawal people have with this Country. Ngunnawal people are a thriving community whose life and culture are intrinsically connected to this land in a way that is core to their physical and spiritual wellbeing, their cultural practices, law/lore, songlines and stories.

Ngunnawal people have maintained a tangible and intangible cultural, social, environmental, spiritual, and economic connection to these lands and waters for thousands of years.

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A preliminary survey of small native mammals and their habitat at Stromlo East and West, ACT

Conservation Research and ACT Parks and Conservation Service
Environment, Planning and Sustainable Development Directorate

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ACT Government
Environment, Planning and Sustainable Development

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Front cover: Common Dunnart by Chris Malam

Contents

List of abbreviations

ACT – Australian Capital Territory

CNP – Canberra Nature Park

FUA – Future Urban Area

GPS – Geographic Positioning System

NCA – National Capital Authority

NUZ – Non-Urban Zone

PCA – Principal Component Analysis

PCs – Principal Components

PCS – Parks and Conservation Service

SFAZ – Strategic Firefighting Advantage Zone

Summary

Small native mammals in the Australian Capital Territory (ACT) are under increasing pressure from habitat loss due to urban expansion, predation by introduced species, and diminished habitat complexity resulting from inappropriate fire regimes, particularly in habitat abutting urban areas. Surveying for small native mammal populations in Canberra Nature Park (CNP) in the ACT was initially conducted in the 1970s (Kukolic, 1990), and three native small mammals were confirmed present: Agile Antechinus (*Antechinus agilis*), Yellow-footed Antechinus (*Antechinus flavipes*), and Common Dunnart (*Sminthopsis murina*). Subsequent surveys have led to few or no detections of these species in areas of CNP where they were once found (Devlin, 1999; Buckmaster, 2005). While these surveys were limited to Black Mountain and Ainslie-Majura Nature Reserves, the absence of detections suggests that local populations of small native mammals are missing from these reserves, and likely to be in decline more broadly in CNP.

In 2020 a single antechinus was recorded at Stromlo East, a remnant patch of Red Stringybark-Scribbly Gum forest abutting the suburb of Denman Prospect. This was a significant find given the historical decline of small native mammals in CNP, suggesting small native mammals may persist in some areas of Canberra where remnant habitat patches remain intact and connected and where impacts from urban development and changed fire regimes are relatively low.

The finding prompted the present work. This study gathered baseline data on the abundance and diversity of small native mammals at Stromlo East (Stromlo Blocks 402 and 403 and Denman Prospect Block 12 Section 1) and Stromlo West (Stromlo Blocks 59 and 511)[1]. These two areas form a remnant patch of endangered Red Gum-Yellow Box grassy woodland with high ecological values, including critically endangered derived native grassland, rare and threatened native flora, the vulnerable Pink-Tailed Worm Lizard, and many woodland bird species. The site is an area of significant conservation concern to Canberra's citizens, particularly in the context of expanding urban development (Denman Prospect) adjacent to Stromlo East. Threats to small native mammals at the site include introduced predators, urban edge effects, and inappropriate fire management. The changing pressures of these threats were considered and incorporated in the design of this study to enable monitoring of impacts over time.

In the autumn of 2021, infrared and white flash cameras were used to monitor the activity of native and introduced fauna at 70 locations across the two sites. Habitat assessments were subsequently performed to identify habitat characteristics associated with small native mammal presence. Common Dunnarts were recorded by eight cameras across Stromlo East and Stromlo West, most frequently in Red Stringybark-Scribbly Gum open forests and Red Gum-Yellow Box grassy woodland. Introduced predators, Red Foxes (*Vulpes vulpes*) and Feral Cats (*Felis catus*), hereafter foxes and cats, were recorded at both sites, with fox activity higher in proximity to roads and trails. No antechinus were recorded in this survey.

Statistical analysis of habitat data found that sites where Common Dunnarts were detected differed in habitat structure and composition, but generally displayed lower canopy cover and reduced leaf litter than sites where Common Dunnarts were not detected. As high canopy cover and leaf litter density can suppress the growth of ground story vegetation, this may reflect dependency by

[1] ACT Blocks: https://data.actmapi.act.gov.au/arcgis/rest/services/data_extract/Land_Administration/MapServer/4

Common Dunnarts on higher groundstorey vegetation cover. Groundstorey vegetation such as tussock grasses, sedges, and low shrubs provide cover from predation and may facilitate foraging. Ongoing monitoring of small native mammal occupancy and associated habitat characteristics will help to elucidate key habitat variables that support small native mammal persistence.

Small native mammals were detected within 100 m of an area zoned for future residential development and associated fire fuel management (Denman Prospect Block 12 Section 1) in the Stromlo East study area. The scale of impacts on small native mammal habitat will rely on the extent of residential development and fire management within Denman Prospect Block 12 and the resulting buffer distance between the suburban edge and the remaining small native mammal habitat within the study area. Ongoing monitoring is needed to understand small native mammal and introduced predator responses to increased recreational use, fire management, and habitat fragmentation following the residential development of adjoining blocks to mitigate the negative impacts of introduced predators and habitat alteration on small native mammals.

To enable the persistence of small native mammal populations at these sites, we recommend the following actions:

1. Establish a planned burning mosaic to preserve unburnt refuge areas for small native mammals by conducting a series of smaller burns over several years rather than burning vegetation communities as a single unit.
2. Implement fire management actions in a way that retains structural habitat features likely to support small native mammals, such as depositing cut material on the ground following mechanical thinning to increase coarse woody debris.
3. Undertake targeted monitoring of small native mammals and introduced predators at Stromlo East to understand response to fire management actions.
4. Undertake targeted monitoring of small native mammals and introduced predators over time to assess the impacts of increasing urbanisation in surrounding areas.
5. Trial innovative methods to control populations of foxes and feral cats and undertake targeted monitoring of small native mammals and predators to assess the effectiveness of these predator control activities.
6. Ensure all suburbs abutting these sites are designated cat containment areas.
7. Avoid impacts from further development by maintaining appropriate habitat buffers and ensuring adequate large-scale landscape connectivity across the Western Edge Investigation Area. Of particular importance is maintaining the current habitat connectivity between Stoney Creek Nature Reserve (Murrumbidgee River Corridor), Stromlo West, Stromlo East and the Lower Molonglo.
8. Consider gazettal of the blocks of both Stromlo East and Stromlo West as reserve estate to protect both habitat and connectivity corridors into the future, as well as to enable active management of habitat to promote the persistence of small native mammals at these sites.
9. Consider the listing the three small mammal species native to the lowlands of the ACT: the Agile Antechinus, Yellow-footed Antechinus, and the Common Dunnart; on the protected native species list under the ACT *Nature Conservation Act* to ensure their consideration in future development planning and conservation management.

Furthermore, to increase our understanding of the current distribution of small native mammal populations in the ACT, we recommend the following actions:

10. Undertake an updated assessment of small native mammal distribution in urban reserves, rural leases, and private land throughout the ACT to identify priority areas for small mammal conservation and habitat restoration.
11. Conduct further habitat assessments in the study areas and other sites inhabited by small native mammals to clarify the relationships between habitat characteristics and small native mammal occupancy to better guide management actions.

1 Introduction

In the ACT, historical small native mammal surveys suggest that populations of Common Dunnart (*Sminthopsis murina*) (Fig. 1), Agile Antechinus (*Antechinus agilis*) (Fig. 2), and Yellow-footed Antechinus (*Antechinus flavipes*) have decreased since baseline surveys in the 1970s (Kukolic, 1990; Buckmaster, 2005). Moreover, past surveys were limited to Black Mountain and Ainslie-Majura Nature Reserves, so the extent of these species' distributions in urban Canberra is mostly unknown. However, a recent camera trap sighting of an antechinus species at Stromlo East in Canberra's west suggested that small native mammals may persist in remnant patches of native vegetation at Stromlo East and Stromlo West in the Lower Molonglo Valley. This study aims to assess occupancy rates of small native mammals at these sites, assess threats to populations and identify the habitat characteristics associated with their occurrence. The findings will support conservation measures to secure these native species.

Figure 1. Common Dunnart (*Sminthopsis murina*). Image by Chris Malam.

Figure 2. Agile Antechinus (*Antechinus agilis*). Image by Mark Jekabsons.

2 Background

Historical small mammal surveys

In the ACT, three species of small native mammal were historically present in urban and non-urban reserves. These are the Common Dunnart (Fig. 1), the Agile Antechinus (Fig. 2), and the Yellow-footed Antechinus. The first recorded surveys for small native mammals in the ACT were conducted in the 1970s, and survey efforts since then have been scant and inconsistent. Hence, the former locations and population densities of small native mammals in the ACT are not well known, and the status of current populations can only be measured against a recent baseline set by studies conducted in the 1970s and 1980s after the city of Canberra had become well-established.

Small native mammals in the ACT are under increasing pressure from habitat loss due to urban expansion, predation by introduced species, and diminished habitat complexity resulting from inappropriate fire regimes, particularly in habitat abutting urban areas (Catling, 1991; Barratt, 1997; McKinney, 2002). Between March 1975 and January 1976, the first systematic baseline survey of vertebrate fauna in the ACT was conducted for the ACT Parks and Conservation Service (ACTPCS) (Kukolic, 1990). The mark-recapture study aimed to determine the species inhabiting Canberra nature reserves and relate species' distributions to broad habitat characteristics. Kukolic sampled thirty-three sites across Black Mountain, Mt Ainslie, and Mt Majura, part of the Canberra Nature Reserve system (Fig. 3), in summer and winter, sampling a range of vegetation types, including open woodland, shrubland, and closed forest. Yellow-footed Antechinus were detected on Black Mountain and Mt Majura at higher densities than Agile Antechinus, while Common Dunnarts were detected only on Mt Ainslie (Table 1).

A follow-up baseline survey was conducted from 1978 to 1979, sampling some of the sites previously surveyed by Kukolic (1990) at Black Mountain, Mt Ainslie, and Mt Majura nature reserves (Dickman, 1980). Of the nineteen sampled sites, two were located at Mt Ainslie, one at Mt Majura, and one at Black Mountain (Fig. 3), while the remainder were located within a 45 km radius of Canberra. In 1980, Dickman reported finding Brown Antechinus (*Antechinus stuartii*); however, since publication, *A. stuartii* has been split into *A. stuartii* and *A. agilis,* with only the latter species found in the ACT. The number of individuals captured for each species was not reported for every site (Table 1), and due to the small sample size, population density could not be estimated. However, Dickman found that Yellow-footed Antechinus were typically associated with rocky sites, whereas Agile Antechinus appeared to be habitat generalists. Unfortunately, the study only examined habitat utilisation by *Antechinus* species. Hence, no data were recorded for Common Dunnarts or other small native mammals.

Following these baseline studies, no further surveys were performed in urban reserves of the ACT until nearly twenty years later. In 1999, Mt Ainslie and Mt Majura were again sampled for small mammals using the mark-recapture method (Devlin, 1999). Thirty-one sites were surveyed across Mt Ainslie and Mt Majura, equalling a higher number of sampling sites at each reserve than in previous studies. However, this survey failed to detect any small native mammals at either location, potentially due to the low sampling intensity (only 1032 trapping nights).

Table 1. The locations, number of sites sampled, total number of trap nights and number of Common Dunnarts, Yellow-footed Antechinus and Agile Antechinus detected during small native mammal surveys in Black Mountain and Ainslie-Majura Nature Parks since baseline surveys commenced.

Study	Date	No. trap nights	Locations and no. sites	No. mammals detected		
				S. murina	*A. flavipes*	*A. agilis*
Kukolic, 1990	March 1975 – Jan 1976	5026	Black Mountain (12)	0	11	0
			Mt Ainslie (10)	1	0	2
			Mt Majura (11)	0	23	0
Dickman, 1980	May 1978 – March 1979	8440	Black Mountain (1)	-	Unknown	Unknown
			Mt Ainslie (2)	-	0	Unknown
			Mt Majura (1)	-	20	0
Devlin, 1999	1999	1032	Mt Ainslie (unknown)	-	0	0
			Mt Majura (unknown)	-	0	0
Buckmaster, 2005	March – August 2005	10,350	Black Mountain (12)	0	0	0
			Mt Ainslie (10)	0	0	0
			Mt Majura (11)	0	0	0

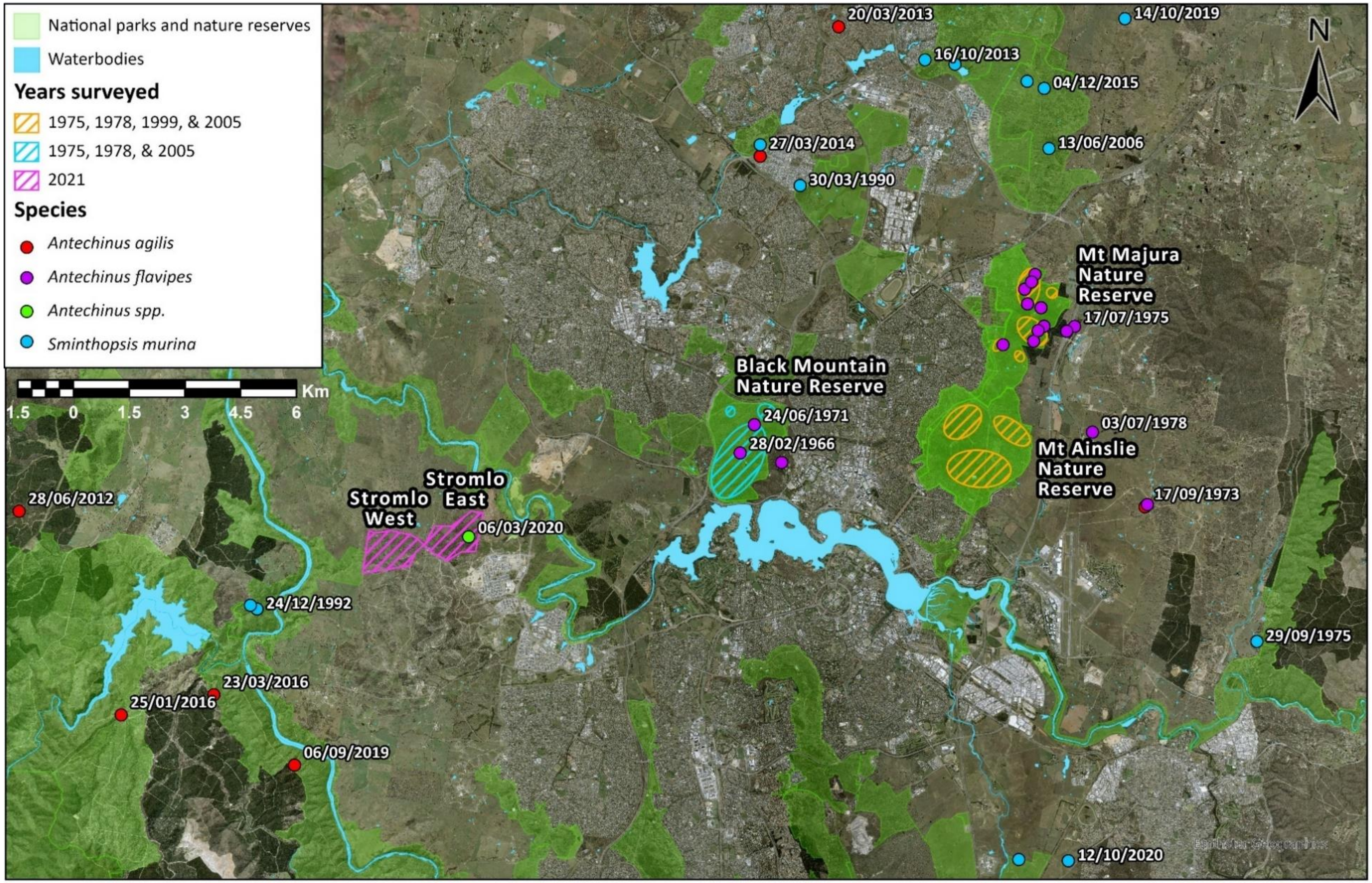

Figure 3. The locations of past small mammal surveys and incidental sightings in urban areas of Canberra, ACT. GPS coordinates and record dates of native small mammal sightings were obtained from Canberra Nature Map, the Atlas of Living Australia, and the ACT Wildlife Atlas (Imagery: ACTMAPi). Cross-hatched survey areas are approximated based on maps of sampling sites (Dickman 1980; Kukolic 1990; Buckmaster 2005).

The most recent systematic survey of small native mammals in the urban reserves of Canberra was carried out in 2005 (Buckmaster, 2005). The project aimed to determine if species assemblages and abundances had changed in Black Mountain, Mt Ainslie, and Mt Majura reserves since the baseline surveys and to compare species diversity between these urban reserves and non-urban reserves in bordering NSW. Although the number and locations of sampling sites in the ACT mirrored those of the 1975 baseline surveys, the study failed to detect small native mammals in these reserves (Table 1). The results of this study led to the conclusion that Common Dunnarts, Yellow-footed Antechinus and Agile Antechinus may be locally extinct within the ACT.

However, in March 2020, during camera trap monitoring of Lace Monitors (*Varanus varius*) at Stromlo East, Denman Prospect, cameras recorded a single *Antechinus* spp. (Fletcher, pers. comm. 2020). Additionally, footprint tunnel trapping at Goorooyarroo Nature Reserve detected Common Dunnarts (Snape, pers. comm. 2016), suggesting that small native mammals may persist in remnant patches of native vegetation outside the urban reserves previously surveyed.

Study aims and objectives

This study aimed to answer the questions: what are the occupancy rates of small native mammals and introduced predators at Stromlo East and Stromlo West, and what habitat characteristics are associated with their occurrences? Specifically, this study aimed to:

1. Conduct baseline surveys at Stromlo East and Stromlo West using camera traps to confirm the presence of antechinus species and determine if other small native mammals (e.g., Common Dunnarts) also occupy the study sites.
2. Use camera traps to establish the occupancy rates of small native mammals and introduced predators (e.g., foxes and cats) at the study sites.
3. Provide a baseline assessment of the general ecological condition of Stromlo East and Stromlo West, including vegetation composition and habitat structure and complexity.
4. Identify which habitat variables are associated with small native mammal occurrences.

Considering current plans for extensive urban development in these areas, the results of this study will support recommendations made to land managers regarding the protection of remnant habitat for small native mammals at Stromlo East and Stromlo West. Additionally, camera trapping data from this project will contribute species occurrence records to the ACT Wildlife Atlas, Canberra Nature Map, and the Atlas of Living Australia to build on current knowledge of small native mammal distributions in the ACT. Moreover, this research provides a foundation for the continued monitoring of small native mammals and introduced predators at Stromlo East and Stromlo West. Such long-term monitoring will aid the detection of changes to population densities and habitat composition as the surrounding areas become increasingly urbanised, allowing appropriate response measures to be promptly implemented.

Study areas

Situated in the Molonglo Valley in Canberra's west, Stromlo East and Stromlo West are remnant patches of native vegetation. For this study, Stromlo East includes Stromlo Block 402, Stromlo Block 403 and Denman Prospect Block 12 Section 1 and Stromlo West includes Stromlo Block 59 and Stromlo Block 511.

The land directly east of Stromlo West and Stromlo East was sold in 2015 for development of the suburb of Denman Prospect (Fig. 4). Denman Prospect South (south-east of Stromlo East) is predominantly high-density residential housing and neighbours the high-density suburbs of Wright and Coombs (Fig. 4). Much of the land surrounding these suburbs, including parts of Stromlo East, is covered by a Future Urban Area overlay (FUA) within the Territory Plan, a statutory document that guides planning and development in the ACT. However, at the time of writing, the only block within the study area zoned for future residential development was Denman Prospect Block 12 Section 1. While the FUA zoning indicates some possibility of future urban development within Stromlo Blocks 402 and 403, these are currently zoned for non-urban use (zones NUZ2 and NUZ3, respectively). At the time of writing, the ecological values in Stromlo Blocks 402 and 403, and additional blocks west toward the Murrumbidgee River, were being investigated as part of Western Edge planning studies.

Stromlo Blocks 59 and 511 within the Stromlo West study area were zoned as Designated Areas at the time of writing, meaning the National Capital Authority (NCA) has responsibility for determining detailed planning policy and for Works Approval (otherwise known as development assessment). These blocks were historically used for grazing but are now public urban open spaces as part of the Stromlo Forest Park Special Urban Reserve (Fig. 4).

Both study areas contain diverse native vegetation communities. Stromlo East, which borders the suburb of Denman Prospect, comprises Red Stringybark-Scribbly Gum dry sclerophyll forest, Blakely's Red Gum-Yellow Box grassy woodland, native shrubland, and native- and exotic-dominated grasslands, while Stromlo West is dominated by Blakely's Red Gum-Yellow Box grassy woodland and native grasslands. The distribution of the Blakely's Red Gum-Yellow Box vegetation community has decreased by 66% since 1750, leading to its classification as an endangered ecological community, providing habitat for many rare and threatened species. Moreover, remnant patches of Blakely's Red Gum-Yellow Box woodlands exist at the lower slopes of Mt Ainslie, where Common Dunnarts and Agile Antechinus were recorded in 1975 (Kukolic, 1990), and may thus provide crucial habitat for these species.

Stromlo East and Stromlo West are potentially significant habitat corridors for native fauna, bridging Stoney Creek Nature Reserve and Molonglo River Corridor (Fig. 4). These, in turn, connect to the Lower Cotter Catchment, Namadgi National Park, and Tidbinbilla Nature Reserve in the south-west, and Lower Molonglo Nature Reserve and Kama Nature Reserve in the north-east, continuing into the Belconnen hills including the Black Mountain and Pinnacle Nature Reserves (Fig. 4). Outside of these areas, the landscape is heavily modified. Stromlo Forest Park, south of Stromlo East and Stromlo West, covers 1,200 ha of land converted to a recreational sporting facility and includes a pine plantation. Beyond this, as well as north of Stromlo East and Stromlo West, the land is predominantly under rural lease and has been cleared for pasture (Fig. 4).

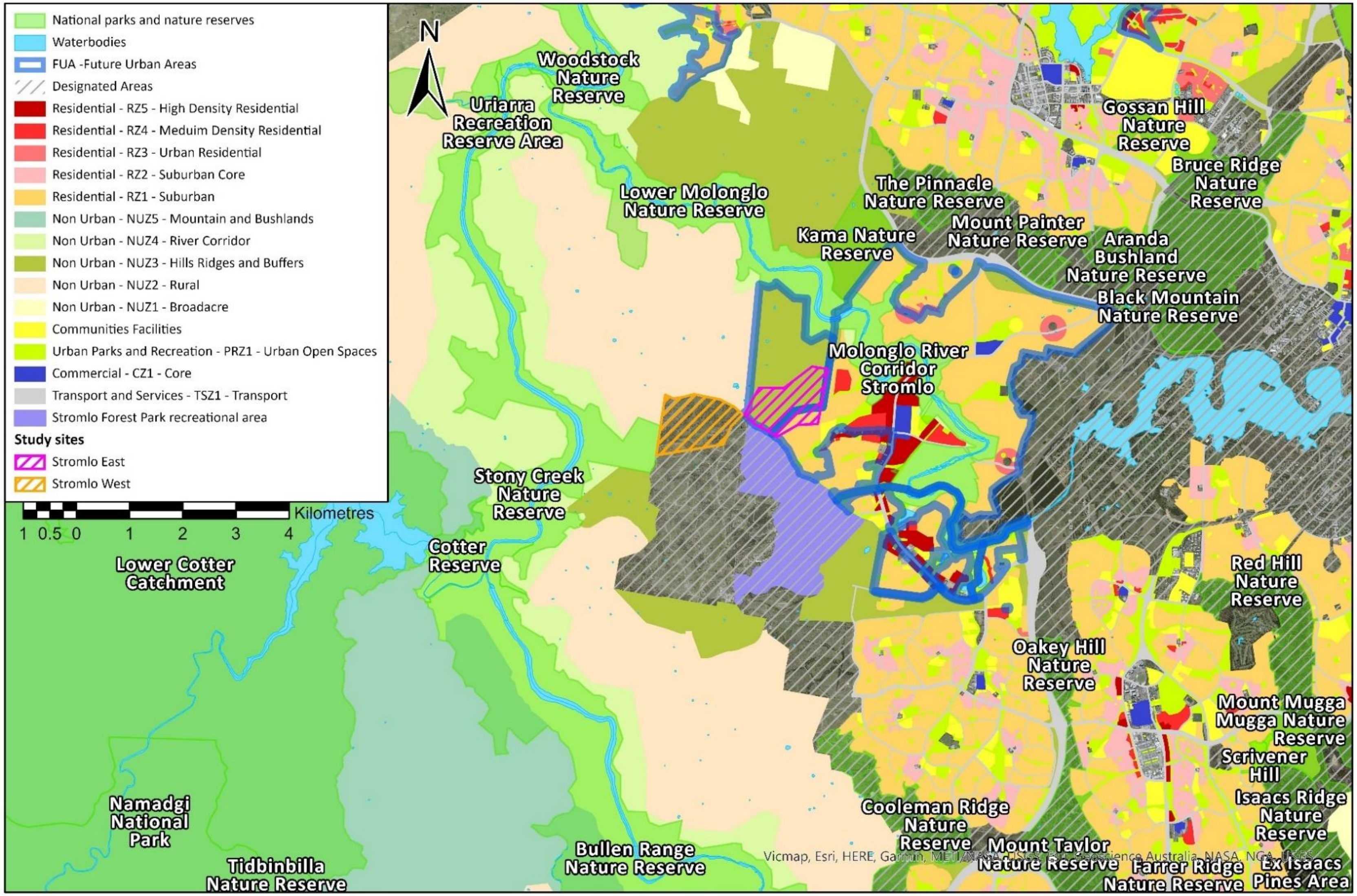

Figure 4. The study sites of interest, Stromlo East (pink) and Stromlo West (orange), in proximity to national parks, nature reserves, and current Territory Plan *Land Use Zones* in Canberra, ACT. The Lower Molonglo Nature Reserve, Molonglo River Corridor, and Kama Nature Reserve have since been amalgamated into one reserve called the "Molonglo River Reserve." (Imagery: ACTmapi)

3 Field methods

Camera trap surveys

Stromlo East was identified as a target site for small native mammal surveys due to an incidental camera trap sighting of an antechinus in 2020 (Fig. 4) (Fletcher, pers. comm. 2020). Stromlo West was selected as an additional study site because it has similar vegetation communities and connectivity linkages to Stromlo East (Fig. 4; Fig. 6).

Camera trapping was used to assess occupancy rates for both small native mammals and introduced predators (foxes and cats). Vegetation surveys were subsequently conducted to compare key structural attributes of habitat between sites with and without small native mammal presence and to assess the general ecological condition of these sites.

Camera traps were established at 70 locations across the two sites. A total of 36 and 34 camera traps were placed at Stromlo East and Stromlo West, respectively (Fig. 6). White flash cameras were placed at each of the 70 camera stations, while 35 infrared cameras were positioned at half of the camera stations (18 at Stromlo East and 17 at Stromlo West). Camera trapping was undertaken over 36 nights from the 13th of April to the 19th of May at Stromlo East and from the 25th of May to the 30th of June at Stromlo West in 2021.

White flash and infrared cameras were used to target small native mammal populations and introduced predator populations, respectively. Both camera types use motion- and heat-sensitivity to trigger the camera. However, the white flash cameras flash a bright white light when triggered, producing a high-resolution colour image which may assist with identifying small native mammals (Burns et al., 2017). In contrast, infrared cameras use infrared light, which is less likely to frighten foxes and cats, which could consequently avoid camera stations (Glen et al., 2013). Although the images produced by infrared cameras are grayscale and lower resolution, this is less of an issue when targeting predators, as foxes and cats are easily identifiable from low-quality images.

The locations of the 70 white flash cameras were selected by overlaying a 200 m x 200 m grid on a map of the study sites in the ArcGIS Pro software (version 2.8; Esri Inc., 2021). The centre-point coordinates of each grid square were used to indicate the general position of each white flash camera. A 400 m x 400 m grid was then overlaid on the 200 m x 200 m grid, and every second white flash camera location was selected to include one of the 35 infrared cameras (Fig. 6). Grids were placed across the entire area of the study sites to ensure representation of all vegetation communities at the sites.

Actual camera locations (Fig. 6) varied from the centre-point coordinates of the grid due to the requirement of a large tree to secure cameras with a chain lock (theft and vandalism of the cameras are common problems during camera trap surveys in urban areas). Where more than one suitable tree was available at equal distances from the grid centre-point, the tree with a higher estimate of coarse woody debris at its base was selected for use, as research suggests that small native mammals prefer complex habitat which provides shelter from predators (Dickman, 1980; Barratt, 1997). The coordinates of each camera station were re-positioned to those of the selected tree using a hand-held GPS.

At each selected tree, a steel star picket was embedded in the ground up to the first pre-drilled hole at the sharp end of the picket (Fig. 5). Both white flash and infrared cameras were set to the highest sensitivity, and to take five rapid-fire photographs per sensor activation with no delay between triggering events. White flash cameras were then fastened perpendicular to the picket using L-shaped brackets 76 cm from the ground so that each camera was oriented downwards (Fig. 5). Infrared cameras were attached vertically to the picket using a flat bracket approximately 1 m from the ground (23 cm above the white flash camera). Infrared cameras were angled south to reduce the chance of overheating and false trigger events caused by the afternoon sun.

A cork tile was pegged to the ground at the base of each picket directly below the white flash camera (Fig. 5). To attract small native mammals, a metal tea infuser containing a ball of peanut butter and oats was pegged to the cork tile, and tuna oil was spread on the tile (Fig. 5). Vegetation, such as long grass, was minimally pruned if it was in the field of view and likely to cause false triggers by activating the camera sensor on windy days. At the end of camera deployment, all materials were removed from the study sites. Camera images were downloaded from the cameras and imported to ExifPro software (Harvey, 2021) for storage and identification.

Figure 5. Camera station set up to include a white flash camera (lower), positioned perpendicular to the star picket to capture images of small native mammals, and an infrared camera (upper), positioned vertically to capture images of introduced predators such as cats and foxes. A cork tile is pegged into the ground directly below the white flash camera. In one corner, a metal tea strainer containing an oat and peanut butter bait ball is pegged to the tile to attract native small mammals. A chain lock secures the cameras to the tree.

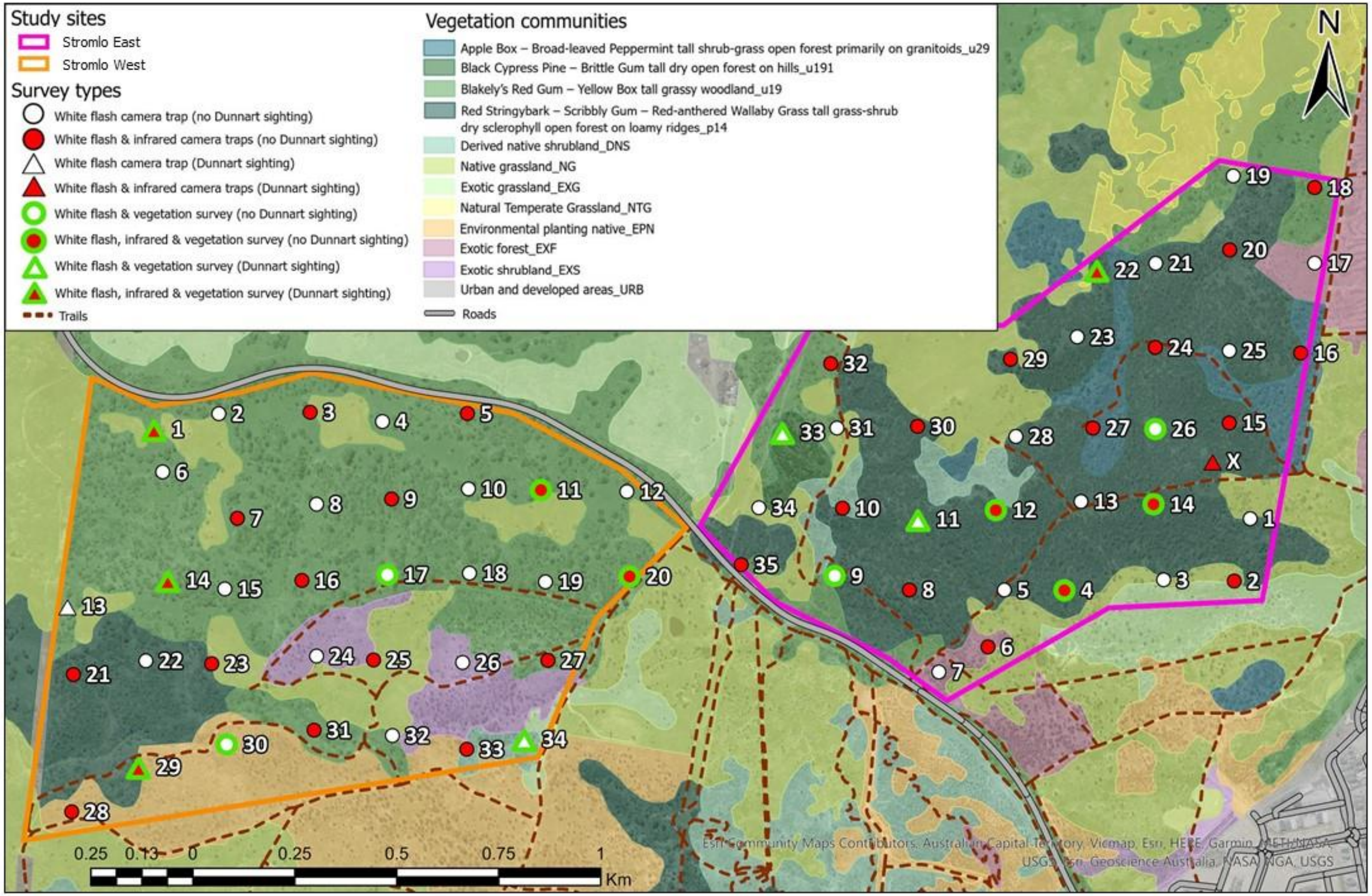

Figure 6. Final locations of camera stations at Stromlo East (pink) and Stromlo West (orange). Camera stations where Common Dunnarts were detected are indicated by triangles, and sites selected for habitat assessment are highlighted in green. Vegetation communities are shown in different colours and represent geographical areas with similar plant species assemblages.

Habitat assessment

Habitat assessments were undertaken at 16 plots across Stromlo East and Stromlo West, where cameras had previously been stationed. Seven of the habitat assessments were conducted at sites where Common Dunnarts were detected during the camera trapping survey, and another nine sites were selected from the remaining camera sites to comprise a range of vegetation communities (Fig. 6).

Habitat assessment targeted variables associated with small mammal presence, including vegetation composition, habitat structure and complexity, and ground cover density (Dickman, 1980; Kukolic, 1990; Table 2). At each habitat assessment site, a 20 m x 50 m plot (area = 0.1 ha) was established with a North-South orientation close to where cameras were formerly set up. Within each plot, three 50 m linear transect tapes were laid, and photographs were taken of the plot from three angles to aid future interpretation of the data.

Five broad habitat variables were measured using six different methodologies (Table 2). The variables assessed were habitat structure, canopy cover, tree and shrub community composition, and the average length of coarse woody debris. Habitat structure was measured along the two transects positioned at the eastern and western edges of the plot using the point-intercept transect method described by Milner and Sharp (2015). At 1 m intervals along the length of each 50 m transect tape, the presence of groundstorey plants (native or exotic perennial tussock grass, annual grass, forbs, sedges, shrubs, and seedlings) and other ground layer habitat features (mineral earth, rocks, depth of leaf litter layer, grass thatch, fine woody debris, moss, ferns, and fungi) was recorded. The number of times a habitat feature touched the tape was summed to provide a frequency score for each feature. The respective depths of the leaf litter (i.e., leaves and bark) and fine woody debris layers were recorded every time they occurred at the intervals along the transects. The measurements were then averaged for each site to provide a mean depth score.

Tree canopy cover was measured along the central transect of each plot using the zigzag transect method described by Milner and Sharp (2015) and the smartphone app HabitApp. For the zigzag method, foliage cover was estimated by sight, beginning at the crown canopy of the tree closest to the start of the transect line. The width of the crown and crown gap distance were then measured. The crown gap is the distance to the next tree towards or across the transect, with overlapping crowns giving a negative value (i.e., if two crowns overlap by 2 m, the crown gap is –2). The crown width of the second tree was then measured, foliage cover estimated, and the crown gap between the next tree across the transect measured, zigzagging until the end of the transect tape was reached. The HabitApp app was then used as a more objective measure of canopy cover by taking a photo at chest height facing directly upwards at 1 m intervals along the central 50 m transect line.

The total numbers of trees and shrubs were counted in a 20 m x 20 m (area = 0.04 ha) sub-plot within each habitat assessment plot, with the camera location in the centre (cameras had been removed at this stage). Trees and shrubs were identified to species level, and trees were categorised into age classes (sapling, young, mature, or very old). The number of trees of each species and age class, as well as the number of standing dead trees, were summed to provide a frequency count quantifying tree community composition for each sub-plot. This process was repeated for shrubs; however, shrubs were only recorded by species, not age class.

The average length of coarse woody debris was determined by measuring the length of all woody debris greater than five centimetres in diameter that touched the central 50 m transect tape. Coarse woody debris was categorised into four different grades by diameter (grade one = 5-10 cm; grade two = 10-20 cm; grade three = 20-30 cm; grade four = >30 cm). The lengths of coarse woody debris were summed for each grade to provide a measurement in metres.

Table 2. Description of the methodologies used for habitat assessments at Stromlo East and Stromlo West.

Methodology	Variables measured	Measurement technique	Justification
Point intercept survey	Number of features in plant groups and abiotic habitat feature groups	Record presence of habitat features at 1 m intervals along two 50 m transect tapes at east and west of survey plot	Habitat complexity (especially litter layer) associated with antechinus detections. Litter used for foraging and shelter (Dickman, 1980; Buckmaster, 2005)
Zigzag canopy cover estimation	Tree crown width (m), crown gap (m) and canopy cover (%)	Foliage cover estimated by observer; crown width measured at widest branching point; crown gap measured between current tree and closest tree across transect to end of transect	Canopy cover associated with antechinus detections; foraging often occurs in the canopy (Buckmaster, 2005)
Photo-based canopy cover estimation	Canopy cover (%)	Smartphone app HabitApp used to estimate % canopy cover from photographs taken at 1 m intervals along central 50 m transect line	As above. Estimation from photographs provides a more objective measure of canopy cover than the zigzag method (Korhonen et al., 2006)
Coarse woody debris count	Length of coarse woody debris (m)	Measure all coarse woody debris touching the central 50 m transect line; categorise into grades by diameter and sum lengths for each grade	Antechinus associated with coarse woody debris >10 cm diameter and tree-log complexes (Dickman, 1980; Buckmaster, 2005).
Tree count and classification	Number of trees	Count all trees within a 0.04 ha subplot and categorise by species and age class	Antechinus species are largely arboreal and associated with tree diversity and abundance (Kukolic, 1990; Buckmaster, 2005)
Shrub count and classification	Number of shrubs	Count all shrubs within a 0.04 ha subplot and categorise by species	Shrubs contribute to habitat complexity; Dunnarts may prefer a less dense shrub layer than antechinus species (Buckmaster, 2005)

4 Statistical methods

Poisson regression model of fox detections in proximity to roads

The total number of images of foxes and cats captured by each camera was visualised spatially using ArcGIS Pro version 2.8 (Fig. 9; Fig. 10) (Esri Inc., 2021). The ACT Government 'Road Centrelines' shapefile was used to represent sealed roads, while the ACT PCS 'Tracks and Trails' shapefile was used to signify unsealed roads, such as fire management access trails and walking tracks. The geodesic distance from each camera station to the nearest road was computed using the 'Near' function in ArcGIS Pro (Esri Inc., 2021). The detection frequency of foxes and distance data for each camera were then exported for statistical analysis in R (R Core Team, 2019). Cat detections were not analysed in R due to a small sample size of eight images across six camera stations.

All statistical analyses were conducted in R version 3.6.2 (R Core Team, 2019). A generalised linear model was constructed using the base R function 'glm' to determine if the number of fox detections at a camera station was influenced by the distance of that camera station to the nearest sealed road or unsealed trail. As discrete count data (i.e., the number of fox detections) were used as the response variable, a Poisson family with a logarithm link function was specified for the model to reflect the Poisson error distribution. After inspecting the model summary, overdispersion was detected ($\phi = 5.83$), so the standard errors were corrected using a quasi-GLM model where the variance was given by the product of the mean, μ, and the dispersion parameter, ϕ.

Following model-fitting, Pearson residuals were calculated and adjusted for overdispersion. The scaled residuals were then plotted against the fitted values to check for outliers, non-linearity, and unequal error variances. As no issues were detected, the model output was used predict about the number of fox detections expected within 0 m to 800 m of camera stations.

Principal component analysis of habitat characteristics

Following a literature review of habitat characteristics associated with dunnarts and antechinus in the ACT, NSW, and Victoria, a subset of nine variables were selected to be included in multivariate analysis (Table 3). These variables represent all habitat strata, including the groundstorey, understorey, and tree canopy.

Data were initially tested for collinearity issues using the Spearman correlation matrix, and a correlation coefficient greater than 0.70 was chosen as the threshold to exclude highly correlated variables. No variables exceeded this threshold, so all nine variables were retained for analysis. Variables were subsequently standardised to have a mean of zero and a standard deviation of one by subtracting the mean of each variable and dividing by the standard deviation.

Principal component analysis (PCA) was performed on the correlation matrix using the 'rda' function from the 'vegan' package in R (Oksanen et al., 2019) to visualise structural and compositional differences in habitat between sites. The function runs a typical unconstrained PCA using a matrix of the habitat variables without a formula. The eigenvalues of the PCA were checked to determine which principal components (PCs) explained the greatest amount of variance between sites. PCs with eigenvalues greater than one are generally considered informative, and hence the first four PCs were extracted for subsequent analysis in logistic regression models (Table 5).

Table 3. Habitat variables included in the principal component analysis (PCA) to assess associations between habitat variables at sites where Common Dunnarts were and were not detected during camera surveys at Stromlo East and Stromlo West.

Habitat variable	Description	Units
Leaf litter layer	Average leaf litter (leaf and bark) depth from a point intercept survey.	cm
Fine woody debris	Average depth of fine woody debris (< 5 cm diameter) in understory layer from a point intercept survey.	cm
Rocks	Total number of rocks counted along the transect line in the point intersect survey.	count
Coarse woody debris	Total combined length of coarse woody debris from Grade 1 (5-10 cm diameter) to Grade 4 (> 30 cm diameter).	m
Canopy cover	Average canopy cover recorded using *HabitApp* every meter for 50 m along centre transect. Provides data on variability and extent of shade.	%
Crown gap	Average distance between the edge of tree crowns along a transect, recorded using the zig-zag method.	m
Native grass	Total number of native grasses (all species) recorded along a transect using the point intercept method.	count
Native shrubs	Total number of native shrubs (all species) recorded along a transect using the point intercept method.	count
Red Stringybark trees (*Eucalyptus macrorhyncha*)	Total number of Red Stringybark (*Eucalyptus macrorhyncha*) trees recorded in a 20m x 20m subplot of the habitat assessment plot.	count

Logistic regression models of habitat characteristics

Logistic regression models were used to examine the relationship between habitat characteristics at sites where Common Dunnarts were and were not detected at Stromlo East and Stromlo West. For the response variable, dunnart detection was encoded as a binary variable, with a value of one indicating dunnarts were detected and zero indicating that no dunnarts were detected throughout the camera surveys.

Initially, a binomial logistic regression model was constructed with the four most informative PCs (PC1, PC2, PC3 and PC4) included as explanatory variables. The loading values, indicative of the correlation between a variable and a component, were examined for the components of interest (Table 5). The components with the lowest p-values were considered the most strongly associated with dunnart detection at the study sites. Positive loadings indicate a positive correlation, and negative loadings indicate a negative correlation. Variables with absolute loading values greater than 0.70 were subsequently included in a logistic regression model examining the association between individual habitat variables and dunnart detection at survey sites.

Before model fitting, the seven habitat variables of interest (Table 5) were transformed where necessary to increase normality and then centred around the mean. Initially, a global model was defined with all seven habitat variables as predictors. A minimum adequate model was then resolved using a stepwise heuristic approach, successively deleting the predictor with the highest p-value and sequentially re-adding the variables into the model. Model averaging was applied to the models with the lowest Akaike information criterion value corrected for small sample sizes (AICc) by averaging the estimated coefficients weighted by the respective model Akaike weights, or the probability that a model is the best of the set. The most suitable model was determined from the averaged coefficients of the predictors.

5 Results

Camera trap surveys

At Stromlo East, 2105 camera detections were made over 1926 trap nights, and at Stromlo West, 1643 detections were made over 1224 trap nights (Table 4). The most frequently detected native species were Brush-tailed Possums (34.01%) at Stromlo East and Eastern Grey Kangaroos (16.86%) at Stromlo West. House Mice were the most frequently detected introduced species at both sites (Stromlo East = 19.52%; Stromlo West = 48.02%) and the most frequently detected overall (32.02%; Table 4). Introduced Black Rats also had high detection rates at both sites (9.69%; Table 4).

Common Dunnarts were the only small native mammal species detected. At Stromlo East, nine detections (0.43%) were made across four camera stations (Fig. 7). Two of these cameras were in Stromlo Block 402 and two in Stromlo Block 403 (Fig. 7). At Stromlo West, 11 Common Dunnart detections (0.67%) were made across five camera stations (Fig. 7). Some individuals may have been detected across multiple cameras.

Common Dunnarts were exclusively recorded at both sites between dusk and dawn, indicating that these individuals were actively foraging. While only Common Dunnarts were recorded in this study, the sighting of an Antechinus in 2020 occurred within 100 m of where a dunnart was detected during this survey, suggesting that the habitat is suitable for both species.

Common Dunnarts were only detected in native vegetation communities, predominantly in the dominant vegetation community of each site (Red Stringybark-Scribbly Gum forest at Stromlo East and Blakely's Red Gum-Yellow Box woodland at Stromlo West). At Stromlo East, 66% of detections (n = 6) were captured by three cameras within Red Stringybark-Scribbly Gum open forest, while a single camera in Black Cypress Pine-Brittle Gum open forest made the remaining detections (n = 3; Fig. 7). At Stromlo West, 73% of detections (n = 8) were made by three cameras within Blakely's Red Gum-Yellow Box tall grassy woodland, 9% (n = 1) were made in Red Stringybark-Scribbly Gum open forest, and the remaining 18% of detections (n = 2) occurred in derived native shrubland (Fig. 7).

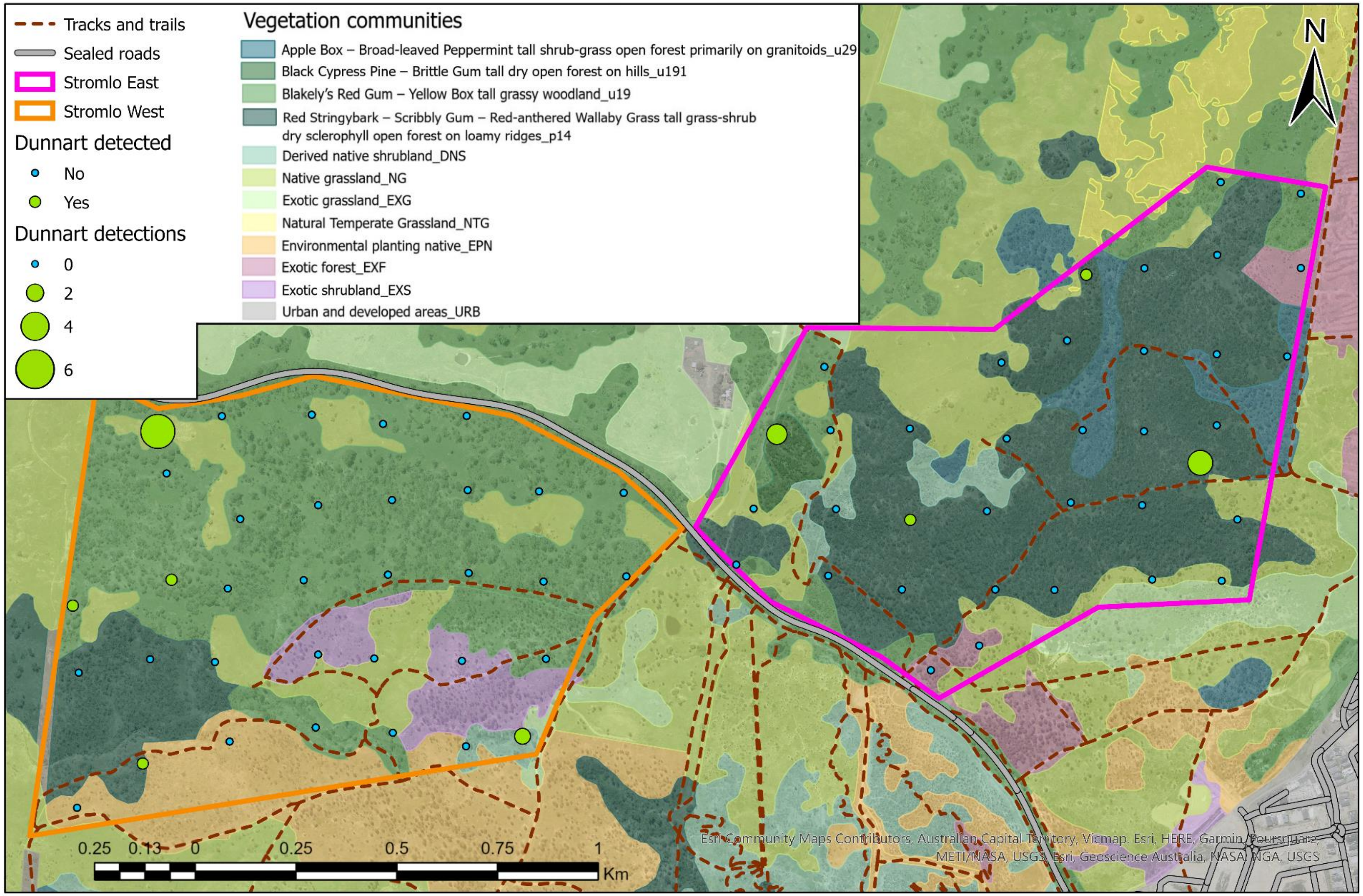

Figure 7. The number of Common Dunnart detections at camera stations at the Stromlo East and Stromlo West study sites. Circles show the locations of cameras, with circle size representing the number of images of Common Dunnarts captured by each camera. Coloured shading identifies the different vegetation communities within the two sites.

Table 4. The total number of detections and the proportion of all detections for animals recorded by white flash and infrared camera traps at Stromlo East and Stromlo West in April, May, and June of 2021.

Species	**Stromlo East** (1926 trap nights)		**Stromlo West** (1224 trap nights)	
	No. of detections	**%**	**No. of detections**	**%**
Bird	258	12.26	105	6.39
Black Rat	115	5.46	4	0.24
Brush-tailed possum	716	34.01	125	7.61
Cat	5	0.24	3	0.18
Common Dunnart	9	0.43	11	0.67
Common Wombat	132	6.27	127	7.73
Dog	2	0.10	2	0.12
Eastern Grey Kangaroo	41	1.95	277	16.86
Echidna	0	0	5	0.30
Fox	109	5.18	115	7.00
Hare	2	0.10	31	1.89
Human	1	0.05	2	0.12
House Mouse	411	19.52	789	48.02
Pig	0	0	1	0.06
Rabbit	4	0.19	3	0.18
Red-neck Wallaby	40	1.90	11	0.67
Reptile	3	0.14	0	0
Sugar Glider	2	0.10	1	0.06
Swamp Wallaby	212	10.07	20	1.22
Unidentified	43	2.04	11	0.67

Of introduced predators, foxes (n = 224) were detected more frequently than cats (n = 8) at both sites (Table 4). Foxes were recorded at 22 camera stations at Stromlo East (61.11%) and 24 stations at Stromlo West (70.59%) on 30 separate nights at each site (83.33% of trapping nights). Cats were recorded at six camera stations at Stromlo East and Stromlo West over six trap nights. Foxes and cats were recorded in native and exotic forests and shrublands at both sites, and all detections were made between dusk and dawn. Although it is uncertain if the cats recorded were feral or domesticated, they were likely feral as Denman Prospect and the surrounding suburbs are designated cat containment areas.

Poisson regression model of fox detections in proximity to roads

The Poisson regression model found modest evidence for a negative relationship between the number of fox detections made by a camera trap and the camera's distance from the nearest road (estimate = –0.004; p = 0.0868). While the result suggests that cameras near roads are more likely to detect foxes than those far from roads, pseudo-R^2 values used to evaluate the model's explanatory power found that only 5.77% of the variation in fox detections among cameras was explained by distance to the nearest road. The unexplained variance is possibly attributable to important covariates missing from the model, such as key habitat variables, which could not be included in the model as habitat data were only collected for 16 camera sites.

Of the 70 camera stations, 28 cameras (40%) were situated within 50 m of a road. Twenty-three of these camera stations (82%) detected foxes, comprising half of fox detections out of a total of 46 camera stations that detected foxes (Fig. 10). Similarly, three of the six camera stations that detected cats (50%) were within 50 m of a road (Fig. 9). Based on the model results, the number of foxes detected by cameras is predicted to decline to zero when cameras are positioned at distances greater than 600 m from a road or trail (Fig. 8).

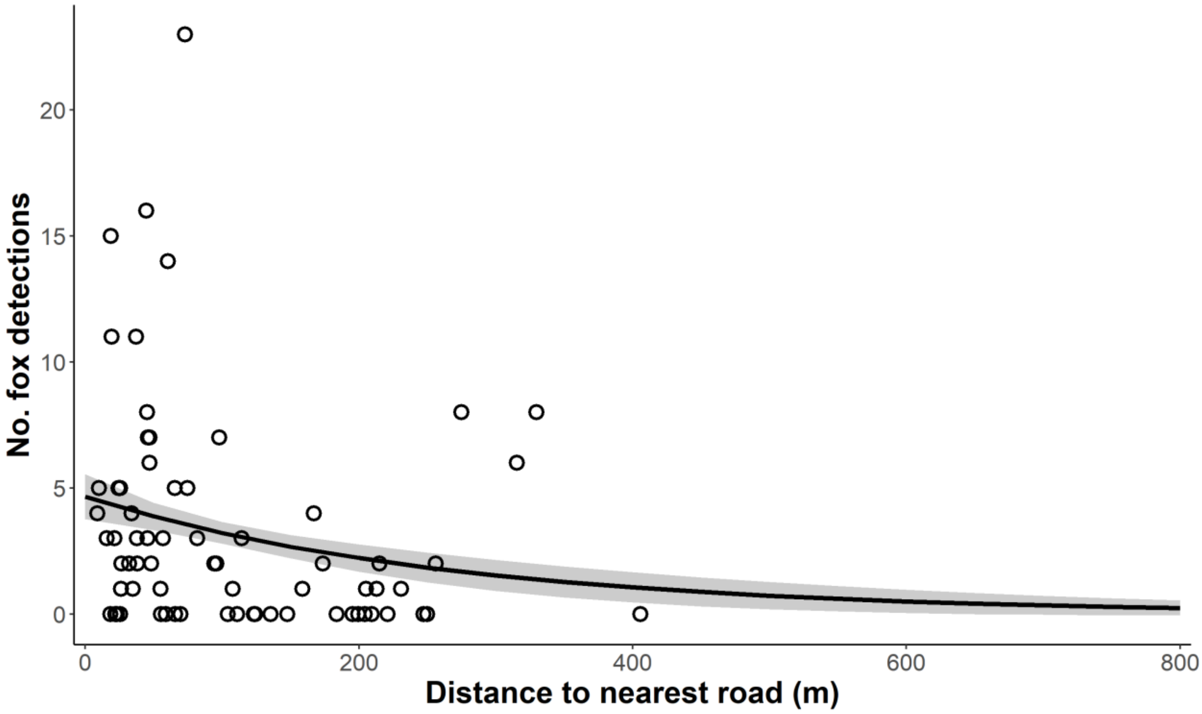

Figure 8. Scatterplot with a fitted regression line and 95% confidence intervals (grey) depicting a negative relationship between the number of fox detections (i.e., images captured of a fox) made by camera stations and the distance (metres) of camera stations from the nearest sealed or unsealed road.

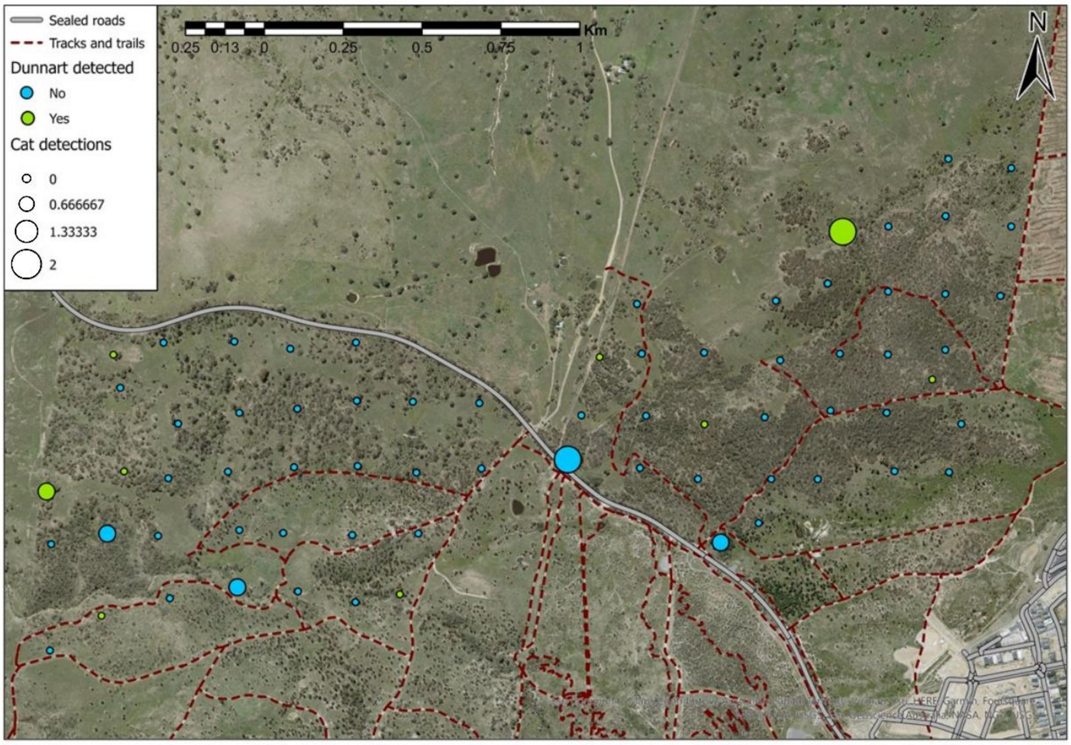

Figure 9. The number of cat detections at camera stations at the Stromlo East and Stromlo West study sites. Circles show the locations of cameras, with circle size representing the number of images of cats captured by each camera. Cameras that also detected Common Dunnarts are shown in green.

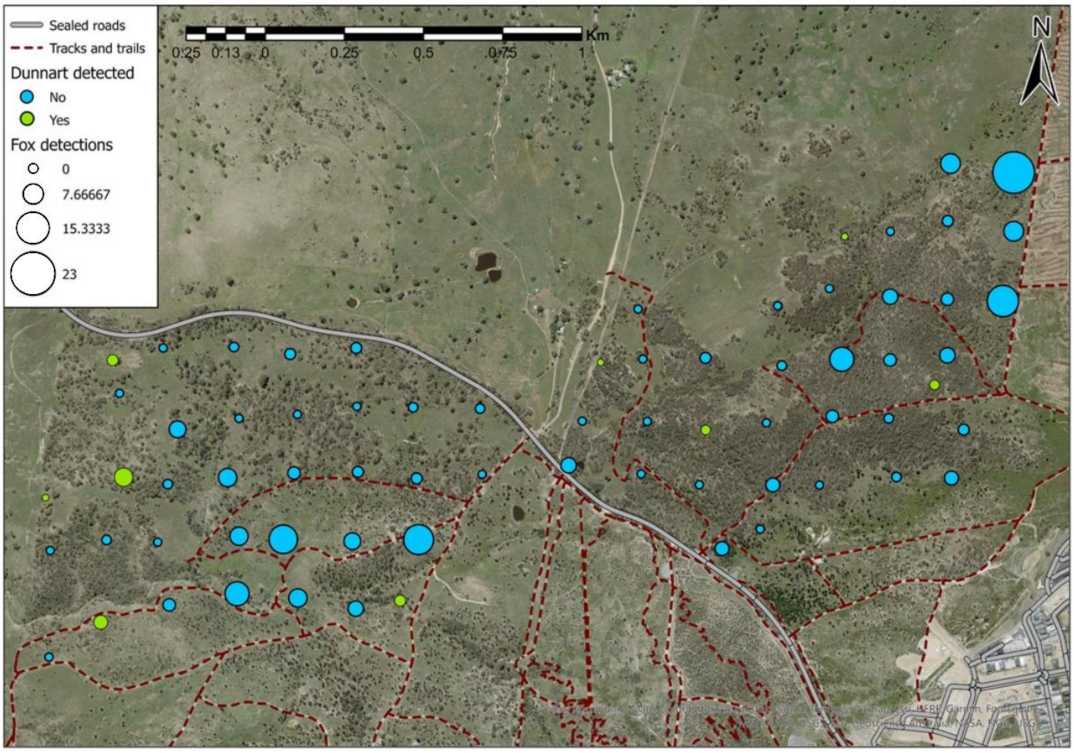

Figure 10. The number of fox detections at camera stations at the Stromlo East and Stromlo West study sites. Circles show the locations of cameras, with circle size representing the number of images of foxes captured by each camera. Cameras that also detected Common Dunnarts are shown in green.

Principal component analysis of habitat characteristics

The first four principal components of the PCA were the most important in explaining the variation among site habitat characteristics (Table 5). PC1 accounted for 30% of the total variation in the group of sites selected for habitat assessment with decreasing crown gap (–0.87) and increasing canopy cover (0.85), rocks (0.71), and Red Stringybark trees (0.70) showing the strongest correlation with the first component (Table 5). PC2 contributed 18% of the total variation and was positively correlated with native shrubs (0.72) and fine woody debris (0.72; Table 5). PC3 contributed 13% of the total variation and had the highest loading value for any variable among the components, with leaf litter strongly negatively correlated with the component (–0.94; Table 5). PC4 explained 11% of the total variation, and no variables had loading values greater than 0.70 (Table 5). The biplots of the PCA show different positioning of the two locations, Stromlo East and Stromlo West, in the multidimensional ordination space, indicating the sites vary in habitat structure and composition (Fig. 11). However, there is no distinct difference in multidimensional space among sites where Dunnarts were and were not detected (Fig. 11).

Logistic regression models of habitat characteristics

Modelling the first four principal components against dunnart detection showed that PC3 had the strongest association with the detection of dunnarts at sites where habitat assessments were conducted ($p = 0.171$), followed by PC2 ($p = 0.195$). In the global model, which included the seven habitat variables with the highest loading values as predictors, no habitat variables were significantly associated with dunnart detection. The reduced model provided weak evidence that leaf litter (estimate = – 1.53; $p = 0.0959$) and canopy cover (slope = –1.44; $p = 0.1306$) are negatively associated with dunnart presence, suggesting that Common Dunnarts may prefer lower canopy cover and leaf litter depth across sites. Neither model differed significantly from the null model.

Table 5. Loading values of the four principal components that account for the greatest amount of variance in the habitat assessment data. Variables are listed in order of those with the highest absolute loading value for the first principal component, PC1. An absolute value of 0.70 (bold) was used as a cut-off for including habitat variables as predictors in the logistic regression models. The eigenvalue, proportion of variance explained, and cumulative proportion of variance explained for each component are given in the final three rows.

Parameter	PC1	PC2	PC3	PC4
Crown gap	**–0.8733**	–0.1098	–0.1367	–0.3515
Canopy cover	**0.8484**	0.4800	0.1365	–0.2493
Rocks	**0.7120**	0.1182	0.1169	0.2521
Red Stringybark trees (*Eucalyptus macrorhyncha*)	**0.7003**	–0.0813	–0.5558	0.1087
Native grass	–0.5181	0.5459	0.27870	–0.5497
Leaf litter layer	–0.5086	0.0707	**–0.9444**	0.1434
Native shrubs	0.4268	**0.7213**	-0.4728	–0.4793
Coarse woody debris	0.4136	–0.6877	–0.1060	–0.4341
Fine woody debris	–0.3252	**0.7227**	0.0597	0.5497
Eigenvalue	2.6847	1.6123	1.2145	1.0102
Proportion explained	0.30	0.18	0.13	0.11
Cumulative proportion	0.30	0.48	0.61	0.72

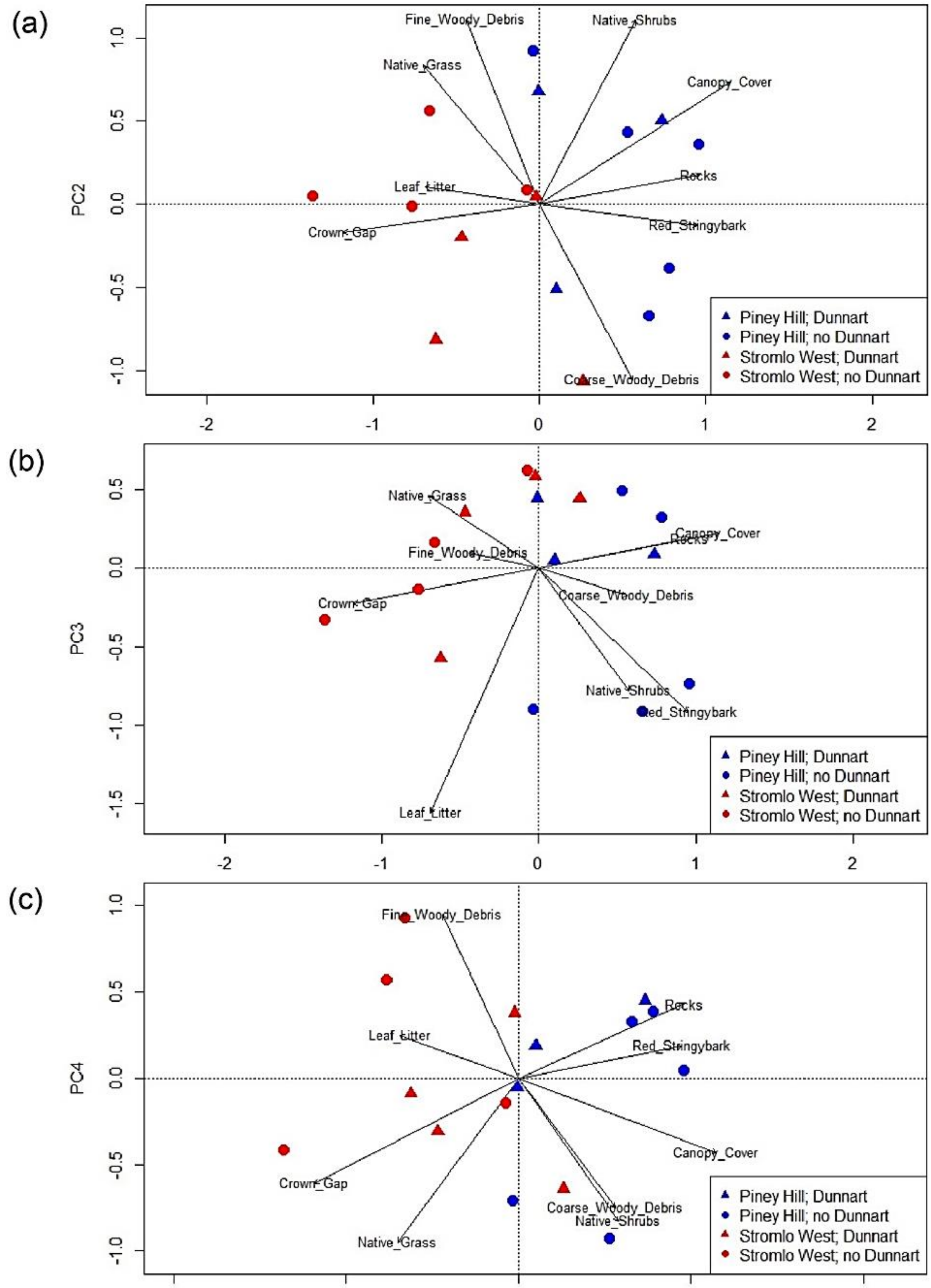

Figure 11. Biplots of the principal component analysis (PCA) for habitat assessment data, performed using the 'rda' command of the 'vegan' package in R (Oksanen et al., 2019). The first principal component (PC1), displayed on the x-axis of all three plots, explains the most variance in the data and is plotted against (a) the second, (b) third, (c) and fourth principal components (PC2, PC3, and PC4 respectively). Arrow length indicates the relative importance of the environmental variable, and the direction of the arrow indicates the trend for that variable.

6 Conclusions and management implications

Small native mammal and introduced predator occupancy, habitat fragmentation and landscape connectivity

This study has provided baseline data on the species composition and abundance of small native mammals in native forests and shrublands at Stromlo East and Stromlo West. The detection of Common Dunnarts by nine cameras across both sites suggests these remnant patches of habitat support a small population of Common Dunnarts. It is possible that multiple cameras detected the same individual as Common Dunnarts frequently disperse over large distances and are thought to occur at densities of less than one individual per hectare (Monamy and Fox, 2005), and the minimum distance between detections was 200 m (Fig. 7). The failure to detect any Yellow-footed or Agile Antechinus in this study was unexpected because of an incidental antechinus sighting made during Goanna surveys in 2020 (Fletcher, pers. comm. 2020). However, the absence of detection does not rule out the possibility that antechinus do inhabit these sites. Antechinus typically forage on the ground, have smaller home ranges than dunnarts, nest communally, and would be expected to occupy the area at higher densities if they were present in large numbers (Dickman, 1980; Lazenby-Cohen and Cockburn, 1991).

Previous research has shown that antechinus and dunnarts may disperse between habitat patches separated by narrow linear barriers such as walking tracks when resources are scarce (Monamy and Fox, 2005). However, their movement appears to be inhibited by wide, permanent clearings such as sealed roads (Carthew et al., 2013). As Stromlo East and Stromlo West are separated by a sealed road (Uriarra Road), remnant populations of small native mammals may be unable to disperse between these patches of habitat, ultimately limiting the species' ability to persist in or recolonise these fragmented sites. Individuals attempting to disperse across Uriarra Road have an increased risk of mortality because of vehicular collision and increased vulnerability to predation along roadside verges. Maintaining connectivity of these areas at a landscape level will be vital to their persistence, given that small, isolated populations are at high risk of local extinction due to stochastic effects (natural fluctuations), edge effects, and inbreeding. The area to the west of the study area is part of the Western Edge Investigation Area, where studies are currently going on to determine areas of potential urban development. Maintaining large-scale links to other intact areas of high-quality habitat will be crucial for small native mammal persistence at these sites.

Cats and foxes typically exist at higher densities in urban areas and are known to prey on small native mammals (Martin, 1995; Saunders, 1995; Barratt, 1997). As foxes often favour dense vegetation bordering urban landscapes due to the provision of shelter and abundant food (Saunders et al., 2010; O'Connor et al., 2021), the high rate of fox detections at Stromlo East and Stromlo West (Table 4) was unsurprising. High fox activity may explain why camera surveys detected fewer cats, as research suggests foxes may suppress cats through competition and predation (Risbey et al., 2000; Glen and Dickman, 2005; Molsher et al., 2017). Careful consideration must therefore be made when managing introduced predators because cats are highly effective hunters of small mammals and might increase in abundance if foxes are eradicated from the study areas, exacerbating small native mammal declines (Risbey et al., 2000). While Denman Prospect and surrounding suburbs are designated cat containment areas, pet owners can be irresponsible, or cats can escape from containment and prey on small native mammals in the adjacent bushland. Establishing a consistent method of monitoring temporal and spatial changes to predator occupancy may help assess the effectiveness of this management action.

The findings of this study indicate that foxes may be more active in fragmented landscapes intersected by roads and trails (Fig. 8; Fig. 10). Furthermore, half of cat detections were within 50 m of roads (Fig. 9), suggesting that cats also utilise roads, albeit at lower densities than foxes. These findings are consistent with previous studies examining landscape use by mesopredators which found that foxes selectively range in forest edges and urban habitats bordered by roads (Frey and Conover, 2006; Hradsky et al., 2017b; Raiter et al., 2018). Roads increase fragmentation and the perimeter-to-area ratio of remnant habitat patches, improving predator access to interior habitat (Doherty et al., 2015). Unsealed roads such as fire management access trails, although not a significant barrier to dispersal, may therefore increase the vulnerability of small native mammals to predation (May and Norton, 1996). Minimising trail development across the sites and the option of maintaining access for fire management through slashed grassy trails should be considered.

Stromlo East will be managed as a Strategic Fire Advantage Zone (SFAZ) for Denman Prospect (Fig. 12), and this will require the establishment of fire management trails which could lead to increased predation pressures on small native mammals. Indeed, foxes and cats were detected at eight camera stations where Common Dunnarts were detected (Fig. 9; Fig. 10). While higher predator detection rates do not strictly denote higher predator abundances, as foxes and cats are territorial and known to have large home ranges, increased activity of a lone predator in a habitat patch intersected by access trails could nevertheless suppress small native mammals (Coman et al., 1991; Meek, 2003). Minimising road access to fragmented remnant habitats will be critical for the persistence of small native mammals in the study areas. Ongoing monitoring of habitat utilisation by predators and small native mammals at Stromlo East and Stromlo West may help elucidate factors underlying the observed trend, such as increased prey abundance or reduced vegetation density at roadsides, and aid in discussions around effective conservation buffer sizes in future planning.

Habitat characteristics associated with small native mammals

The habitat assessment conducted in this study adds to our understanding of the habitat requirements of small native mammals in two remnant patches of native woodland and open forest in the ACT and shows that Common Dunnarts may depend on various structural and compositional features for persistence. The two sites differed in the vegetation communities present with Stromlo East comprised predominantly of Red Stringybark-Scribbly Gum dry sclerophyll forest while Stromlo West consisted mainly of Blakely's Red Gum-Yellow Box grassy woodland. Except for one camera in native shrubland at Stromlo West, all Common Dunnarts were recorded in cameras stationed in these two vegetation communities. Interestingly, most of these cameras were located near transition zones between vegetation communities (Fig. 7), suggesting dunnarts may utilise resources from a broad range of vegetation types.

Common Dunnart presence was negatively associated with leaf litter depth and canopy cover, which was contrary to expectations since the litter layer is an abundant source of invertebrates and the typical foraging substrate for insectivorous mammals (Stokes et al., 2004). Sites with high canopy cover and leaf litter depth may constrain small native mammal foraging by limiting the availability of vegetative cover and increasing susceptibility to predation. Growth of groundstorey vegetation, such as tussock grasses, sedges, and rushes, is often suppressed in dry Eucalypt forests with high canopy cover and leaf litter density due to competition for light, soil nutrients, and water (May and Ash, 1990; Xiong and Nilsson, 2001). Reducing leaf litter through controlled burning and mechanical thinning of trees in areas with high canopy cover could benefit small native mammals by promoting the growth of groundstorey vegetation and providing refuge from predation.

The designation of Stromlo East as an SFAZ due to its proximity to the proposed residential development necessitates the application of prescribed burns and mechanical thinning of trees to protect personal property and human lives (Fig. 12). While controlled burning can benefit small native mammals by stimulating new vegetation growth, it can also be detrimental if burns are applied homogeneously across large areas, depleting vegetation cover and increasing susceptibility to predation (Catling, 1991). Research on the impacts of fires on small native mammals in forests of south-eastern Australia repeatedly emphasises the importance of retaining unburnt patches of habitat as refugia from predation because fox and cat activity often increases at burnt sites following prescribed burns (Fox, 1982; Catling, 1991; Swan et al., 2016; Hradsky et al., 2017a). Extensive mechanical thinning of Red Stringybark trees could similarly be detrimental since the fibrous bark, considered a fire hazard, provides essential habitat for many invertebrates on which small native mammals prey (Dickman, 1991; Croft et al., 2012). The negative impacts of fire fuel management on small native mammals at Stromlo East may be mitigated by applying patchy, low-intensity cool burns to produce a mosaic of varying stages of plant regrowth, and leaving cut material on the ground, thereby providing ample habitat for native species (Fletcher et al., 2021). Fire management should aim to retain naturally fallen coarse woody debris, and cut material in areas receiving mechanical thinning, to maintain habitat complexity for small native mammals.

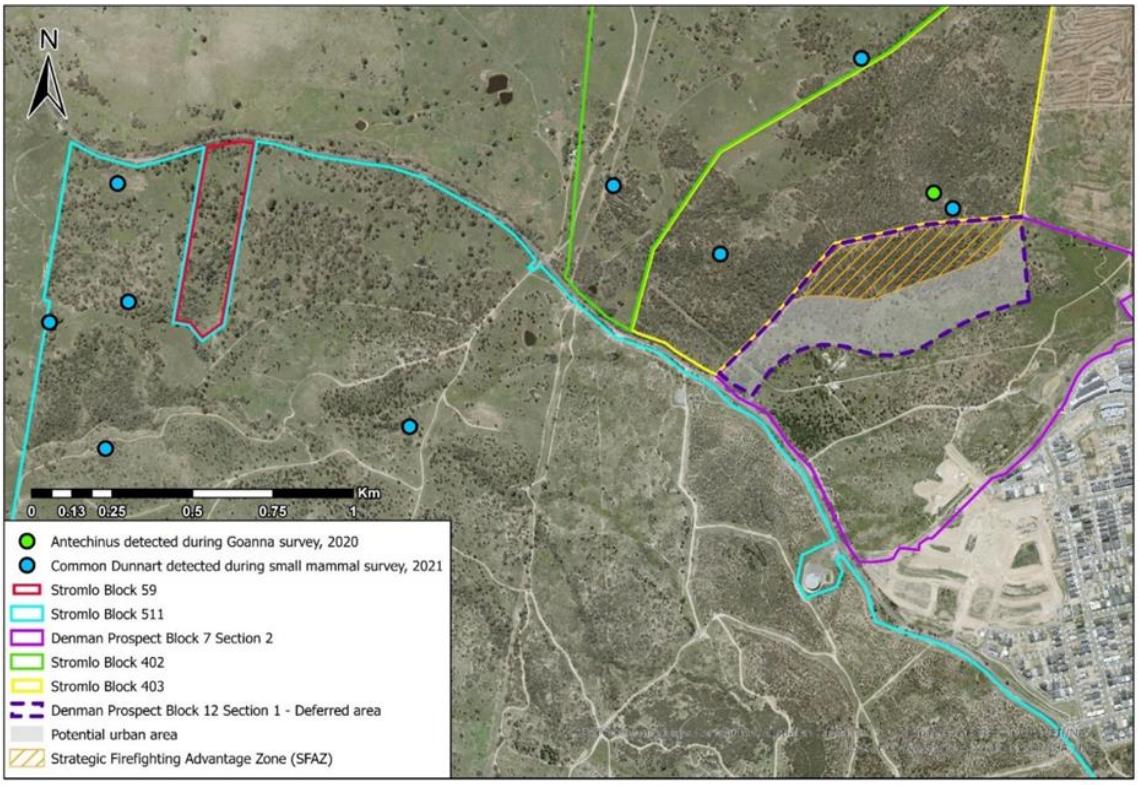

Figure 12. The locations of cameras where Common Dunnarts were detected during small mammal surveys in 2021, and where an antechinus was detected during goanna surveys in 2020, in relation to rural leases (Stromlo Block 402), Designated Areas (Stromlo Blocks 59 and 511), and potential residential development zones (Denman Prospect Block 7 Section 2 and Block 12 Section 1).

Future monitoring and research

Surveys of small mammal populations at Stromlo East and West were undertaken to better inform managers of the natural values of these areas that need to be considered in planning and management. Baseline surveys have established that small native mammals persist at these sites; priority gaps for further research and monitoring should be targeted at establishing a body of knowledge that can assist managers to actively manage the sites for small native mammal conservation, particularly in areas impacted by urban development.

The initial design of this study enabled the establishment of baseline activity and occupancy rates for predators and small native mammals and the ability to monitor this periodically following planned residential development and land-use changes. Ongoing monitoring could be used to assess the impact of increasing urban edge effects and explore management options on mitigating these. Ongoing monitoring should therefore be question-driven and include monitoring the impacts on small native mammals of changes in predator activity, fire fuel management, increasing habitat fragmentation, and increased recreational use of the area.

Monitoring predator distributions and activity in response to urban development and fire fuel management (including access trail development) is recommended and could be conducted in conjunction with further small native mammal surveys every 2-3 years or similar. Monitoring is particularly important to assess the effectiveness of predator management actions (e.g., cat containment areas) in mitigating predation impacts on small native mammals. Similarly, further habitat assessments should be conducted to monitor changes in habitat with urban encroachment, changes in fire regimes, and increasing use of the area by the public. There is also a unique opportunity in Stromlo East to undertake targeted research on small native mammal response (e.g., in abundance and behaviour) to various fire fuel treatments, including prescribed burning and mechanical thinning, as well as the impacts of the construction of access trails on habitat fragmentation and predator occupancy. In addition to small native mammals, monitoring of floristic and woodland bird responses to these actions is recommended.

Further work is required to better understand the critical habitat needs of small native mammals in the ACT and clarify relationships between habitat characteristics and small native mammal occupancy. Interpretation of results relating to habitat occupancy of different vegetation communities within this study was limited because of the small number of sightings. This limits the ability to provide specific advice and recommendations to managers on where suitable habitat currently exists and how management actions, such as fire, might be used to promote, restore, or maintain suitable habitat and enable small native mammal persistence or recolonisation. The mapping of refugia will be important to inform planning and target appropriate management actions. Understanding the relationship between key habitat variables is also potentially important in mitigating the impacts of climate change on habitat suitability in the future.

Finally, using species distribution models to identify potential habitat could lead to a more targeted approach for a much broader survey effort to provide an updated assessment of small native mammal distribution and prevalence in the ACT. This is likely to include other PCS-managed areas but should also include suitable habitat on rural lease lands and other tenures. Efforts to improve habitat condition and connectivity will likely form part of the urban biodiversity initiative in the coming years.

Recommendations

This study has shown that, in addition to endangered Blakely's Red Gum-Yellow Box grassy woodland, critically endangered derived native grassland, rare and threatened native flora, and the vulnerable Pink-Tailed Worm Lizard, Denman Prospect Block 12 Section 1 and Stromlo Block 403 also contain populations of small native mammals. Maintenance of connectivity and habitat condition at Stromlo East will be critical to enable the persistence of small native mammals in this area following proposed residential development and associated fire fuel reduction, as well as at Stromlo West, which provides connectivity routes between the Lower Molonglo and Stony Creek Nature Reserves.

To enable the persistence of small native mammal populations at these sites, we recommend the following actions:

- Establish a planned burning mosaic to preserve unburnt refuge areas for small native mammals by conducting a series of smaller burns over several years rather than burning vegetation communities as a single unit.
- Implement fire management actions in a way that retains structural habitat features likely to support small native mammals, such as depositing cut material on the ground following mechanical thinning to increase coarse woody debris.
- Undertake targeted monitoring of small native mammals and introduced predators at Stromlo East to understand response to fire management actions.
- Undertake targeted monitoring of small native mammals and introduced predators over time to assess the impacts of increasing urbanisation in surrounding areas.
- Trial innovative methods to control populations of foxes and feral cats and undertake targeted monitoring of small native mammals and predators to assess the effectiveness of these predator control activities.
- Ensure all suburbs abutting these sites are designated cat containment areas.
- Avoid impacts from further development by maintaining appropriate habitat buffers and ensuring adequate large-scale landscape connectivity across the Western Edge Investigation Area. Of particular importance is maintaining the current habitat connectivity between Stoney Creek Nature Reserve (Murrumbidgee River Corridor), Stromlo West, Stromlo East and the Lower Molonglo.
- Consider gazettal of the blocks of both Stromlo East and Stromlo West as reserve estate to protect both habitat and connectivity corridors into the future, as well as to enable active management of habitat to promote the persistence of small native mammals at these sites.
- Consider the listing the three small mammal species native to the lowlands of the ACT: the Agile Antechinus, Yellow-footed Antechinus, and the Common Dunnart; on the protected native species list under the ACT *Nature Conservation Act* to ensure their consideration in future development planning and conservation management.

Furthermore, to increase our understanding of the current distribution of small native mammal populations in the ACT, we recommend the following actions:

- Undertake an updated assessment of small native mammal distribution in urban reserves, rural leases, and private land throughout the ACT to identify priority areas for small mammal conservation and habitat restoration.
- Conduct further habitat assessments in the study areas and other sites inhabited by small native mammals to clarify the relationships between habitat characteristics and small native mammal occupancy to better guide management actions.

As development advances, the data presented in this report, combined with ongoing research, and associated monitoring of species abundance and habitat condition, will allow planners, conservation managers, rural lessees, Ngunnawal Traditional Custodians, and residential developers to collaboratively implement measures that will prevent the further decline of Canberra’s small native mammals.

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